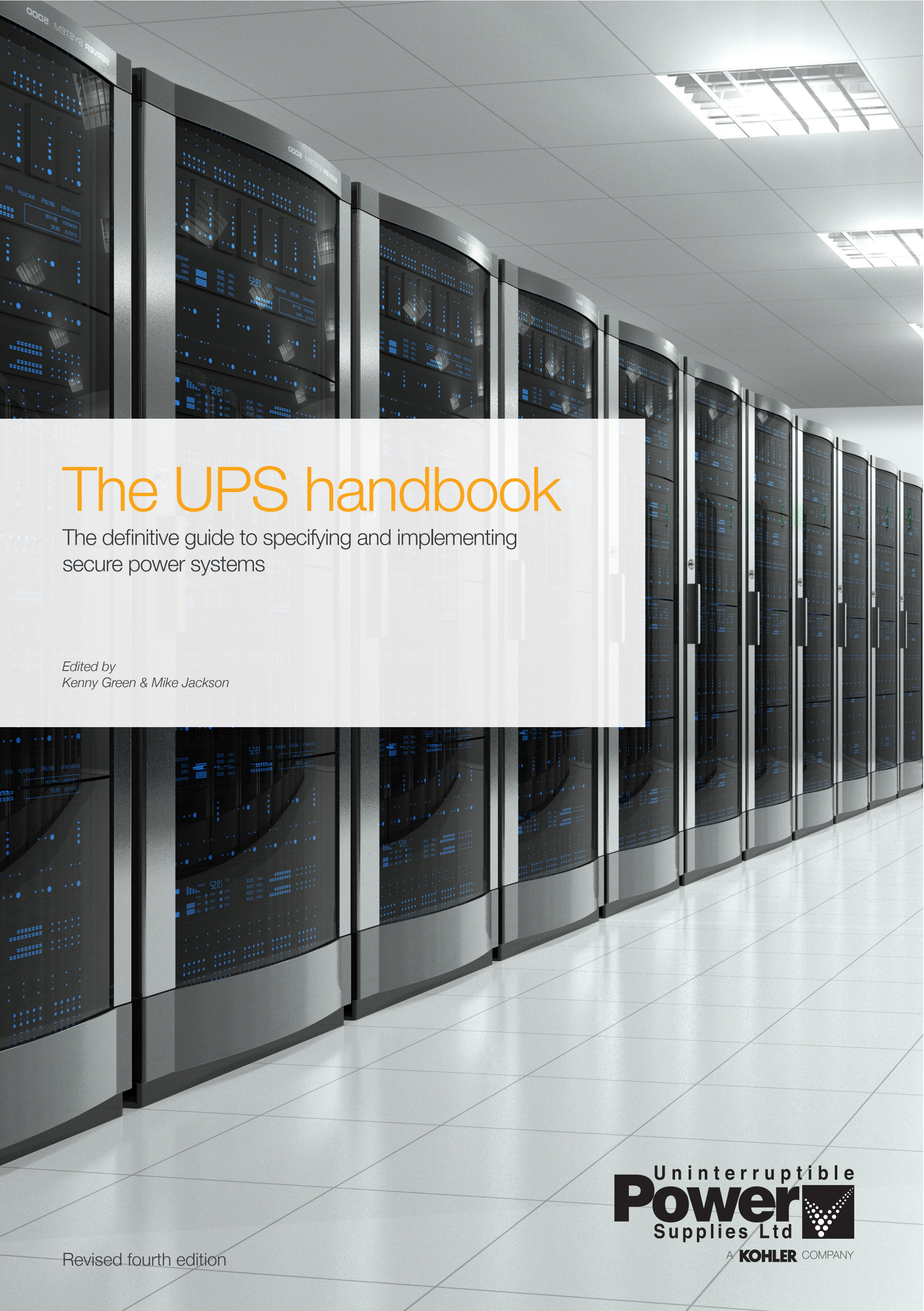


The UPS handbook

The definitive guide to specifying and implementing secure power systems

Edited by
Kenny Green & Mike Jackson

Uninterruptible Power Supplies Ltd
A KOHLER COMPANY

Revised fourth edition

The UPS **Handbook**

Uninterruptible Power Supplies Ltd, A Kohler Company

ISBN 978-0-9538398-3-4

Published in October 2013 – 4th edition
UK Publisher: Uninterruptible Power Supplies Limited

For further information: Uninterruptible Power Supplies Limited
Woodgate,
Bartley Wood Business Park
Hook
Berkshire RG27 9XA

Telephone: 01256 386700
Fax: 01256 386701
Email: sales@upspower.co.uk

The authors would like to acknowledge the valuable assistance given by:
Yuasa Battery Sales UK Ltd
Advanced Battery Care Ltd
Mike Elms
Peter Bentley IEng MIEE
Adrian Orr
In the production of this handbook.

The UPS **Handbook**

Edited by: Kenny Green BSc (Hons) ARCS AMInstP
Mike Jackson

Foreword

The UPS Handbook - Fourth Edition

In 2000, UPSL, a Kohler company, published the highly respected UPS Handbook - the first of its kind for the industry. UPSL has over 16 years of experience relating to the pressures faced by owners and operators of ICT equipment and the role UPS play in mitigating these potential issues. Accordingly, the company wanted to offer engineers, buyers and project managers a single-source UPS reference; a comprehensive set of theoretical and practical guidelines, essential to achieving an appropriate, cost-effective and successful UPS installation.

Unsurprisingly, the UPS and ICT landscape has changed dramatically since then, leading us to the publication of this, the fourth edition of the UPS Handbook. Today our objectives remain largely the same - to inform the specification and installation tasks required for successful UPS power protection. While doing so, we have endeavoured to highlight the differences arising from advances in UPS technologies, the changes in user situations and expectations, and, more recently, green legislative pressure from the political environment in which organisations of all sizes have to operate.

Our ever-growing dependence on IT is obvious to all, as we conduct increasing proportions of our business and social lives online, through our smartphones, tablets and computers. Less obvious to those not involved with ICT, but far more significant in terms of power protection challenges, is the vital role of data centres; large scale installations with sufficient capacity to handle future expansion, as well as existing high volumes of data processing. With their high processing capacity, data centres have a correspondingly heavy thirst for electrical power. Such installations' demands are typically measured in MVA rather than kVA. Add to this the inexorable and continuing rise in energy prices and it becomes easy to see why maximising energy efficiency throughout the data centre has assumed top priority for data centre operators.

Cost savings, although very significant, are not the only reasons for eliminating energy wastage. The Government's Climate Change Act of 2008 sets legally binding emissions reduction targets of at least 34% by 2020 and at least 80% by 2050, against a 1990 baseline. This directly affects large public and private sector organisations through the CRC Energy Efficiency Scheme. Under the scheme, companies that fail to demonstrate a reduction in carbon emissions are penalised financially, depending on their shortfall in reduction. However, the penalty for poor performers is more than just financial. From 2011, an annual CRC Performance League Table has become publicly available, showing how each participant has performed compared to others in the scheme. This has a significant impact on a company's reputation with its customers, employees, shareholders and suppliers. Therefore, the boards of such organisations are highly motivated to maximise their green credentials as well as their direct energy cost savings.

Operators of smaller organisations are equally keen to minimise their energy costs, due to the increasingly significant sums at stake. In addition, even if the business falls outside the CRC scheme, it is coming under increasing pressure to preserve its green performance and reputation. This is simply because such issues now genuinely matter to customers, employees and shareholders, influencing their decisions on the organisations they deal with.

As a result, design and operational staff responsible for purchasing and installing UPS systems need to make informed decisions for achieving maximum UPS efficiency. The latest edition of the Handbook directly addresses this need, with detailed information about UPS technology, configuration and scalability. It describes the use of these factors in minimising energy demand. While doing so, the Handbook has not forgotten the two remaining key issues that continue to influence purchase and design decisions - power availability and lifetime cost.

We referred earlier to society's increasing dependence on ubiquitous, uninterrupted ICT services. At the time of writing, the far-reaching consequences of service failure have been rather disturbingly demonstrated. Loss of availability under any circumstances is simply not acceptable. The results range from a frustrating interruption to working and social life, to loss of livelihood and business closures on a large scale.

Fortunately, today's UPS technology and the way it can be deployed give ICT operators the opportunity to prevent power problems developing into disasters. Transformerless systems have now been available for several years, and a well-designed transformerless UPS built with high-quality components can be very reliable indeed. Moreover, the very highest availability comes from building reliable UPS units into redundant configurations; systems that support the load without interruption even if one or more units fail.

The fact that such high availability systems can so readily be configured for loads of all sizes is due partly to transformerless technology, but also very much to how the technology is deployed. UPS units are available in the form of rack-mounting modules, which allow UPS capacities to be easily and efficiently matched to load size - and then scaled to track load growth over time. The modules can also be hot swappable, minimising repair time and boosting availability.

Another recent trend is the extension of energy efficiency, high availability and scalability into much larger installations. UPS cabinets of up to 500kVA capacity are now available, up to 10 of which can be paralleled for a total capacity of up to 5MVA.

In fact the energy savings, cost savings, power availability and scalability of modular transformerless solutions are all interrelated. Energy savings, and therefore operating costs are reduced both because of transformerless technology's inherently superior efficiency, and because it can be scaled - or right sized - to match the load size efficiently. Right sizing also reduces capital costs, and further savings accrue from the reduced size, weight and footprint of rackmount modular systems. The ability to incrementally add relatively small modules minimises the cost of achieving redundancy.

Overall, all UPS users seek maximum power availability and efficiency from the most cost-effective possible solution. We believe that the fourth edition of our UPS Handbook supplies the theoretical and practical information needed to achieve the highest availability, most energy efficient and most cost effective solution, now and into the future.

David Renton

Managing Director, Uninterruptible Power Supplies Ltd,
A Kohler Company.

Table of Contents

4

1 Introduction

How to Use this Book

This book is intended to be a comprehensive source of information to any individual or organisation needing to establish a totally reliable source of electrical power. The requirement for this level of electrical power integrity is most commonly, although not exclusively, to be found in computer based data processing applications.

Readership

As an information source, the UPS Handbook should be useful to -

- data centre managers
- financial managers
- facilities managers
- building services engineers
- project managers and engineers
- electrical consultants
- electrical engineers
- electrical contractors.

In order to produce this book it has been necessary to try to take into account the requirements of all of the above professional disciplines, and of course each have their own specific areas of interest.

The data centre manager's main objective, for example, may be simply to ensure that his computers never crash due to mains problems, and that auto-shutdown software is available to protect his valuable data files in the event of a prolonged mains blackout. The technicalities of how this is achieved are probably of secondary interest to him.

The electrical consultant, on the other hand, may be responsible for ascertaining which UPS system design technology best meets a particular user's requirements, and for ensuring that the systems proposed for installation meet a pre-defined technical specification.

For these reasons the UPS Handbook has been produced in such a way that the reader can easily identify the subject matter which is relevant to his requirements.

2 Why do I Need a UPS?

Introduction

A sudden loss of power will disrupt most business operations, and in some cases lead to a total inability to trade. There are many examples of companies which have gone into liquidation as a direct result of the consequences of mains power failures. However, it is not only total mains failures or 'blackouts' which can trigger devastating effects. Many electrical loads, such as computer systems, are equally susceptible to:

- power sags
- brown-outs
- black-outs
- power spikes and surges
- noise and radio frequency interference
- supply frequency changes.

Such loads are often referred to as '*critical loads',* partly because their continuous operation is fundamental to the functioning of the business, and also because they require a more stable and reliable power source than that generally offered by the utility mains supply in order to guarantee their correct function.

Critical Load Applications

The numbers and types of load falling into the '*critical*' category are rapidly expanding as an ever increasing range of microprocessor-based equipment enters both the industrial and commercial marketplaces. This is typified by the growth of online transaction processing and E-commerce where 24 hour trading demands absolute power quality with zero downtime.

Among typical critical loads are:

- computers – e.g. data processing and control systems
- industrial process equipment – e.g. precision manufacturing
- medical equipment – e.g. life support and monitoring systems
- telecommunications network equipment – e.g. PABX
- point of sales (POS) terminals – e.g. retailing environment
- online business transactions – e.g. internet shopping.

The effects of an inadequate supply to a *critical* load can include:

- cessation of the business process – i.e. a total inability to trade and/or communicate
- data loss or corruption due to software crashing
- expensive hardware failure including component damage – e.g. due to power sags, spikes etc.
- production loss due to incorrect operation of a manufacturing process and possible production equipment damage
- inappropriate control system operation
- lost business due to failed POS or telecommunications equipment
- possible time penalty paid to repair/reset affected systems.

Power Problems

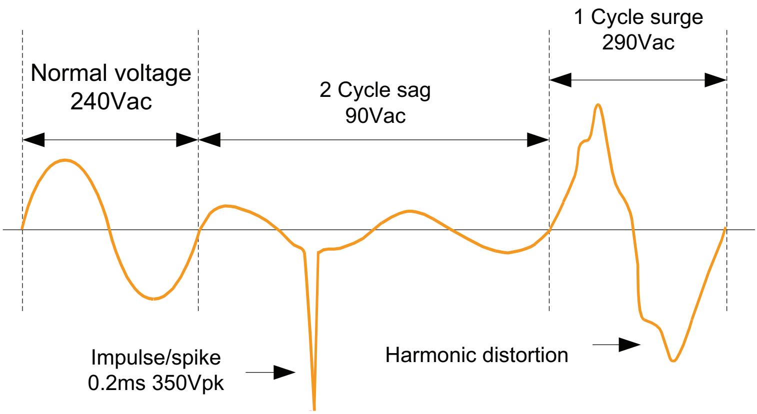


Figure 2.1: Power problems

Spikes

Spikes are short duration rapid voltage transitions superimposed on the mains waveform. Spikes can inflict both positive and negative voltage excursions and can damage or destroy electrical/electronic components. Spikes are typically caused by thermostats or other equipment switching high electrical currents, or load switching by the power companies. Locally grounded lightning strikes are without doubt the most serious and dramatic cause of spikes, particularly when induced into telecommunications cables.

Spikes can damage hardware and corrupt software. Hardware damage is an inevitable result of exposing sensitive electronic devices to high voltages. Software damage can be more costly in the long run, as periodically read files become corrupted and routine system processing may compound the errors.

Electrical Noise

Common Mode noise is a result of disturbances between the supply lines and earth. Normal Mode noise is the result of disturbances between line-to-line and line-to-neutral and can be caused by lightning strikes, load switching, cable faults, and nearby radio frequency equipment etc.

High frequency noise energy entering the earth line can affect sensitive circuits that use the supply earth as reference for internal control logic. This type of interference is not only mains borne but can also be induced through communications cables and other external connections. It is generally minimised by fitting surge suppression filters to offending equipment and implementing proper cable screening and earthing arrangements.

Electrical Noise can cause computers to ‘hang' and corrupt data.

Surges

Surges are sustained voltage increases above the normal mains value that last for more than one cycle. They typically appear after a large load is switched off or following load switching at substations.

Due to their relatively long duration, voltage surges can degrade a computer’s switched mode power supply components and lead to premature failure.

Sags

Sags are drops in the mains supply that can last for several cycles. They are similar in generation to negative spikes but have a much longer duration.

Sags are very common occurrences that are usually the result of switching on a large load, such as air conditioning equipment, or starting rotating machinery.

Sags can cause a computer re-boot if the mains voltage falls so low that the computer believes it has been switched off.

Harmonics

Harmonics are generally caused by non-linear loads which pull current from the mains supply in large peaks. Loads containing controlled rectifiers, switched mode power supplies, or rotating machines are particularly noted for generating this type of interference – for example computers, photocopiers, laser printers and variable-speed motors.

Harmonics cause a disproportionate rise in current, resulting in increased temperatures which can cause component failure, general equipment overheating etc.

Most PCs are driven by internal switched mode power supplies and the problems relating to harmonics build up progressively as the number of PCs in a building increases. In extreme cases the heat generated by the harmonics could destroy the site's main neutral busbars unless they are significantly over-rated.

Brownouts

Brownouts are identical to sags but have a much longer duration and are generally more serious. They are caused when the mains supply is unable to cope with the present load demand and the generating company drops the overall network voltage.

Depending on the supply company response, brownouts could last for several hours in extreme circumstances.

Blackouts

Blackouts are complete power losses, where the mains supply fails totally. They can be caused by supply line faults, accidents, thunderstorms and a range of other conditions.

Blackouts have an obvious, sometimes devastating effect.

Mains Power Reliability

Power availability has improved in the UK since the turn of the millennium – due in part to quality of service incentives being imposed on suppliers by Ofgem.

Ofgem figures show that the number of power interruptions per 100 customers have reduced to date. However, there are broad indications that this trend will reverse in the future as a result of greater demands on supply capacity whilst existing power generation plants (fossil fuel as a well as nuclear) reach their end of design life and need to be replaced.

Maintaining the energy mix is an area of debate in the UK, and until such plans are finalised there will be a period of uncertainty in security of supply until at least the late 2010's. Ultimately this will lead to greater supply interruptions. There will be further squeeze if greener approaches to energy generation and use are required – it will take some time for consumers to modify usage behavior to meet possible lower availability of supply.

As we have just seen, for users of sensitive electrical equipment a supply disconnection is not the only electrical supply problem that can adversely affect the operation of their equipment.

If a mains "failure" is defined only as a complete absence of mains power then the Mean Time Between Failures (MTBF) of the mains is approximately 10,000 hours (445 days). If a mains "failure" is more broadly defined as the occurrence of any mains event (spike, noise, surge, sag etc.) that adversely affects the mains supply then the MTBF of the mains could be as low as 50 hours. In practice the MTBF of the mains will be somewhere between 50 hours and 10,000 hours as these figures represent the worst cases and ignore local, site related problems such as accidental digging up of cables etc.

Summary

A substantial number of possible power disturbances can affect the operation of a critical load.

The one common aspect to all disturbances is their total unpredictability. Any measures taken to safeguard the critical load supply must be effective at all times when the load is in use.

Computers typically have specified upper and lower limits for steady state slow averaged rms line voltage variations of between ±5% to ±10%, depending on the manufacturer, but will tolerate short duration line voltage excursions outside those limits. The shorter the duration of the excursion, the greater the excursion which can be tolerated.

Some computers have sufficient energy stored in their internal power supply reservoir capacitors to sustain the dc supply to logic circuits during line voltage sags and power line interruptions of up to a 1/2 cycle (10ms), although not all units have this much ride-through capability.

If the computer user is striving for less downtime and fewer errors, the electrical environment must be closely controlled.

The UPS Solution

After identifying an item of load equipment as being ‘critical’ the argument for protecting its power supply is overwhelming. However, to some extent the necessary degree of protection depends on the particular load application.

If the load calls for a particularly close-tolerance supply, or is intended for 24-hour daily use, there is no alternative but to install a form of Uninterruptible Power Supply (UPS) to provide it with continuous, processed, clean power.

Radio frequency noise interference and spikes can be substantially reduced by fitting suitable filters and some form of isolation transformer in the supply line. Surges also can be reduced using externally connected components.

Power disruptions of just a few milliseconds may cause some equipment or operations to fail completely; yet others will ride through several cycles of mains failure without harmful effects.

Consider the different supply needs of a computer network and an emergency lighting system. Installing line-conditioning equipment and a standby generator might afford the most appropriate protection in the latter case.

3 What is a UPS?

Introduction

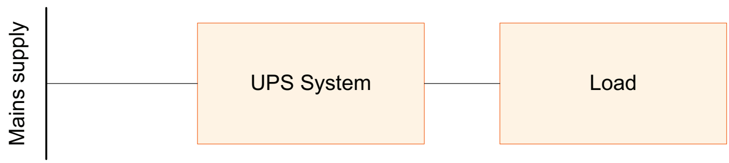


Figure 3.1: UPS System Installation

The Uninterruptible Power Supply (UPS) systems described in this book cover a range of solid-state equipment which can be connected between the incoming mains supply and critical load to protect against supply aberrations including total mains failures.

Because these systems are solid-state they are often described as *static* UPS systems, as opposed to *rotary* systems which are based on motor/generator technology. Rotary systems are still available, and have their uses, but in recent years they have generally been superseded for most applications by the developing static UPS technology. Therefore this book concentrates on static UPS systems.

There are several forms of static UPS system available, employing various power topologies (*see Chapter 4*). However, irrespective of their category they all currently use a battery to provide a back-up energy store which can be called upon if the mains supply fails. Emerging energy storage devices such as flywheels and hydrogen fuel cells are discussed in Chapter 8 but this book will focus on the use of batteries in UPS applications because, at the time of writing, flywheels and fuel cells are very much in their infancy and are unlikely to be used in mainstream UPS applications within the next 5 to 10 years.

UPS Rating

The power rating of electrical equipment may be stated in Watts (W) or Volt Amperes (VA) (1kVA=1000VA) but rarely both. UPS manufacturers generally use VA (or kVA) to describe the UPS output ratings, and it is this rating which determines the maximum load that can continuously be supported by the UPS when the mains supply fails.

When selecting a UPS to service a particular load it is important that the combined load does not exceed the UPS output rating, and if the load equipment is specified in Watts it is necessary to convert this to VA in order to assess the UPS/load rating compatibility.

VA and Watts Explained

The terms 'VA' and 'Watts' are often confused, but an understanding of the relationship between the two parameters is necessary when matching a UPS to a combination of load equipment.

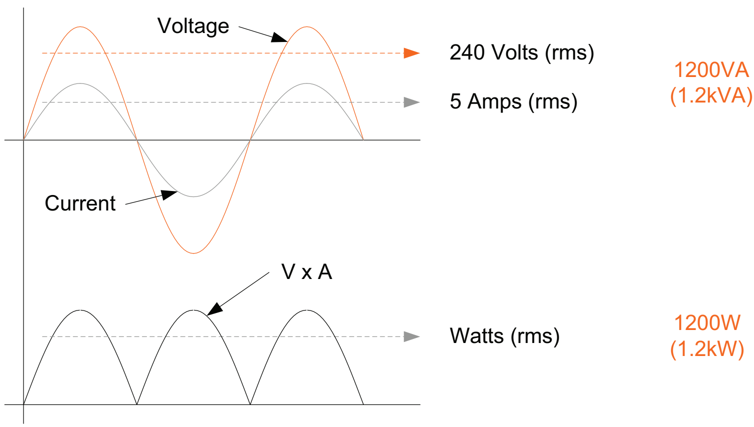


Figure 3.2: VA and Watts in a linear circuit

The VA (Volt Ampere) rating of electrical equipment is calculated by multiplying the supply voltage (*V*) by the current (*A*) drawn from the supply – using the rms (root mean square) values of voltage and current in each case. This is illustrated in the upper diagram of Figure 3.2 which shows that a load drawing 5A from a 240V supply is rated at 1200VA (or 1.2kVA).

Watts (W) are a measure of the *'real power'* consumed by a load. In a dc circuit this is calculated by multiplying the supply voltage by the load current in exactly the same way as described above for VA – i.e. (W = A x V). In fact, in an ac circuit feeding a *purely resistive* (linear) load, where the supplied voltage and load current are in phase, the circuit values of VA and Watts are identical. The lower diagram in Figure 3.3 illustrates an instantaneous power waveform for a linear load and shows how the r.m.s. wattage value is obtained.

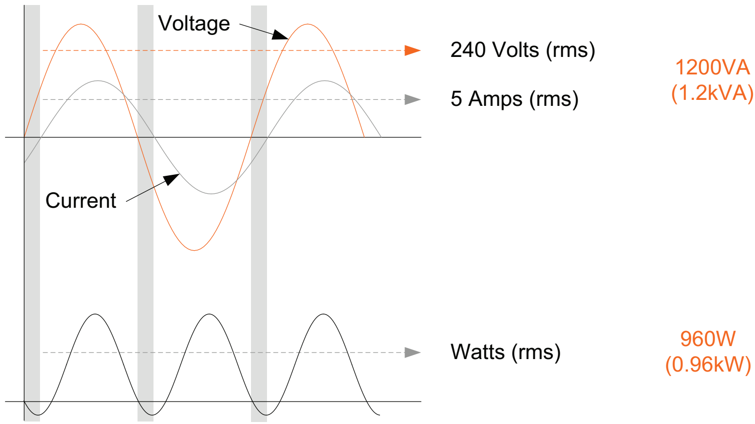


Figure 3.3: VA and Watts in a non-linear circuit

In practice the load connected to an ac circuit is usually far from linear. Typical ac loads such as transformers, switched mode power supplies, motors etc. are all inductive in nature and cause the load current to lag behind the applied voltage by an amount proportional to the load's reactance. This is illustrated in Figure 3.3, where the current is shown to lag the supply voltage by approximately 36°.

Notice that the VA rating in this example is identical to that calculated in Figure 3.2, because the rms values of the voltage and current waveforms are unaffected by the relative phase shift and the current drawn from the supply is the same in both examples. However, the lower diagram in Figure 3.3 shows a reduction in wattage rating to 960W from the previously calculated 1200W – i.e. the load is dissipating fewer Watts for the same value of VA.

The reduced wattage is due to the phase relationship between the voltage and current waveforms in that the product of V x A generates a negative value when the parameters are of different polarities. This is shown graphically in Figure 3.3 as negative excursions in the *'Watts'* curve which occur during the shaded areas of the voltage and current waveforms.

The illustrated negative power excursions are broadly theoretical but represent *'wasted'* power – i.e. power not dissipated usefully in the load. This is sometimes referred to as *'reactive'* power as it is caused by, and is proportional to, the load's reactance.

Power Factor (pf)

In an ac circuit the relationship between *real* and *reactive* power is known as the 'power factor' (pf) and is the ratio of Watts to VA.

$$\text{Power Factor (pf)} = \frac{Watts}{VA}$$

The power factor can also be determined by calculating the cosine of the phase angle between the voltage and current waveforms.

For example, in Figure 3.3 where a phase angle of 36° was assumed, the load power dissipation (W) could be calculated as:.

$$Watts = VA \times \cos(36) = 1200 \times 0.8$$
$$Watts = 960$$

Clearly, if two loads of the same wattage rating but different power factors are connected to the same supply voltage, the load with the lower power factor will draw more current from the supply in order to produce the same power as its partner having the higher power factor.

As mentioned at the beginning of this section, it is usual to describe a UPS in terms of its output VA (kVA) rating. If the UPS output power factor is not specified it is usual to assume a figure of 0.8 lagging – i.e. where the load current lags behind the supply voltage. For example a 1kVA UPS would have a maximum power rating of 800W (0.8kW) and under these circumstances the total load must not exceed either of these values.

Where large or highly reactive loads are concerned, measures are sometimes taken to improve the overall power factor, bringing it closer to unity. This is known as 'power factor correction' and is generally achieved by adding a capacitive load in parallel with the load equipment to reduce the overall circuit reactance.

What is Available?

The range of UPS modules currently available is vast, beginning with ultra compact desktop units to modules of hundreds of kVA. Furthermore, some manufacturers design UPS modules which can be configured as parallel-controlled multi-module systems, increasing the total system rating to several thousand kVA – e.g. 2 or 3MVA systems are possible.

Desktop Systems

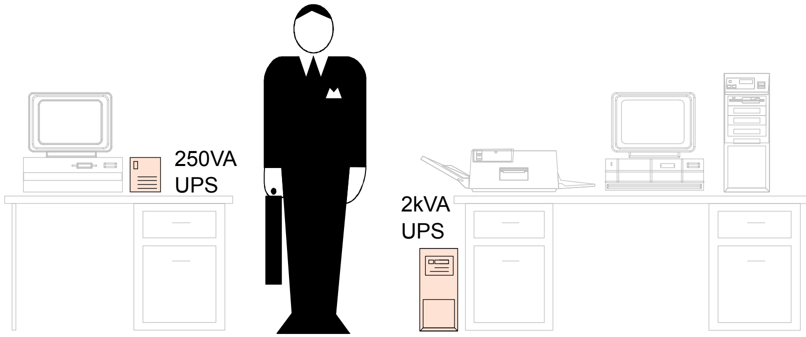


Figure 3.4: 'Desktop' UPS models

Micro Systems – up to 1000VA

Modules in this power range are typically designed to supply a single personal computer (PC) workstation and are normally housed in a mini-tower case about half the size of a typical personal computer system unit. The UPS is connected to a standard utility mains supply outlet such as a three-pin 13A socket (UK) and due to their small weight and dimensions can be considered as being portable. Modules at this power level include on-line, off-line and line interactive designs (*See "UPS Topologies" on page 21*) and provide a single point solution to a particular power need.

Load equipment is usually connected to a standard mains connector (IEC) on the back of the UPS which is usually protected by a circuit breaker or fuse.

At this power level the batteries are usually integral to the UPS cabinet, and extended battery cabinets are unlikely to be offered as an optional extra.

Because these modules are designed to be placed adjacent to the load equipment user it is not generally necessary to provide any remote alarm facilities to warn the operator of the module's operational status. However, current practice might include installing an automatic control interface between the UPS and computer e.g. SNMP (Simple Network Management Protocol) or automatic shutdown software (*See "UPS Communications" on page 155*).

Mini-Systems – 500-2000 VA

Modules in this power range are in many ways similar to the 'micro' UPS systems described above in that they are designed for office use and can be considered to be portable. However, the increased rating makes these modules suitable to supply a fileserver or a complete workstation comprising a PC and its peripheral equipment, such as printer (but not a laser printer), scanner etc.

These modules are again connected to a standard utility mains supply outlet such as a three-pin 13A socket (UK) and can include on-line, off-line and line interactive designs (See *"UPS Topologies" on page 21*).

The load equipment is usually connected to standard mains connectors (IEC) on the back of the UPS which are usually protected by a circuit breaker or fuse, but it is likely that several supply outlets are provided to facilitate the connection of several small items of load equipment.

At this power level the batteries are usually integral to the UPS cabinet, but some modules might have provision to connect to additional batteries contained in a purpose built *extended battery cabinet* to increase the total battery back-up (autonomy) time. Where this is the case the battery charger within the module is usually sufficiently rated to provide the additional battery charging current. However, in extreme circumstances the extended battery cabinet must include a dedicated charger system to cater for the additional batteries and will therefore also require connecting to the mains supply.

As with the 'micro' UPS systems, it is not generally necessary to provide any remote alarm facilities for this size of UPS due to the close proximity of the system to the load operator. However, as with 'micro' systems, SNMP or automatic shutdown software may well be a requirement depending upon the criticality of the load.

> Laser printers may cause harmonic distortion of the UPS output.
> Be sure to check the UPS can handle this type of load.

Medium-Sized Systems – 3-20kVA

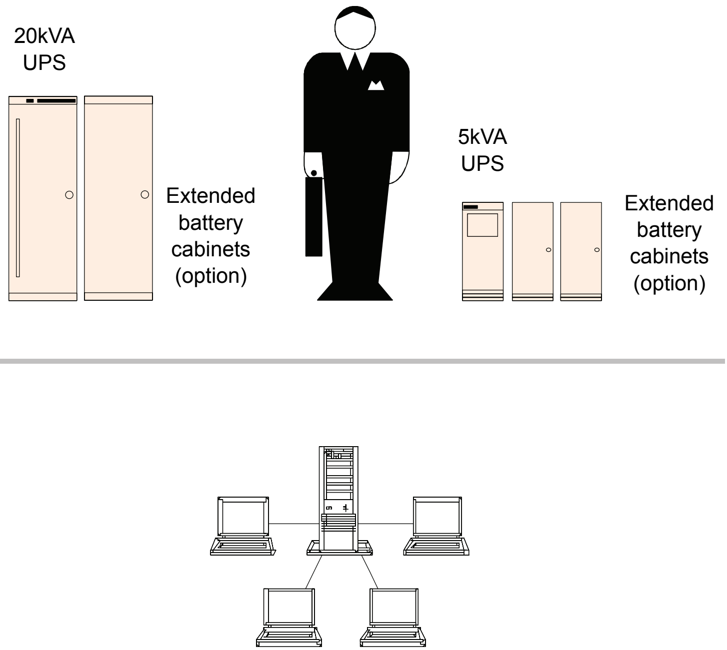


Figure 3.5: Medium-Sized Systems

Modules in this power range are designed to offer more than the single point power provision afforded by the smaller desktop modules, being typically used to power a complete office network, small server farm or communications centre.

These modules, which cannot be considered as being portable (especially those in the upper end of the range), are permanently wired to the mains supply using medium power switchgear and may require some external input overload protection device as a standard part of the installation. The larger modules in this range may require a three-phase input supply – and indeed may even offer a three-phase output.

The question of batteries varies across this particular power range. At the lower end the comments concerning the batteries fitted to the desktop systems are still valid, but when considering modules rated 15-20kVA it may well be that the batteries are housed in a separate cabinet which is positioned alongside the UPS module. In fact, most manufacturers offer a series of matching cabinets at this power level to provide a range of aesthetically appealing equipment that fits into an office environment.

At the higher power levels the load equipment is either hard wired to distribution busbars fitted within the module cabinet or the UPS output is fed to a purpose designed distribution system. At the lower end of the power range it is possible that the UPS may be fitted with standard utility power outlet sockets in the same way as the desktop models. Most modules in this power range will include facilities for remote alarms and status indications.

High-Power Systems (typically 30-500kVA)

Modules of this rating can service a major data centre but are not generally suited to an office environment due to the noise levels associated with their cooling fans and the heat generated when operating on high loads. Such modules are therefore usually located in a remote position such as a plant room, and their outputs connected to numerous loads using a dedicated mains distribution system incorporating external switchgear and protective devices.

Modules in this power range are almost exclusively of an on-line design and invariably three-phase input and output.

It is unlikely that the batteries are housed within the UPS module cabinet itself, and depending on the module rating and projected autonomy time, they may be housed in a separate cabinet(s) adjacent to the UPS module or, in the case of very large systems, rack-mounted in a dedicated battery room.

Some of the larger modules in this range may employ a 12-pulse rectifier to reduce the amount of mains polluting harmonics generated within the UPS and reflected back to the utility mains supply. Where a 12-pulse rectifier is used it is usually contained in a separate cabinet which must be positioned immediately adjacent to the main UPS cabinet, increasing the required system footprint and weight.

Single modules of up to 800kVA are available, however for the reasons of efficiency, availability and scalability discussed in Chapter 7, it is becoming increasingly more common for very large loads (300kVA to >1MVA) to be powered by UPS systems which comprise several “high power” UPS modules operating in parallel rather than by just one very large single UPS module.

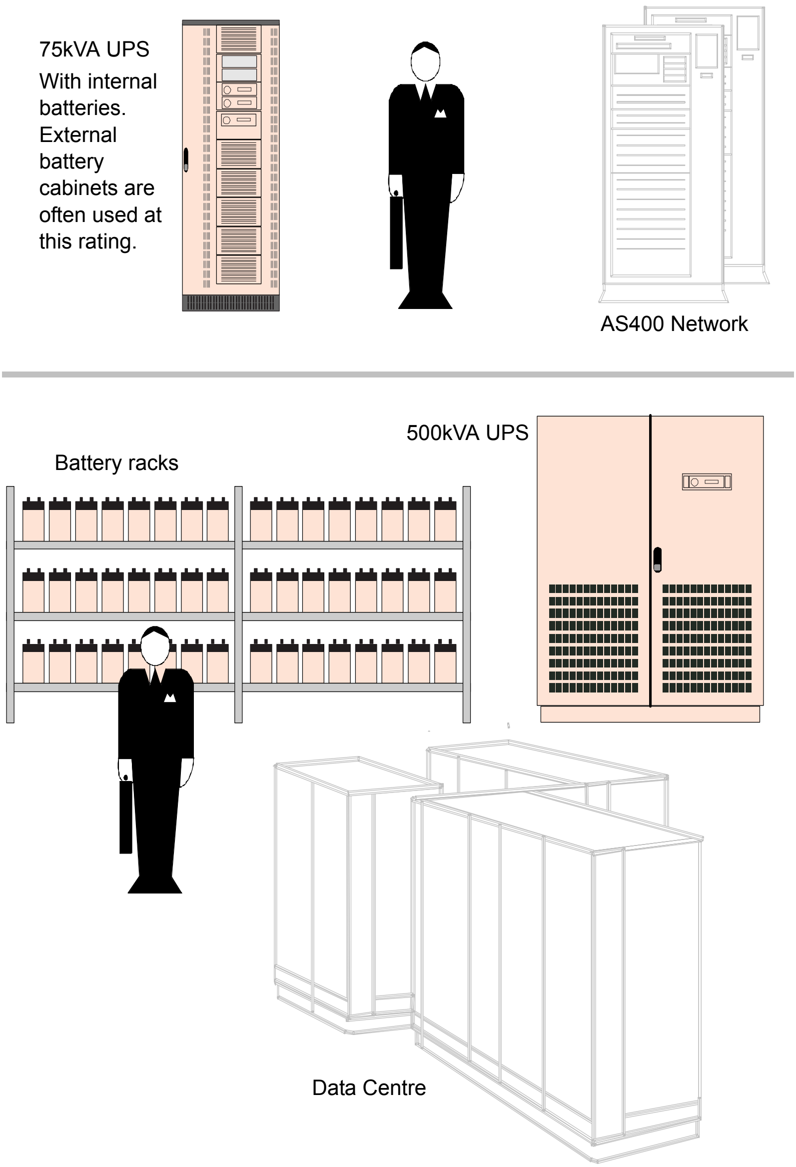


Figure 3.6: Large Systems

A standby generator may be incorporated into the system design to provide an alternative source of UPS input power during a utility mains failure. Such a generator must be self starting and be sufficiently large to maintain a stable output with the UPS on full load. When selecting a standby generator for this duty several features must be taken into account in order to ensure proper operation because the UPS input can present a hostile load to some generator systems (*See "Generators" on page 137*).

Due to the module's location it is usual to include a remote alarm/control panel with this type of installation, and virtually all modules in this range offer this facility as a standard feature.

4 UPS Topologies

Introduction

There are several categories of static UPS systems available. Broadly speaking, UPS modules fall within one of three operational design architectures, namely off-line, line interactive and on-line.

However, irrespective of their individual design criteria certain features are common to all forms of static UPS systems – i.e. they all contain batteries which store energy when the mains supply is available and a means of converting the battery charge into an alternating current (ac) supply in times of mains failure. All systems must therefore include a *battery charger* and a *power inverter* circuit, as illustrated in Figure 4.1.

As described above, the battery provides a power source for the inverter when the mains supply fails, whereupon it discharges at a rate determined by the critical load connected to the UPS output. The inverter automatically shuts down when its dc supply falls below a certain voltage, therefore the duration for which the critical load can be supported in times of mains failure depends upon the battery capacity and the percentage applied load.

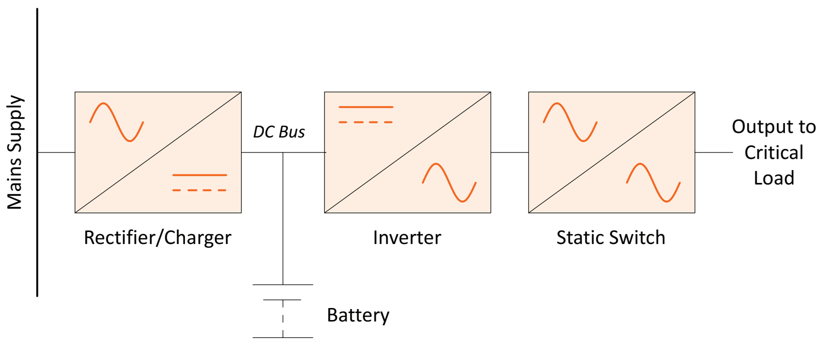


Figure 4.1: Typical UPS Block Diagram

A typical UPS system will contain sufficient battery capacity to support its fully rated output load for 5 to 15 minutes. However, in most cases this can be extended by adding further battery cabinets or selecting batteries of a higher capacity. The battery backup time is often referred to as the *autonomy* time.

Virtually all UPS contain a ‘bypass’ system which, in conjunction with some form of output switching circuit, provides a means of connecting the critical load directly to the mains supply. In most cases the output switching circuit is implemented using solid-state switching devices, hence the ‘static switch’ annotation to the block diagram in Figure 4.1, but this function is sometimes carried out using switching relays in smaller units.

The rules governing the static switch control depend on the UPS operating mode, as described in the remainder of this chapter.

Off-Line Systems

A typical off-line UPS module is shown in Figure 4.2. With this design the critical load is powered from the bypass line (i.e. raw mains) and transferred to the inverter if the bypass supply fails or its voltage goes outside preset acceptable limits. During normal operation the load is subjected to any mains disturbances that fall within the acceptable bypass voltage range although most modules of this type include a degree of spike suppression and rf (radio frequency) filtering in their bypass circuit.

Under normal conditions the battery charger operates continuously to keep the battery fully charged. In some models the inverter may be turned off to improve the overall system efficiency, although its control electronics are fully operational in order to provide a very fast inverter start when called for.

If the bypass voltage falls below a minimum value the inverter is immediately started (if not already running) and the load transferred to the inverter supply by the static switch (or output transfer relay). Due to the fact that the bypass supply is already failing when the transfer sequence is initiated there is an inevitable load supply break while the transfer takes place, albeit brief and typically in the range 2 to 10ms. Most loads should, however, ride through this period satisfactorily without adverse affects. The load is re-transferred to the bypass line once the bypass supply is restored.

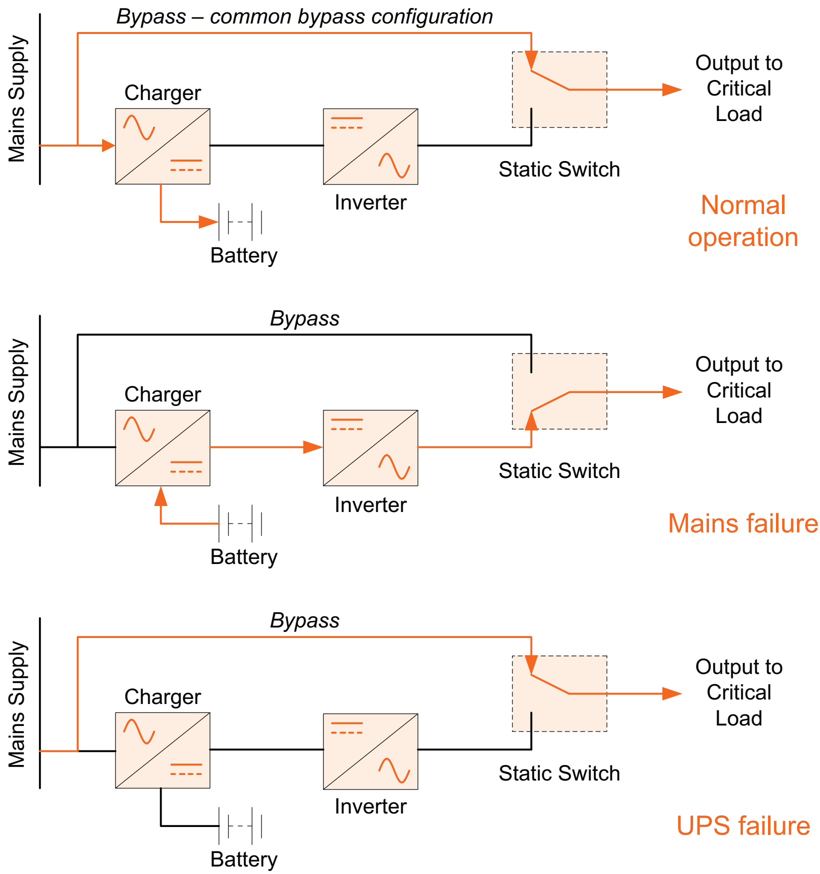


Figure 4.2: Off-line Illustration

Due to the inevitable load break during transfer some purists argue that this type of system is really a form of standby power supply rather than a *true* UPS.

When the load is transferred to inverter in this type of module the inverter immediately operates from battery power and can sustain the load only until the battery voltage falls to its end-of-discharge level, whereupon the UPS output supply will fail if the bypass supply is not restored.

Summary

The following key points might influence the choice of this system:

- output voltage not closely regulated under normal operation
- 2 to 10ms. load break during load transferring between inverter and bypass (in either direction) – minimal power protection
- lower capital costs than an on-line system due to lower rated components/omission of power rectifier
- lower running cost than an on-line system – overall efficiency is greater due to the fact that the charger and inverter are not permanently on load.

Line-Interactive Systems

This type of UPS covers a range of hybrid devices that attempt to offer a higher level of performance than conventional off-line designs by adding voltage regulation features in the bypass line. The two most popular types of system in this category employ either a buck/boost transformer (Figure 4.3) or a ferro-resonant transformer (Figure 4.4).

Like off-line models, line-interactive UPS normally supply the critical load through the bypass line and transfer it to the inverter in the event of a bypass supply failure. The battery, charger and inverter power blocks are utilised in the same manner as in an off-line system but due to the added 'regulation' circuits in the bypass line the load is transferred to the battery-fed inverter supply less often, making this type of system slightly more efficient in terms of running costs and battery 'wear' compared with an off-line system.

Buck/Boost Transformer Design

One of the drawbacks of the straightforward off-line design is that the load must be transferred to the inverter immediately the bypass supply voltage reaches the voltage limits acceptable to the load. This means that the UPS might transfer between bypass and inverter quite frequently if it is set up to operate with a critical load having a tight voltage tolerance. Apart from the power break each time this occurs, this method of operation incurs frequent battery usage which reduces battery life and might perhaps result in a battery that is inadequately charged when it is called upon to support a prolonged mains blackout.

A buck/boost transformer connected in the bypass line helps overcome this problem (see Figure 4.3). The transformer has tapped secondary windings which are selected by relays to either step-up or step-down the bypass voltage as appropriate to maintain the UPS output voltage within the required output voltage limits. This means of controlling the output voltage permits a wider variation of bypass voltage to exist before the output voltage reaches its limits and initiates a load transfer to inverter.

A typical UPS in this category will sustain the load voltage over a bypass voltage range of +20% to -30%.

Note that although the output voltage is maintained within its preferred window using this method, buck/boost switching unavoidably leads to a degree of step voltage changes as tap changes take place.

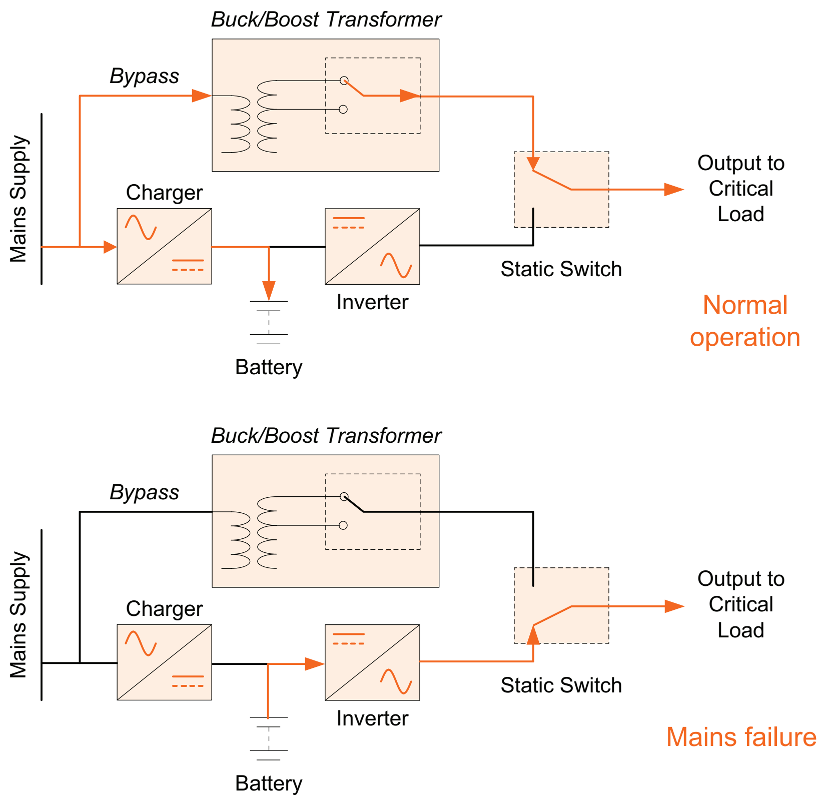


Figure 4.3: Line-Interactive UPS with Buck/Boost Transformer

Ferroresonant Transformer Design

Figure 4.4 shows this design is similar to the buck/boost system, but in this case the buck/boost transformer is replaced by a ferro-resonant transformer.

The transformer provides voltage regulation and power conditioning for disturbances such as electrical line noise and will typically maintain the output voltage to within 3% of nominal over a bypass voltage range spanning +20% to -40%. It also stores a reserve of energy that is usually sufficient to power most computers, i.e. PCs, briefly when a total outage occurs. This keeps the computer supplied with power within most input requirements until the inverter is switched on and effectively turns the system into a *true* on-line system in that the load is effectively transferred without a power break.

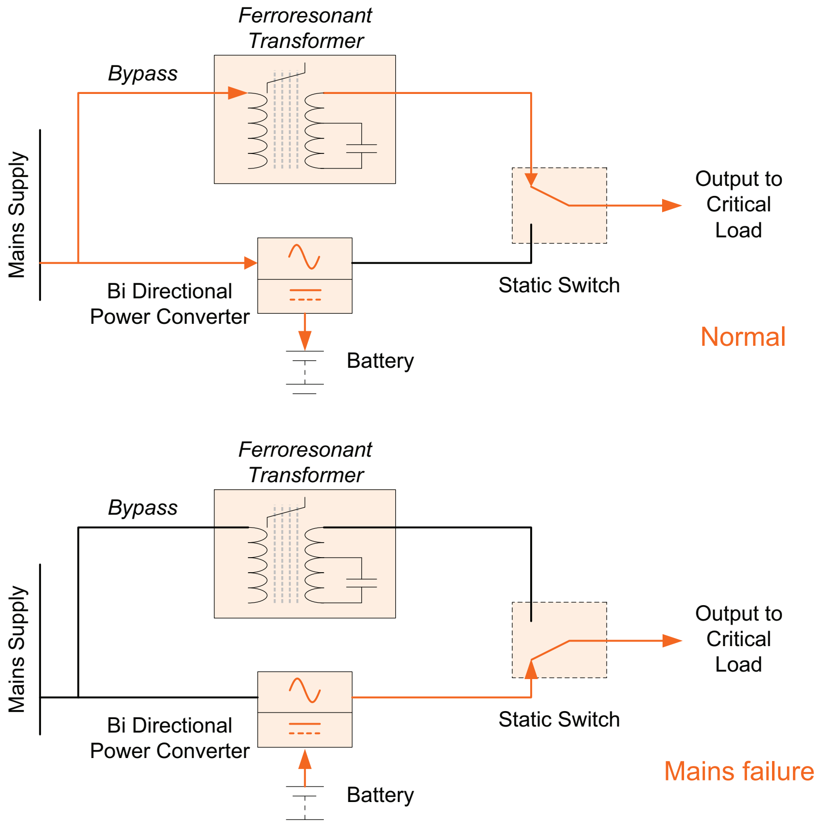


Figure 4.4: Line-Interactive UPS with Ferroresonant Transformer

Bi-directional Power Converter

In Figure 4.4 a single block has been used to replace the rectifier/charger and inverter power block shown in earlier diagrams. As its name suggests, this is a dual purpose power circuit which acts as a controlled battery charger under normal circumstances when the load is connected to the bypass, and very quickly changes over to operate as a power inverter when the bypass supply fails and the load is transferred to the inverter supply.

This type of design can also be used with the buck/boost circuit shown previously or indeed any other line-interactive hybrid.

Summary

The following key points might influence the choice of line-interactive systems:

- when comparing line-interactive and on-line systems the advantages/ disadvantages are similar to those described above for off-line models, with the exception of the advantage of providing a degree of automatic voltage regulation
- may reduce UPS battery usage in comparison with off-line systems, and therefore cause less degradation to battery life.

On-Line Systems

A typical on-line UPS module is illustrated in Figure 4.5.

An immediate difference between this design and the off-line systems is that the battery charger is replaced by a 'rectifier/charger' block. The rectifier/charger may be two separate units or a combined power block. When the mains supply is present this block float charges the battery and supplies the inverter with a stable dc voltage. In the absence of the mains supply the charger shuts down and the inverter dc supply is provided by the battery, which begins to discharge. The connection between the rectifier/battery and inverter is often known as the *dc busbar*, or *dc bus*.

As part of its control function the rectifier/charger generally includes an input current limit feature to provide overload protection and a dc overvoltage shutdown mechanism to protect the battery/inverter and dc filter components.

This UPS design is sometimes referred to as a *double conversion* UPS, due to its two conversion stages of AC-DC and DC-AC, and offers the greatest degree of critical supply integrity in that the load is supplied with processed power at all times. That is, when the UPS input mains supply is present the rectifier, charger and inverter power blocks are all active and the load is connected to the inverter output via the static switch. As the load is powered from the inverter under normal circumstances it is well protected from input supply aberrations because the rectifier and inverter act as a barrier to mains borne noise and transient voltage excursions, in addition to providing a well regulated output voltage.

If the input supply goes outside a preset voltage range (typically +10% to -20%), or suffers a total failure, the inverter continues operating from battery power and the event is totally transparent to the load as there is no transfer operation involved. When operating from battery power the inverter supplies the same degree of supply regulation as when the mains is present.

If the mains is not restored before the battery reaches its end-of-discharge voltage the inverter shuts down.

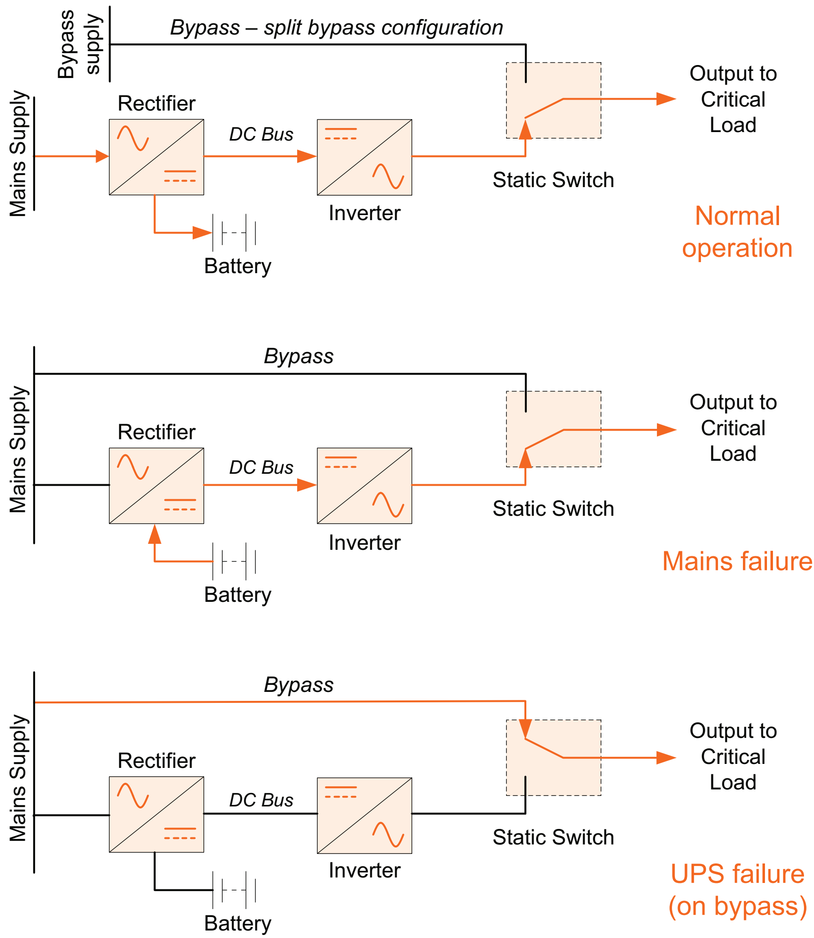


Figure 4.5: On-line UPS Operation

One means of overcoming this potential problem is to include a standby generator in the system design which provides an alternative source of UPS input supply during a prolonged utility mains failure. This is connected to the UPS via an automatic change-over switching circuit which detects the absence of the mains supply and very quickly brings the generator into operation (see Figure 4.6).

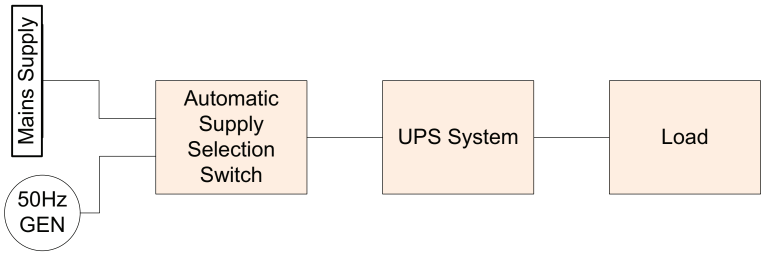


Figure 4.6: Standby Generator

In this application the generator is started automatically when a monitoring circuit detects a mains supply failure. Once the generator has run up and stabilised, the 'automatic supply selection switch' changes over to connect the generator output to the UPS input terminals, thereby replacing the regular mains supply: whereupon the UPS batteries immediately begin to recharge. Note that this facility can be used only if the UPS input and bypass supplies are connected to the same L.V. supply.

What Happens if the UPS Fails?

A UPS fault is generally seen as the inability of the inverter to provide the correct voltage or frequency at the UPS output terminals and the resulting actions that take place may vary between models. Usually, the UPS control logic will detect the failing output voltage/frequency as the fault occurs and immediately signal the static switch control system to transfer the load to the bypass line in a make-before-break fashion, as illustrated in the lower diagram of Figure 4.5. However, if the inverter is not synchronised to the bypass supply when the transfer is called for it will be impossible to perform a break-free transfer operation. Consequently there will be a brief supply break while the transfer takes place.

These are the only circumstances under which the load is subjected to a (brief) supply break in a *true on-line ups* system.

Note that although the break-free transfer to bypass is transparent to the load, it is no longer supplied with processed power once it is transferred to the bypass supply; also, if the bypass supply is unavailable when the ‘fault’ transfer is necessary a total loss of power to the critical load is unavoidable.

Depending on the UPS design, and nature of the problem, the static switch may transfer the critical load back to the inverter automatically once the inverter fault clears.

The response of an on-line system to an output overload is usually similar to that of the UPS failure described above in that the load is transferred to bypass until the cause of the overload clears, whereupon it automatically re-transfers back to the inverter. If the bypass supply is unavailable this will lead to a total loss of load supply (see above). Therefore some systems allow an overload condition to continue to be supplied from the inverter for a finite time – that is the UPS equipment is able to supply enough current to a faulty piece of load equipment to ensure that the load protection fuse or circuit breaker will automatically disconnect it from the UPS.

While feeding the overload under these circumstances the inverter operates in a current-limit mode and its output voltage may be reduced deliberately, but in most cases this is preferable to total power loss and of course conditions will return to normal if the overload is cleared during the allotted time.

Summary

The following key points might influence the choice of an on-line system:

- offers highest level of critical load protection – the load is supplied with closely regulated power at all times
- no load break when transferring between inverter and bypass (in either direction)
- mains failure totally transparent to the load
- most expensive capital cost
- most expensive running cost – system efficiency is lower than the other types of system due to the fact that the rectifier and inverter are permanently on load, although advances in on-line efficiency have been made – *See "Transformerless UPS Systems" on page 73.*

Maintenance Bypass

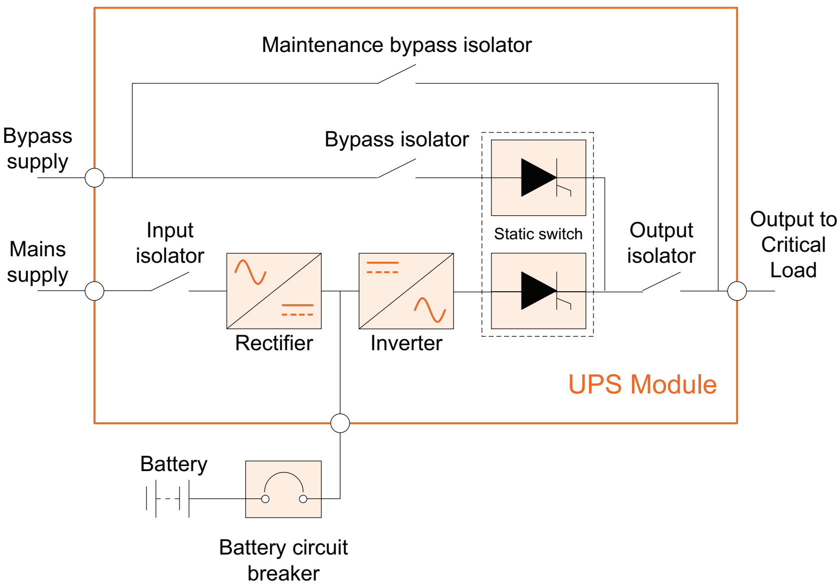


Figure 4.7: Internal Maintenance Bypass Illustration

A *maintenance bypass* provides a means of powering the load from an unprotected bypass supply while the UPS module is isolated for service or repair. Some modules include an integral maintenance bypass circuit as a standard design feature while others rely on an external maintenance bypass isolator being added as part of the UPS electrical installation.

Internal Maintenance Bypass

Figure 4.7 illustrates the isolator configuration of a typical high power, three-phase on-line module fitted with an internal maintenance bypass facility.

This diagram shows that although the UPS power blocks can be totally isolated while the load is powered through the maintenance bypass supply, making it safe to carry out maintenance procedures etc., there will still be live power within the UPS at its power isolators and input/output terminal connections.

External Maintenance Bypass

An external maintenance bypass system is illustrated in Figure 4.8, which shows three external isolators connected to the UPS installation. This configuration is often referred to as a 'wrap-around' bypass – for reasons that are readily apparent from the block diagram.

The illustration clearly shows that the UPS system will be totally isolated when SW1 and SW2 are open and SW3 is closed. This renders the UPS entirely safe for maintenance and troubleshooting, to the extent that the complete unit can be 'swapped-out' if necessary.

When this type of bypass is implemented the circuit breakers are usually housed in a purpose designed switchgear cabinet located near to the UPS equipment.

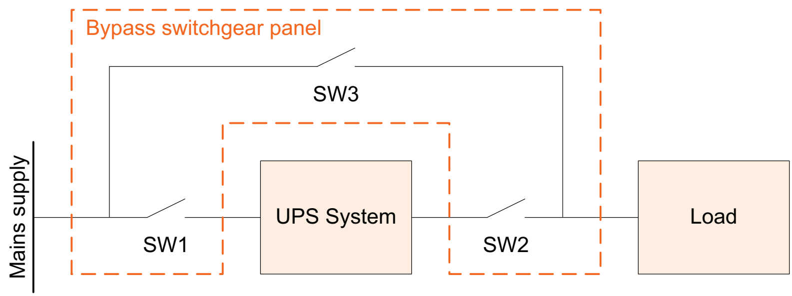


Figure 4.8: External "Wrap-Around" Bypass

Bypass Interlocking

Interlocking between the maintenance bypass and UPS isolators is required to ensure that the load is transferred between the two power sources in a controlled manner. This is necessary to ensure that the load is uninterrupted during the transfer, and the UPS is not damaged by back-feeding from maintenance bypass supply into the UPS output terminals while the inverter is on load.

The power isolators within the UPS are invariably electrically interlocked to prevent such problems occurring. However, when an external maintenance bypass circuit is employed, additional electrical or mechanical interlocking devices are usually required.

5 Major UPS Components

Introduction

As described elsewhere in this book the only *truly uninterruptible* UPS is a double conversion system comprising rectifier/charger and inverter power blocks operating in an on-line mode – Figure 5.1. The rectifier/charger converts the input mains to a direct current (dc) supply which provides the inverter power source and charges the battery when the mains supply is healthy. Alternatively, when the mains supply is disrupted the battery takes over the role of providing the inverter power without any switching or break in supply.

When viewed at this basic level the design principles appear straightforward. However, there are several fundamentally different approaches taken by manufacturers to implement both rectifier and inverter functions.

This chapter begins by presenting an overview of the conversion processes performed by the rectifier and inverter power blocks and explains various design principles including examples of transformer and transformerless UPS architecture. The chapter continues by describing the operating principles of typical UPS power modules in common use.

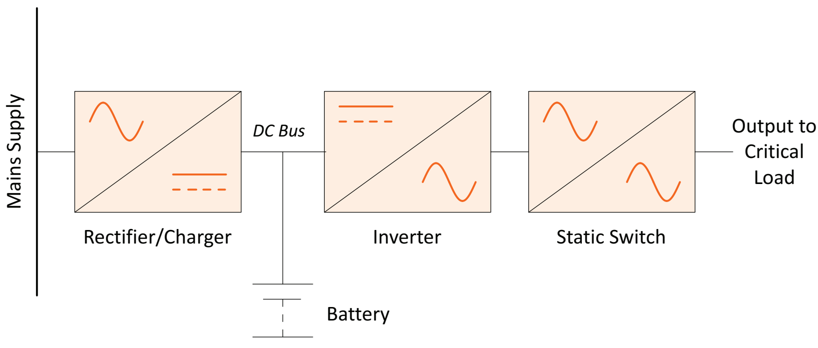


Figure 5.1: Basic Double Conversion UPS Block Diagram

Voltage Conversions

Figure 5.2 illustrates one of the most commonly used UPS power circuit designs in which the battery is connected directly to the rectifier's output 'dc busbar'. However, due to the rectifier and inverter voltage conversion factors this design is unusable in its basic form without the addition of a transformer.

For example, consider the case of a 240Vac single-phase fed unit:

If a 240Vac full-wave rectifier is used as the UPS's rectifier stage, the theoretical maximum dc busbar is approximately 340Vdc. This is possible only if the dc busbar is unloaded and the rectifier's dc filter capacitors (and battery) charge to a constant level equal to the incoming peak voltage, which is not a practical proposition. The achievable dc busbar voltage is somewhat less than this in reality.

As the inverter is a switching circuit connected across the dc busbar, the busbar voltage dictates the maximum possible peak-to-peak value of the inverter output voltage. A dc busbar of 340Vdc can be seen to restrict the inverter output voltage to $170V_{pk}$ which allows a maximum of $120V_{rms}$ – assuming a sinusoidal output waveform.

These conditions are shown graphically in Figure 5.3.

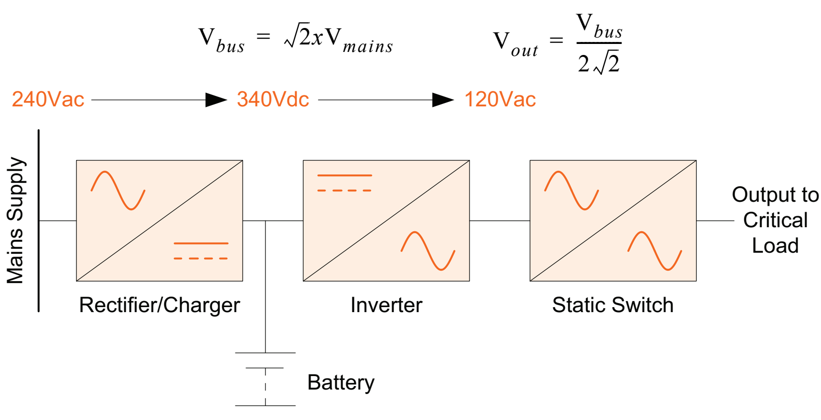


Figure 5.2: Voltage Conversion Block Diagram

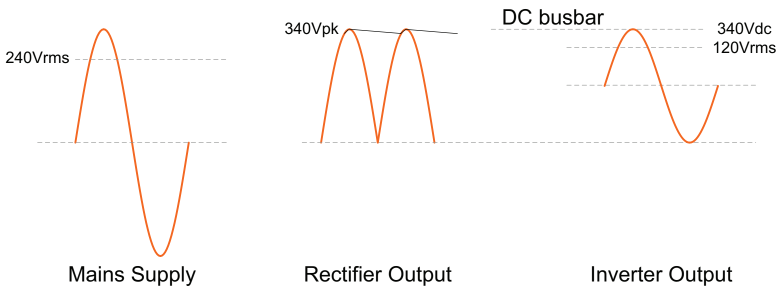


Figure 5.3: Voltage Conversion Waveform Diagram

Clearly, as it stands the circuit is unusable as it requires twice the dc voltage available from the rectifier if the inverter is to produce a single phase 240Vac output.

Traditional Transformer Solution

A traditional method of overcoming the problem highlighted above is to include a transformer at either the input or output of the power circuit. An input transformer can be used to step-up the mains supply to a level which increases the dc busbar voltage sufficiently for the inverter to produce its required output. However the main disadvantage of using this option is the significant number of extra battery cells required to cope with the increased bus voltage – *See "DC Busbar (Battery) Voltage" on page 39*.

Alternatively a transformer can be connected to the inverter output to increase the UPS output voltage to its nominal level.

In practice both solutions can be used, although the output transformer option is the more popular.

Example of a Practical UPS Output Circuit

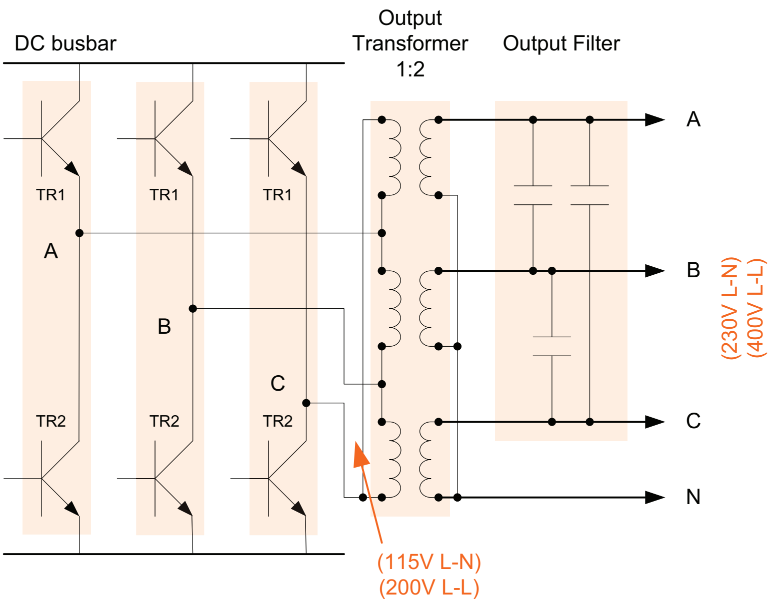


Figure 5.4: Output Transformer

Figure 5.4 shows a practical example of a three-phase UPS output section set to produce 400V_{L-L} output voltage. The output transformer has a 1:2 voltage step-up ratio, therefore the inverter output is controlled at 200V_{L-L} which is equivalent to 115V_{L-N} $(200/\sqrt{3})$ and approximately 325V_{p-p} $(2x115x\sqrt{2})$.

As the inverter cannot produce a peak-to-peak output voltage greater than the dc busbar voltage, the output waveform would clearly be clipped if the dc busbar falls below this 325V minimum level.

Note that the output transformer does not provide galvanic isolation. The neutral point of the secondary winding is bonded to the bypass supply neutral (where used) to provide a common reference point between the two supplies. The output filter works in conjunction with the output transformer to remove switching harmonic currents from the output waveform, resulting in a clean sinusoidal UPS output supply.

DC Busbar (Battery) Voltage

As a rule of thumb the type of batteries used in conjunction with UPS systems are float charged at around 2.25–2.27V/cell when the mains supply is healthy and allowed to discharge to about 1.65–1.67V/cell when providing the back-up power source to the inverter. These figures will vary slightly depending on the actual cell type and manufacturer.

In a typical UPS system the dc busbar voltage will vary by as much as 30% during 'on-battery' operation. However, it is the end-of-discharge battery voltage which is the limiting factor regarding the inverter output voltage.

For example, in the practical output circuit shown in Figure 5.4 the minimum permissible dc busbar voltage was calculated to be 325Vdc. To obtain this minimum voltage when reaching its end-of-discharge state the battery must comprise approximately 197 cells (i.e. $325/1.65 = 196.9$ – in practice this could vary by a cell or two depending on the actual battery specification).

A battery of 197 cells requires a float charge voltage of the order of 443Vdc. This is well within the operating capabilities of a 415V three-phase power rectifier as it can produce up to approximately 560V on its output dc busbar. However, if the battery were to be connected to 560V is would be significantly overcharged and would suffer catastrophic damage. To present the battery with its correct float charge voltage the rectifier output must be 'controllable.' There are several rectifier designs which satisfy this criterion but the most popular, especially in three phase applications, is the 'phase controlled rectifier' comprising a full wave SCR bridge. Such a rectifier can be used to regulate the dc busbar at 443Vdc (*see Figure 5.7*).

Inverter Regulation

The figures shown in Figure 5.4 illustrate the need for the inverter to provide a regulated output voltage ($115V_{L-N}$) over a wide range of dc busbar voltages – from 443Vdc when the battery is float charged, down to 325Vdc at the end of its discharge cycle. Some UPS systems offer a battery boost facility to reduce the time taken to restore the battery to full charge following a discharge cycle. This is achieved by increasing the dc busbar voltage above the normal float charge level, and the range of dc voltages applied to the inverter is even greater. *Note: Boost charge is not suitable for all types of battery.*

There are several methods of controlling the inverter to enable it to provide a well regulated output voltage over a wide range of dc input voltages. The most commonly used method is 'pulse-width modulation' *(see page 57)*.

Rectifier Power Block

Introduction

Apart from the obvious, the main difference between transformer and transformerless UPS designs is the means used to obtain the controlled dc busbar. Traditional, transformer based UPS designs invariably use a form of ‘phase-controlled’ rectifier to convert the incoming mains supply into a controlled dc busbar. However, the more recent transformerless designed systems have abandoned the phase-controlled rectifier and replaced it with a boost-converter type switched mode power supply (SMPS), which can offer several advantages.

The following section explains the operation of ‘phase controlled’ and ‘switch-mode’ rectifier systems and compares the relative advantages of both methods of implementing controlled rectification.

Basic Phase-Control Principles

This circuit is effectively a form of full-wave rectifier, either single or three phase fed, that employs silicon controlled rectifiers (SCRs) rather than diodes.

The bridge output is controlled by delaying the SCR turn-on action with respect to the point at which it becomes forward biased. By doing this the amount of energy allowed through the rectifier is reduced from that of an equivalent diode bridge as illustrated. Figure 5.5 shows a single SCR connected in a simple ac circuit and can be used to illustrate the basic principles of phase control techniques. Note that the half-wave circuit shown has no practical use but is shown for simplicity.

The top diagram shows the conditions where the SCR gate is held permanently positive with respect to its cathode – this is equivalent to providing the SCR with a permanent turn-on signal. In this condition the SCR passes current during the whole of the input ac positive half-cycle but blocks the negative half-cycle because the anode-cathode are reverse biased during the ‘negative’ period. This results in a ‘half-wave rectified’ voltage being developed across the load resistor, and the SCR can be seen to perform exactly the same as a normal rectifier diode. In this example the mean (dc) load voltage is approximately 0.45 times the peak ac voltage, and is shown as a dotted line superimposed on the output waveform.

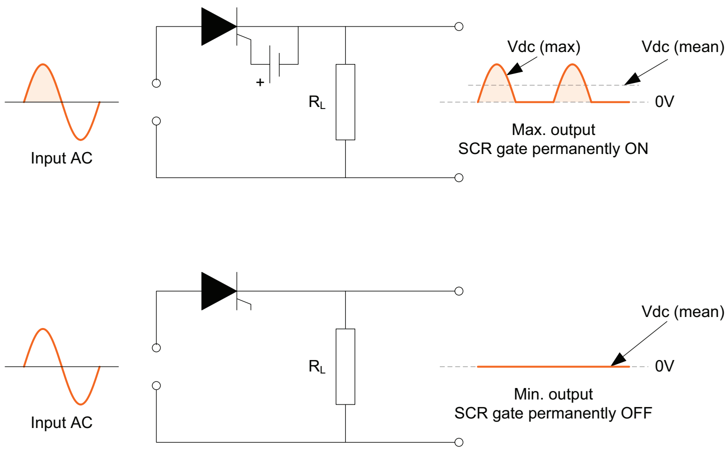


Figure 5.5: Basic SCR Principles

In the lower diagram the SCR has no gate drive voltage and, under these circumstances, is permanently turned off during both halves of the input waveform. In this case the mean (dc) load voltage is of course zero.

The two conditions illustrate the ‘maximum’ and ‘minimum’ output voltages obtainable from this simple circuit. However, this voltage can be varied between these two extremes using phase-control techniques.

The top diagram of Figure 5.6 illustrates the situation where the SCR gate is triggered when the input waveform is 45° into its positive half-cycle. Under these conditions the SCR conducts during the period between 45° and 180° only – i.e. it is not turned on between 0° and 45°, and is turned off by natural commutation after 180°. As shown in the top waveform diagram, this results in a mean dc voltage Vdc(mean) that is slightly less than maximum Vdc(max).

In the lower diagram the SCR gate trigger is delayed by a further 45°, to a total of 90°, which leads to a further reduction in output voltage.

This is the basic principle of a ‘phase-controlled’ rectifier, where the rectifier output voltage is controlled anywhere between its maximum and minimum limits by applying a variable phase delay between the point at which the SCR becomes forward biased and the application of its gate drive signal.

The period for which the SCR is allowed to conduct is often referred to as its ‘conduction angle’.

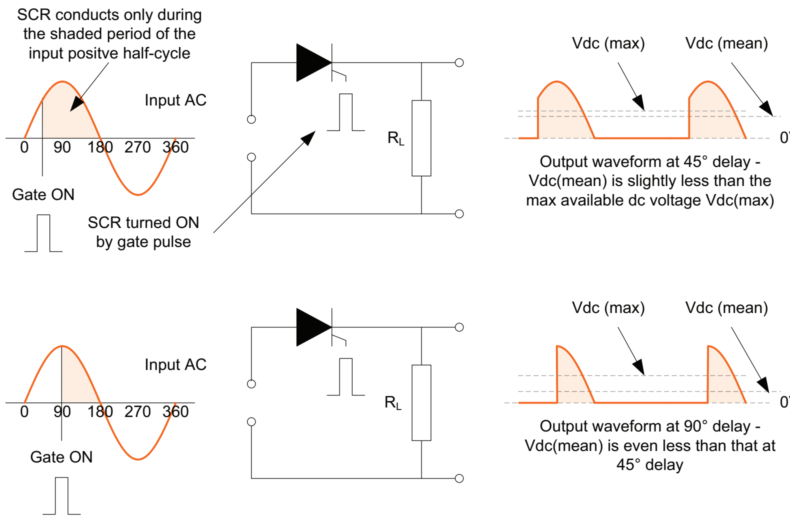


Figure 5.6: Phase Control Principles

Six-Pulse Rectifier

Figure 5.7 shows a three-phase full-wave controlled rectifier. Each SCR controls the rectifier conduction angle during one half-cycle period of an input cycle. Taking the R phase as an example, the top SCR (A+) controls the A phase positive half-cycle, and the lower SCR (A–) controls the negative half-cycle. In the practical circuit all six SCRs are controlled at the same conduction angle in order to maintain balanced input line conditions.

Looking at the A phase positive half-cycle (A+) in detail, the three-phase waveform diagram shows that this device is forward-biased only for a 120° period between 30° and 150° of the incoming A phase waveform. This means that the bridge output voltage can be controlled over its full range by controlling the SCR over this conduction angle.

This circuit is sometimes referred to as a ‘six-pulse’ phase-controlled rectifier because six SCRs are turned on during each complete three-phase cycle.

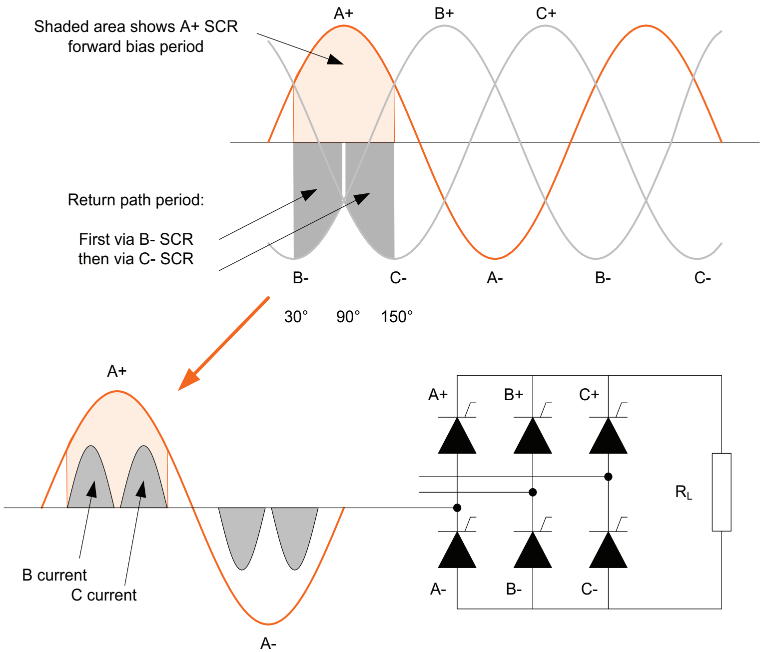


Figure 5.7: Three Phase (6-pulse) Phase Controlled Rectifier

Harmonic Current Generation

The A-phase positive SCR current is shown in Figure 5.7 to comprise two pulses, corresponding to the commutation changeover from the B- and C-phases.

When the load current is discontinuous or is not proportional to the line voltage, the overall effect is equivalent to the presence of harmonically related higher frequency components of current superimposed upon the fundamental 50Hz sinusoidal current. All these components added together equal the actual current wave shape. Since each of the current components is not in phase with the line voltage, the products of voltage and current represent reactive Volt-Amperes. These harmonic currents interact with the mains power source impedance to create line voltage distortion. They also reduce the UPS input power factor, increase loading on the mains power circuits, and create additional electrical losses. A low impedance power source will minimise line voltage distortion, but will not correct the source of the problem.

Input Total Harmonic Distortion (THDi)

The level of harmonics created by the rectifier switching is measured as the input current total harmonic distortion (THDi) and in a six-pulse rectifier will be typically 30% to 35%. For medium and large UPS systems such high input current THD will cause site mains voltage distortion that may well adversely affect the operation of other equipment connected to the mains supply (*See "Applicable Standards" on page 257*). Additionally, the power generated by the harmonics that create the distortion must be supplied by the available mains and is therefore wasted energy. For these two reasons high input current THD is very undesirable (see *"Reducing Input THDi" on page 49*).

Twelve-Pulse Rectifier

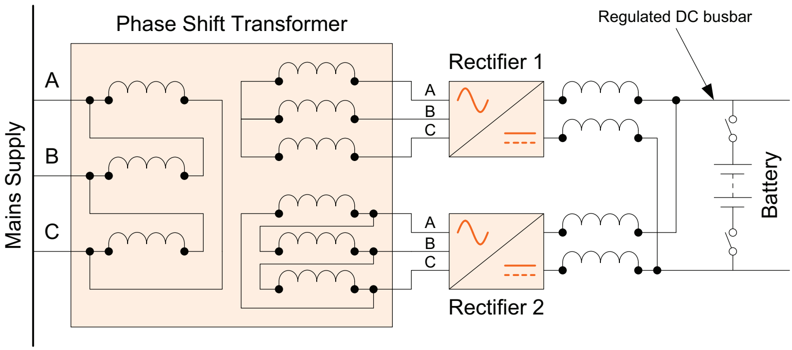


Figure 5.8: Twelve-Pulse Rectifier Block Diagram

A costly, but effective, means of reducing the harmonics is to use a twelve-pulse rectifier which employs two three-phase (six-pulse) rectifiers operating at 30° with respect to each other. An example circuit is shown in Figure 5.8, which shows that the phase shift is produced by a suitable transformer connected between the rectifiers and mains supply. The rectifier output dc busbars are connected in parallel via large chokes to dampen the load currents and facilitate current sharing.

This circuit helps attenuate the harmonics in two ways. First, because there are now twelve SCR switching actions per 50Hz cycle rather than six, the frequency of the pulses imposed on the mains supply is double but their individual amplitudes are lower, making it easier to filter the harmonics if a separate filter circuit is also used. Second, due to the 30° phase shift the triplen harmonics between the two rectifiers are now in anti-phase and should cancel each other. A twelve-pulse rectifier will reduce the input current THD from about 30% to about 10%. For both the input filter and 12-pulse rectifier solutions the size and cost of the additional components can become significant when dealing with large UPS modules and will most likely require housing in additional equipment cabinets.

12 pulse rectifiers are expensive, reduce the UPS system efficiency and increase the total footprint of the UPS system which adds to installation costs.

Input Power Factor

In a phase-controlled rectifier the current waveform progressively lags the input voltage waveform as the rectifier conduction angle reduces – i.e. as the rectifier output dc busbar voltage is reduced.

A classical definition of power factor (pf), is that it is equal to the cosine of the phase angle between the voltage and current in an ac circuit. Therefore the input power factor is directly affected by changes in the rectifier conduction angle, falling further from unity as the rectifier phases back.

This concept of power factor is true only if the voltage and current concerned are sinusoidal and at the same frequency. However, it has already been shown that the currents associated with the phase-controlled rectifier are not sinusoidal, but are rich in harmonics which cause a circulation of wattless power within the circuit. The generated harmonics therefore affect the power factor in addition to the prevailing rectifier conduction angle.

A typical phase-controlled rectifier used in a UPS application will produce a power factor of around 0.8 when operating on full load and charging the battery. The reduced input harmonics attained when using a twelve-pulse rectifier will typically improve this to around 0.86.

Some of the disadvantages of the phase-controlled rectifier, such as harmonic generation and less than unity power factor, are addressed by the boost converter circuit used in the transformerless UPS design.

Boost Converter – (Transformerless UPS)

The boost converter circuit is a form of peak-current switching regulator normally associated with dc-dc converters rather than the ac-dc conversion utilised in this application. To understand how the circuit works it is best to consider the operation of a standard dc-dc converter and then discuss its additional control features. Figure 5.9 shows a simplified diagram of a boost converter operating with a dc input supply.

If the input voltage (E) in the circuit above is held constant (i.e. a dc value) and transistor Q1 is never turned on then clearly all that will happen in the circuit is that positive dc bus reservoir capacitors C1/C2 will charge to the input voltage (+E volts) via D1/D3.

If a logic high pulse is applied to Q1 gate it will turn hard on and effectively ground the right-hand side of L1 (via D1/D2). This will not affect the charge on C1/C2 as D3 blocks any discharge current. However, it will increase the current drawn through L1 and D1/D2. The amount of increased current depends on the values of the input voltage (+E) and the drive pulse width - and can be described using the formula $E = -L^{\partial i}/_{\partial t}$.

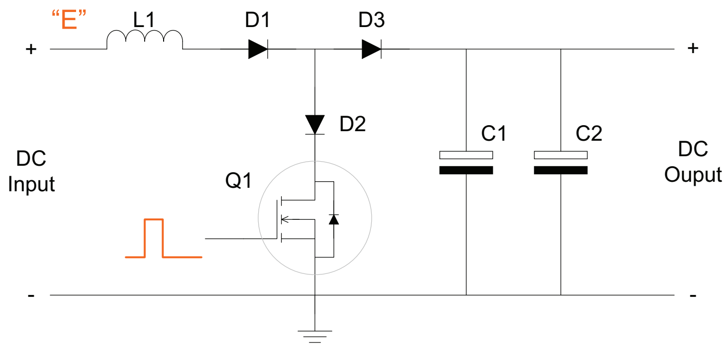


Figure 5.9: Boost Converter Basic Principles

As the input voltage (E) and inductance are both constant, the current through L1 increases linearly while Q1 is turned on and therefore reaches a peak value at the end of Q1's drive pulse.

Q1 turns off when the drive pulse is removed from its gate. However, the current through L1 cannot reduce to zero instantaneously (one of the properties of a choke) and since Q1 now represents an open circuit the only path available for the decaying current is through D3 and C1/C2, which therefore charge up to a voltage greater than the input voltage. The voltage across these capacitors forms the dc busbar voltage.

Another way to view this action is to consider that the energy stored in the magnetic field around L1 when it draws current ($½LI^2$) is transferred to capacitors when Q1 turns off.

In the practical UPS boost converter circuit the current passing through D3 not only charges the capacitors but also supplies the UPS load (via the inverter). C1/C2 therefore act as a reservoir capacitor, taking on charge when D3 is passing current (Q1 off) and providing the dc busbar load current when Q1 is turned on.

In a standard dc-dc converter the output voltage is regulated by comparing it with a reference level and using any resulting error signal to control the width or frequency of the drive pulse. For example, if the circuit's output voltage falls below the reference level, the control circuit would increase the pulse width (or increase the pulse repetition rate), allowing more current to build up in the choke and thereby restore the output voltage to its nominal value.

Benefits

The boost converter, shown in Chapter 6, in the transformerless UPS block diagram essentially works in the same way as the dc-dc boost converter. The major difference between the two circuits is that the input voltage is from the ac mains supply and not a fixed dc level. To overcome the fact that the circuit is fed with an ac voltage, the transistor drive pulse is made very narrow compared with the period of the input supply by using a high switching rate, typically between 20kHz and 100kHz. If for example a 50kHz switching rate is used it will have a maximum pulse width of 20 µs and the transistor will switch on and off 100 times during a 50Hz mains cycle.

If this is the case, the duration of the turn-on pulse is so short compared with the incoming ac cycle that the input to the boost converter can be considered to be constant during the pulse period.

Thus every time the transistor turns on it ‘sees’ a ‘constant’ voltage which is marginally higher or lower, depending on whether the sinusoidal waveform is rising or falling, than that which was present at the previous pulse.

The circuit maximises the input power factor by controlling the input current in such a way as to not only make it sinusoidal but also keep it in phase with the input voltage. This is achieved by pulse-width modulating the drive signal applied to Q1 – i.e. by turning Q1 on for shorter periods when the input mains voltage is at the low points of its waveform, drawing less current, and for longer periods when it is at the higher points. This means that although Q1’s drive signal is held at a constant frequency, the mark-to-space ratio (or duty cycle) is made to vary in sympathy with the input voltage waveform amplitude.

The waveform diagram Figure 5.10 shows the principles of this circuit by illustrating the rising and falling current pulses superimposed on the input voltage waveform. However, this diagram shows only a few current pulses (due to the restriction of the drawing definition) and in practice the current waveform outline at 50kHz is very smooth in comparison to that shown.

The converter diagram in Figure 5.9 and waveforms in Figure 5.10 help describe the action only during the positive half-cycle of the input mains supply. In practice a second, identical converter is used to process the negative mains half-cycle and the outputs from the two converters are combined to provide a single dc busbar equal to their collective value.

In addition to the improvements in harmonic generation and input power factor correction, the advantages of the boost converter over the phase-controlled rectifier as the UPS front end are clear. Not only does it contain fewer power components, making it less expensive and lighter, but it also leads to a smaller

UPS cabinet footprint due to the lack of twelve-pulse input transformer and/or additional heavy harmonic filter components.

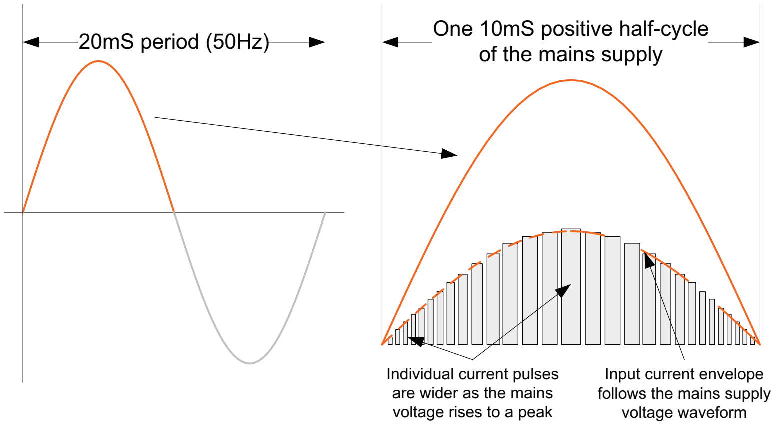


Figure 5.10: Power Factor Correction

Reducing Input THDi

The acceptable degree of harmonics generated as a result of connected load equipment is specified in the Energy Networks Association Engineering Recommendation G5/4-1 (*See page 264*). It is therefore necessary to take steps to reduce such harmonics wherever possible.

Transformer Based UPS

A 6-pulse rectifier generates THDi levels in the region of 30%. This high level can be reduced to around 10% by utilising a 12-pulse rectifier which can be lowered even further (to around 5%) by installing passive filtering.

Passive Filters

Passive filtering can be fitted to both 6 and 12 pulse rectifiers but this is not an inconsequential or inexpensive option as the filter components must be inserted into the input power cabling and rated at mains voltage and able to carry the full UPS input current.

Passive filters generally comprise a combination of inductors and capacitors shunt tuned to the worst offending harmonic.

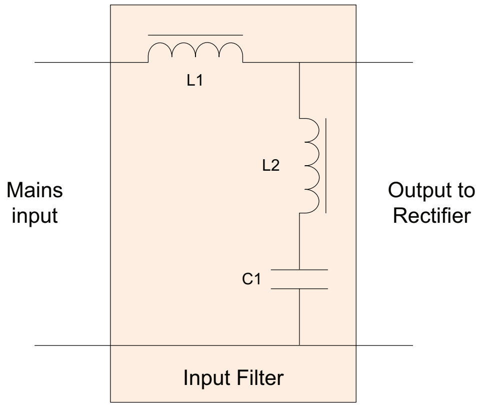


Figure 5.11: Passive filter arrangement

Passive input filters can cause problems at light UPS loads, since under these circumstances the only load 'seen' by the input mains is the filter circuit itself. This can cause the UPS input power factor to drift from lagging to leading, which may present problems for generator alternators.

Transformerless UPS

The latest generation of transformerless UPS systems (*See "Transformerless UPS Systems" on page 73*) employ active filters to continuously monitor and counteract the effects of unwanted harmonics generated by the rectification process. This can result in THDi levels of less than 2% at full load and around 3.5% at 25% load.

Active Filters

An active filter works by monitoring the input current waveform at all times and "adjusting" it when it varies from the ideal, perfect, sinewave.

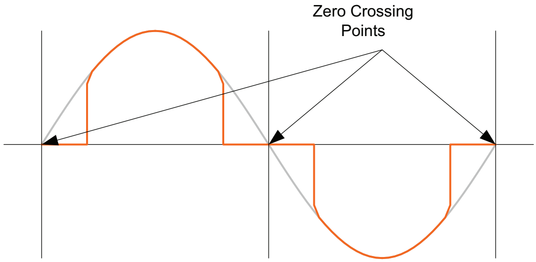


Figure 5.12: Zero crossing waveform distortion

The majority of the harmonic distortion occurs at, or near to, the zero crossing point of the current waveform where almost no current is drawn from the supply by the rectification process. The active filter purposely draws current during this period.

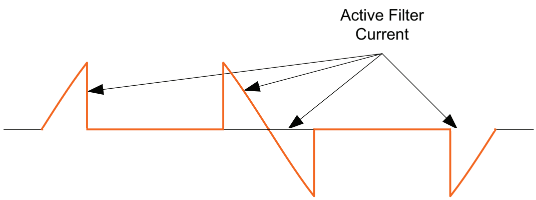


Figure 5.13: Active filter current

The sum of the rectification current and the active filter current is a mains-drawn current waveform approaching the ideal.

The current drawn by the filter is used to charge the UPS battery, reducing the load requirement of the standard rectifier and maintaining a high efficiency.

Inverter Power Block

As previously explained, the purpose of the inverter is to convert the dc busbar (battery) voltage into an ac output suitable for connecting to the load. In the case of the double-conversion, on-line UPS models considered in this chapter, the inverter output is a synthesised 50Hz sine-wave.

Since the inception of solid state UPS the advances in inverter technology have been vast. Early inverter designs exceeding a few kVA invariably used SCRs as their base switching components, later to be superseded by bi-polar transistors when devices with sufficient power rating were introduced – parallel-connected transistors were often used to meet the inverter power requirements. Today, modern inverters tend to use Insulated Gate Bipolar Transistors (IGBT) devices, which offer very reliable high power operation.

Although SCR-based inverters are still operating in the field they have virtually disappeared from current design briefs, and for this reason the inverters discussed in this section relate only to those of transistorised design.

Inverter-Phase 'Switch' Analogy

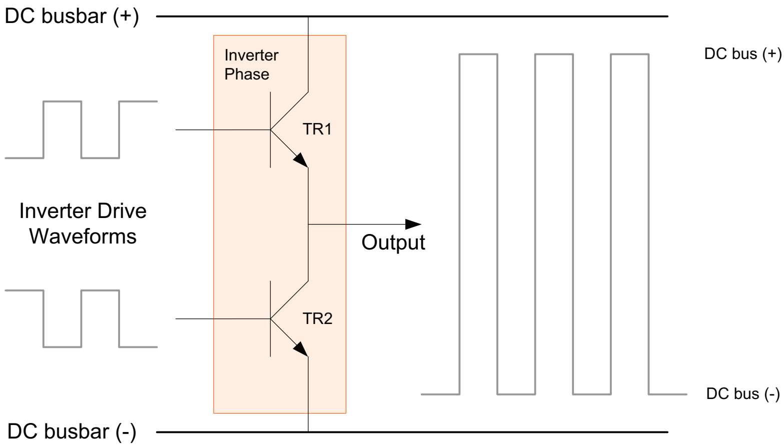


Figure 5.14: Inverter Phase Switch Analogy

An inverter is a switching circuit comprising two transistors connected in series across the dc busbar, as shown in Figure 5.14. In this diagram the transistor connected to the positive dc busbar is identified as TR1 and the one connected to the negative dc busbar as TR2. The connection at the junction of the two transistors provides the inverter output.

The inverter power components are usually assembled on a large heatsink which is often referred to as an ‘inverter phase’.

When this circuit is used as a switch it has two stable states of interest: first, when TR1 is switched on and TR2 is off the inverter output is effectively connected to the positive dc busbar. Second, when the transistors are in their opposite state the output is connected to the negative dc busbar. Ignoring any voltage drop across the switching devices themselves, by alternating between these two stable states the inverter output voltage is made to switch between the dc busbar voltages.

Clearly, the transistors’ low power drive signals must always be in anti-phase for this circuit to operate as shown, because if both transistors turn on simultaneously they will create a short circuit on the dc busbar and cause an equipment failure.

DC-AC Conversion (Output AC Voltage Production)

In Figure 5.14 the two inverter transistors were shown operating with a 50% duty cycle. That is, the transistor turn-on and turn-off period were equal. This produces a square-wave output waveform with a peak-to-peak value equal to the dc busbar voltage and with a frequency determined by the drive signal frequency.

Note that the dc busbar is usually derived from some form of full-wave controlled rectifier and is in practice approximately equidistant from neutral – for example if the bus voltage is 450Vdc the busbars will be approximately ±225Vdc with respect to neutral (ground).

The output waveform shown above is not suitable for supplying the critical load equipment and it must be converted to a 50Hz sinusoidal format, equivalent to the mains supply. The method used almost universally to obtain a sinusoidal inverter output is that of Pulse-Width Modulation (PWM) and is described below.

Before discussing in depth the pulse-width modulation (PWM) methods employed to control the inverter output voltage, it is necessary to gain a basic understanding of the effects of varying the pulse width of the inverter drive waveforms together with the fundamental principles of the output filter.

Begin by considering the effects on the output waveform of a single inverter power block when switching the inverter transistors at a constant rate (known as the ‘modulation frequency’) but at various mark to space ratios.

This is illustrated in Figure 5.15 overleaf, which shows the inverter output waveform when TR1 and TR2 are turned on at ratios of 2:1, 1:1, and 1:2 respectively.

The top diagram illustrates the case where the inverter is operating at a constant 2:1 mark-to-space ratio (m:s) – i.e. TR1 ON period being twice that of TR2 – which results in a 'mean' output voltage (with respect to the negative dc busbar) approximately equal to 66% of the dc busbar voltage.

In the middle illustration the transistors are shown operating at a mark/space ratio of 1:1 (i.e. equal ON and OFF periods). In this example the inverter output is a true square wave and has a mean voltage approximately equal to 50% of the dc busbar voltage – once again with respect to the negative dc busbar.

A m:s ratio of 1:2 is shown in the lower illustration to produce a mean voltage of approximately 33%.

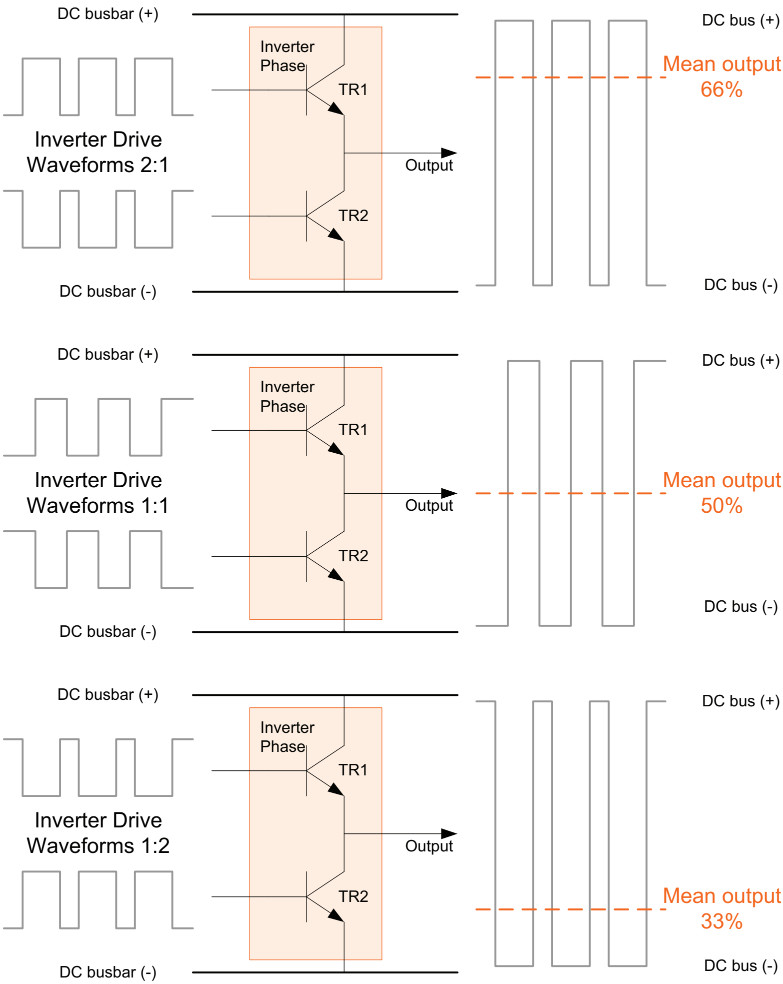
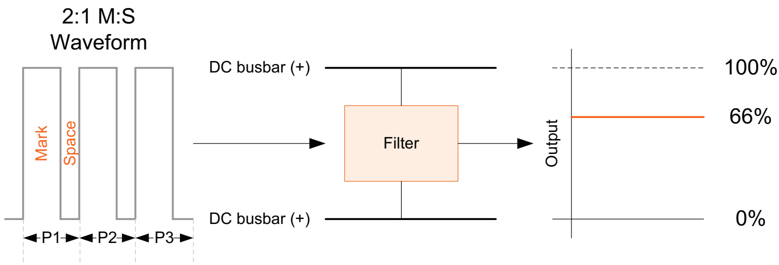
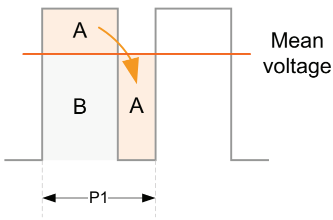


Figure 5.15: Effects of Varying Drive Signal Mark to Space Ratio

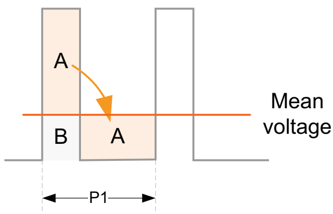
Notice that in the above examples the inverter switching frequency (or 'modulation frequency') is constant in all three cases and the 'mean' output voltage is varied by changing the mark-to-space ratio of the drive signals only.

Basic Filter Principles





The above 2:1 m:s waveform shows three pulses of mark + space period *'P'*. The waveform to the left illustrates the effects of the filter for period 1 (*P1*) and shows how part of the energy (*A*) absorbed during the *mark* period is put back into the circuit during the *space* period, leading to the 'mean' voltage shown.



This waveform illustrates the same principles at a 1:2 mark space ratio. In this case less energy is stored during the *mark* period due to its shorter duration; therefore the 'mean' value is lower.

Figure 5.16: Basic Filter Action

In the examples shown in Figure 5.15 the 'mean' output voltages are obtained by *filtering* the variable m:s output waveforms. The filter works by absorbing energy (charging) when the pulse is present and returning it back to the circuit (discharging) when the pulse is absent – i.e. energy is stored during the *mark* period and returned to the circuit during the *space* period of the output waveform. This has the effect of averaging-out the energy provided by each pulse over the complete pulse period (e.g. *P1, P2...*), as shown in Figure 5.16 – i.e. the 'mean' value is the integral of the pulse width (shown shaded) taken over each complete pulse period (*P1, P2...*). In each of the examples in Figure 5.16 the 'mean' voltage produced is proportional to the width of the output voltage pulse.

Pulse-Width Modulation

Pulse-width modulation entails generating rectilinear output voltage pulses at a repetition frequency considerably higher than the fundamental frequency (50 Hz) and modulating their duration so that the integrated value of each pulse is proportional to the instantaneous value of the required fundamental component at the time of its occurrence. That is, the pulse duration is modulated 'sinusoidally' – as illustrated in Figure 5.17.

In practice, the modulation frequency is typically several kHz. However, for ease of illustration Figure 5.17 shows a modulation frequency of only 16 times the output frequency – i.e. eight pulses per output half-cycle.

Figure 5.17A shows an expanded view of a positive half-wave sinewave with eight instantaneous values plotted at times t_0 to t_8. These coincide with the centre of each pulse period: for example, the instantaneous voltage at time t_1 coincides with the centre of the period allocated for pulse 2 (*P2*).

Figure 5.17B shows the individual pulses *P1-P9* superimposed on the instantaneous voltage plot and illustrates how varying pulse widths are employed to ensure that the 'mean' value of the pulse equals the plotted instantaneous value for the particular pulse period. In each case the pulse amplitude is identical and comprises a 'light' and 'dark' shaded area – where the 'dark' shaded portion represents the 'mean' amplitude. For example, the 'mean' value resulting from the m:s ratio of the pulse during *P3* equals the instantaneous voltage plotted at t_2. This is shown in more detail in Figure 5.17C, here the 'lightly' shaded portion at the top of pulse P3 is shown to replace the space left at either side of the pulse.

A representative complete output cycle is shown in Figure 5.18.

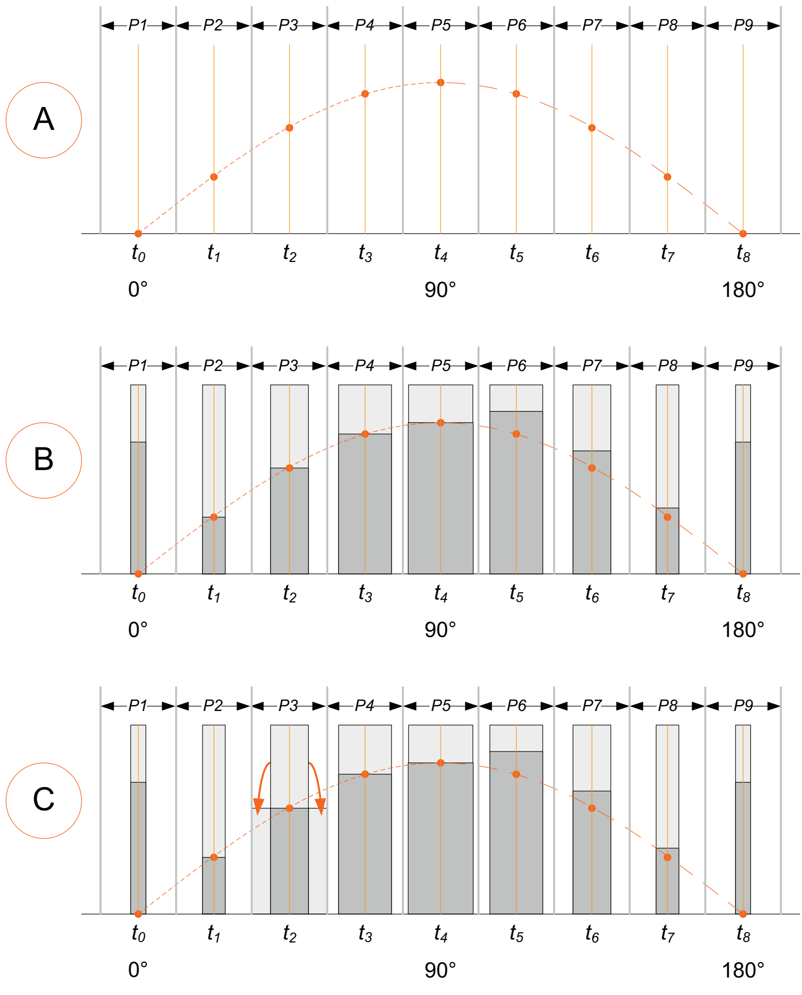


Figure 5.17: PWM Control Principles

Inverter PWM Duty Cycle

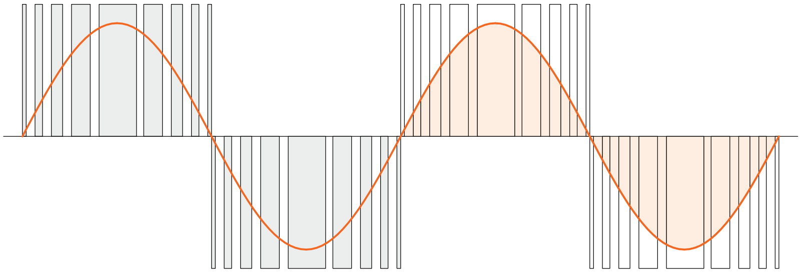


Figure 5.18: Output Power Derivation

The power delivered to the load by the inverter can be described mathematically as the integral of the voltage and current:

$$\int_0^{\pi/2} VIdt$$

A PWM-controlled inverter provides load power each time it is turned on. Therefore the power produced by the inverter during each output cycle is represented by the total area of the pulses contained in that cycle. Thus, when dealing with a PWM waveform the integral equation above can be visualised by considering that *the area of the output sinewave is equal to the sum of the areas of the individual pulses used to generate the sinewave (See Figure 5.18)*. The total amount of time the inverter power devices are turned on and delivering load-power during each output cycle can be described in terms of the inverter's *duty cycle*. As will be shown below, this varies in accordance with the available dc busbar voltage and the prevailing load current demand.

Effects of the DC Busbar Voltage on the PWM Duty Cycle

Figure 5.19 illustrates a typical UPS output section set to operate at a standard 400Vac output voltage. The output transformer has a 1:2 voltage step-up ratio, therefore the inverter must operate at 200 $V_{L\text{-}L}$ – this example was used earlier to describe the transformer-based system *(See Figure 5.4)*. A voltage of 200$V_{L\text{-}L}$ is equivalent to 115$V_{L\text{-}N}$ (i.e. $200/(\sqrt{3})$) which in turn equals approximately 325$V_{p\text{-}p}$ (i.e. $2 \times 115 \times \sqrt{2}$). This defines the minimum permissible dc busbar voltage because the inverter cannot produce a peak-to-peak output voltage greater than the dc busbar voltage itself.

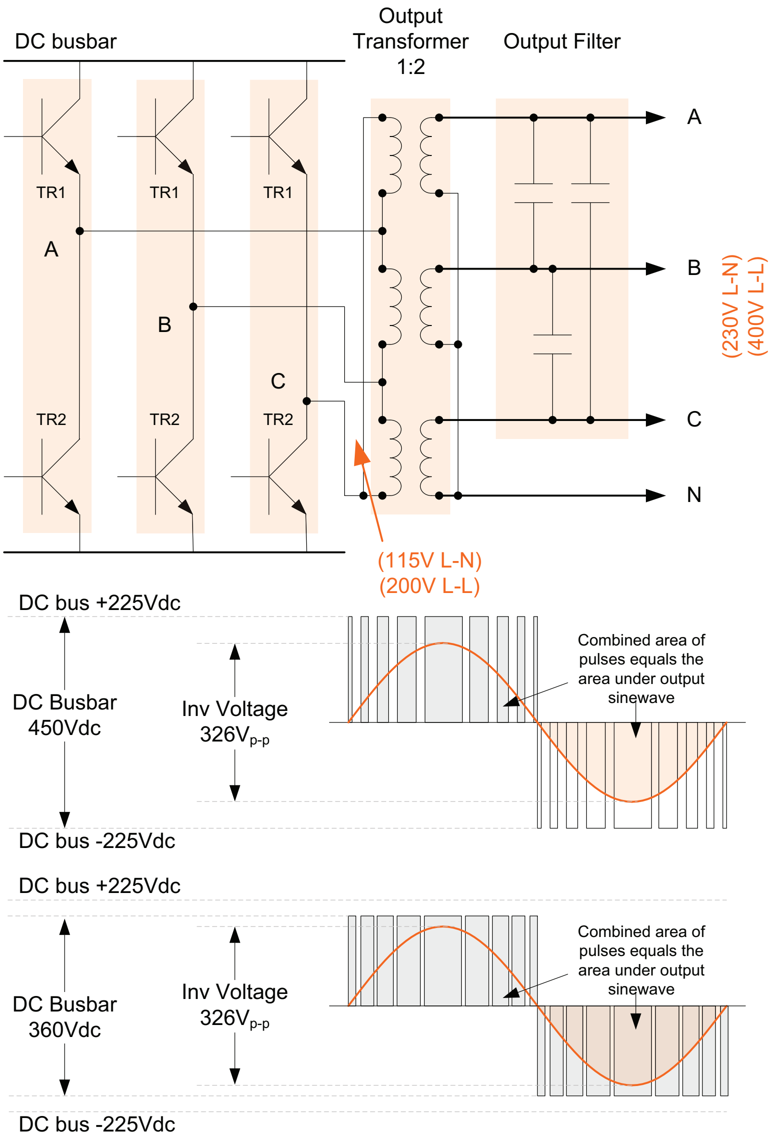


Figure 5.19: Effects of Falling DC Busbar Voltage on the PWM Duty-Cycle

In practice, the minimum dc busbar voltage is usually set to 1.67V per battery cell, and this example system would typically employ 198 cells under these circumstances which leads to a minimum dc busbar voltage of 330V.

This results in a dc busbar ranging from 450Vdc when the batteries are being float charged and 330Vdc at the ‘end-of-discharge’ voltage – at which point the inverter is shut down.

It has already been shown that in each output cycle the area of the sine-wave is equal to the combined area of the associated PWM pulses; and also that the amplitude of the inverter pulses is equal to the dc busbar voltage. Therefore, when the batteries are on-load, and the dc busbar voltage falls from 450 V to 330 V, the width of the PWM pulses must increase proportionally as their amplitude decreases in order to maintain a constant output voltage. This is illustrated in Figure 5.19. Notice that this diagram shows that the peak, and therefore rms, value of the inverter output remains constant as the bus voltage falls. Once again, for reasons of clarity the illustration in Figure 5.19 uses only 16 PWM pulses per cycle.

In a typical PWM inverter the duty cycle will vary from 75° when the inverter is off-load and the dc busbar is operating at its nominal float voltage value, to about 105° when operating at the end-of-battery-discharge voltage.

Effects of the Load Demand on the PWM Duty Cycle

The PWM waveform duty-cycle is directly affected by variations in the demanded load current. For example, the previous paragraph illustrated that when operating off-load from the normal busbar, the duty-cycle is approximately 75°. However, if the inverter is loaded under these conditions the PWM pattern would require increased pulse widths to maintain the output waveform while allowing more power through to the load. In practice, this would increase the duty-cycle by around 5°.

Inverter Output Detail

In a UPS system fitted with an output transformer to boost the inverter voltage to that required at the UPS output there are two configurations in common use. The first contains three inverter phases whose outputs are connected to a delta-star transformer, as shown previously in this chapter *(See Figure 5.19)*. This configuration is sometimes referred to as a 'single-ended' inverter.

The second configuration employs two inverter switching blocks per output phase connected in a bridge configuration, as shown in Figure 5.20 – sometimes referred to as a 'double-ended' or 'bridge' inverter configuration. A greater output power can be provided by a 'bridge' output than is possible from a 'single-ended' inverter operating from the same dc busbar voltage, as explained below.

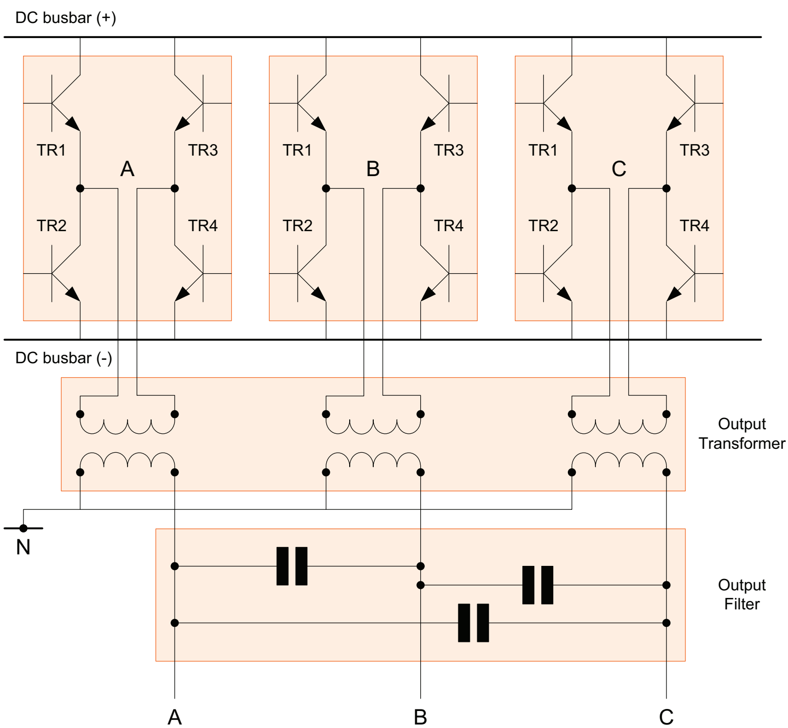


Figure 5.20: Inverter Bridge Output Detail

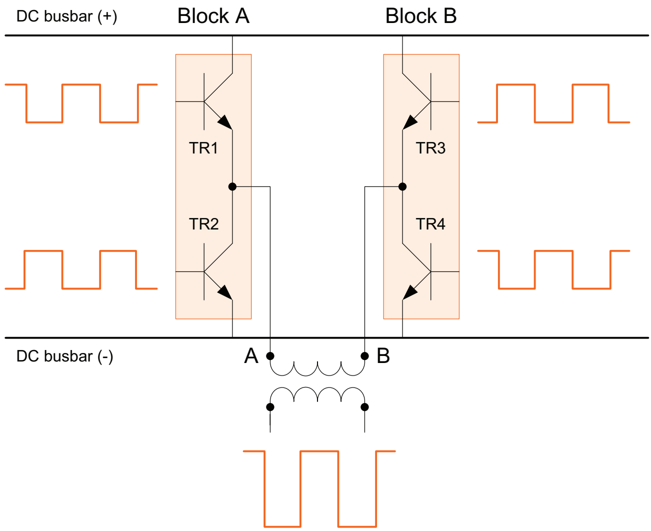


Figure 5.21: 'Bridge' Inverter Operation

Inverter Bridge Operation

Figure 5.21 illustrates the two power inverter blocks associated with one output phase connected together by a transformer, with inverter block A comprising TR1/TR2 and block B comprising TR3/TR4. As described earlier, the drive signals to each pair of transistors within an inverter block are always at 180° with respect to each other. The diagram in Figure 5.21 also shows that the signals to the two inverter blocks are also in anti-phase – i.e. the drive signals to the 'high' transistors of Block A (TR1) and Block B (TR3) are in anti-phase, as are the signals to the two remaining transistors (TR2 and TR4).

At the instant in time highlighted in the top diagram in Figure 5.22, TR1 and TR4 are both turned ON and TR2 and TR3 are OFF. This leads to the left-hand side of the output transformer primary winding being connected the positive dc bus and the right-hand side to the negative dc bus, and current flows through the primary winding in the direction A-to-B. Although at first glance this circuit may appear to present a short-circuit across the dc busbar, the current flowing through the transformer is limited by the impedance presented by the primary winding – which comprises the impedance of the transformer itself, together with the reflected impedance of the output filter and load.

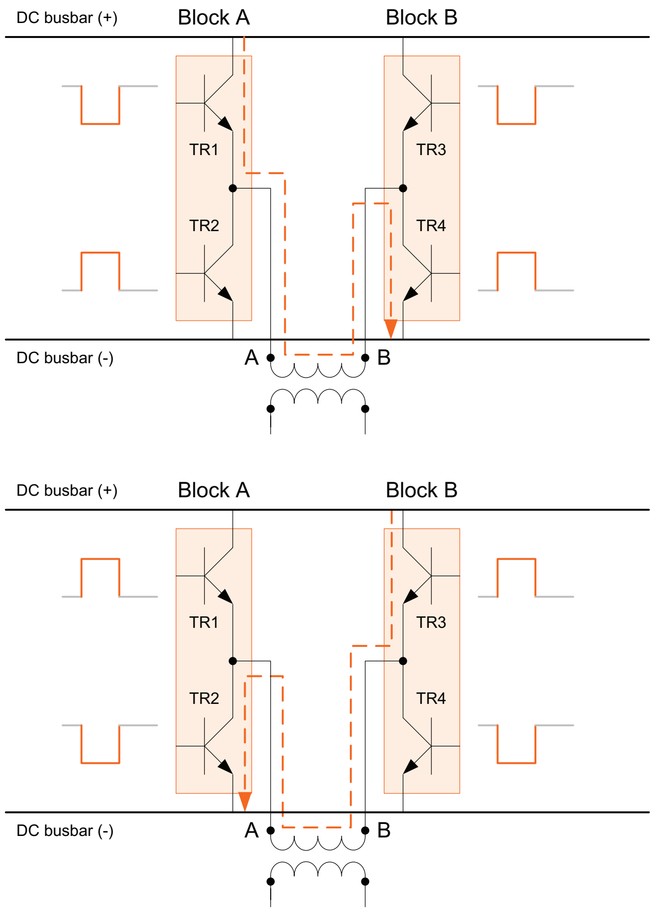


Figure 5.22: Bridge Operation

When the control electronics reverse, the drive signals to TR1 and TR4 turn OFF and TR2 and TR3 turn ON. This reverses the polarity across the output transformer primary and current now flows through the transformer from B-to-A, as illustrated in the lower diagram in Figure 5.22.

By controlling the relative switching sequence of the two inverter blocks, current flows through the transformer primary in either direction, this induces an 'alternating current' in the transformer secondary and the production of an (alternating) secondary voltage. In practice the output transformer is of a step-up design and its secondary voltage represents the required UPS output voltage.

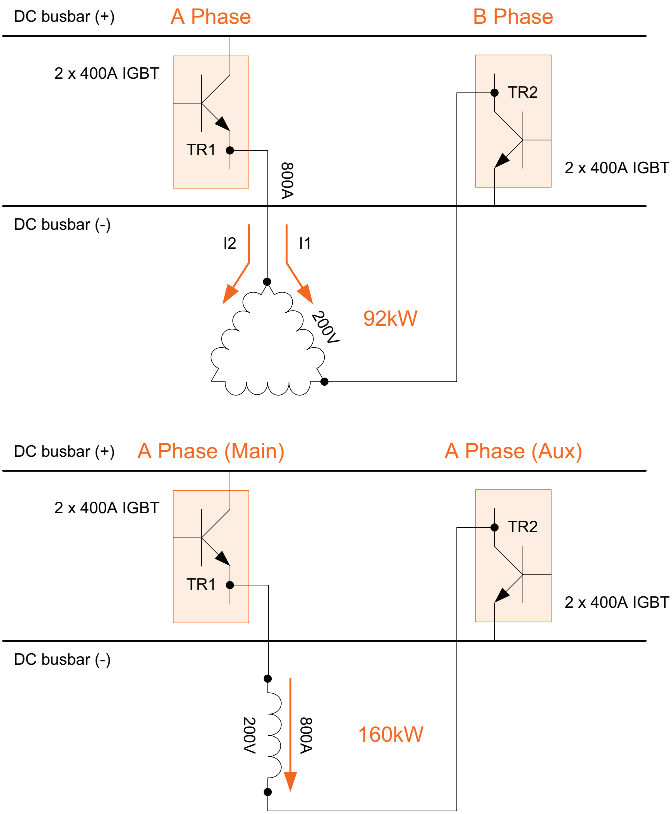


Figure 5.23: Output Power Comparisons

Figure 5.23 shows the comparative primary current flows in the ‘single-ended’ and ‘bridge’ inverter A-phase output circuits. In the ‘single-ended’ circuit (top diagram) the transformer primary windings form a closed delta circuit, and the current supplied by one inverter power block is always shared between two windings. In the ‘double-ended’ circuit the output transformer primaries are individually connected between the ‘main’ and ‘auxiliary’ power blocks of their respective phases and act as three single-phase windings so the full current passes through each individual winding. The power increase offered by a double-ended over a single-ended inverter is equal to $\sqrt{3}$, i.e. the relationship between a single-phase and three-phase system.

Static Switch

For a UPS to maintain supply to the critical load even under fault or overload conditions, the output to the critical load can be supplied **either** from the UPS inverter output or from the mains (bypass) supply.

The static switch of an on-line UPS has two operational states, 'on UPS' (the normal condition) and 'on bypass'. When the UPS is operating on bypass there will be an accompanying alarm or warning condition as in this state the critical load is not protected from mains disturbance or interruption. In both cases it is the job of the static switch to provide a very fast, break-free, transfer between the inverter output and the bypass.

The static switch can be considered to be an intelligent switch that decides whether to use the UPSs inverter output voltage or the raw mains to supply the load. The decision is made by the static switch's own and/or the UPSs control logic which continually monitors the bypass (raw mains) and inverter voltages. The control logic typically controls the phase and frequency of the UPS inverter(s) to ensure that the bypass and inverter voltages are in phase (synchronised) with each other. Bi-directional, break-free transfer between the two supply sources is only possible when the bypass and the inverter are 'synchronised'.

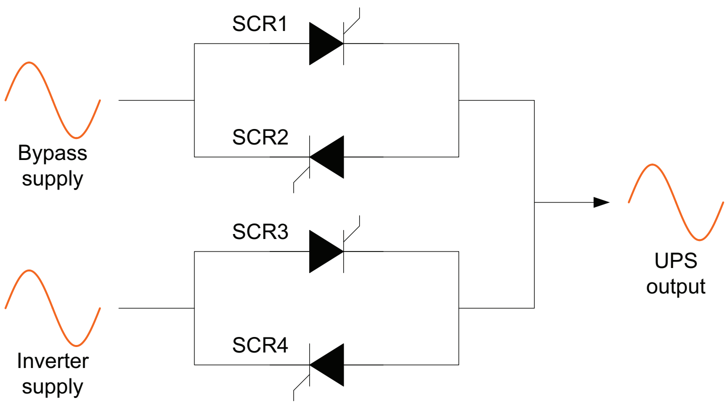


Figure 5.24: Simplified Static Switch

Static Switch Operation

The static switch circuit will have two inputs and one output and could comprise a pair of inverse parallel connected SCRs connected in series with the bypass and inverter supplies – as shown in Figure 5.24, or alternatively comprise a system where the inverter side SCRs are replaced by a contactor. Using a contactor instead of the SCRs has slight system efficiency benefits as there are less losses associated with a contactor than with SCRs.

Figure 5.24 shows a single phase circuit – in a three phase circuit a pair of SCRs is connected in series with each of the phases. The bypass (raw mains) supply is connected to SCRs 1 and 2, and the inverter supply to SCRs 3 and 4. As previously stated, SCRs 3 and 4 could be replaced by a contactor.

During normal operation, with the inverter supplying the load, SCRs 3 and 4 are triggered (switched on) and SCRs 1 and 2 are not triggered (switched off). In the event of an inverter supply problem or an overload condition etc. the static switch monitoring circuitry would identify that there was a problem and decide to transfer the critical load from the inverter supply on to the bypass supply. By stopping the triggering of SCRs 3 and 4 and by starting the triggering of SCRs 1 and 2 a supply to the critical load is maintained. As described earlier (*See "Basic Phase-Control Principles" on page 40*), once an SCR is triggered it continues to conduct until the voltage across it is zero (i.e. in an ac circuit, when the voltage waveform passes through zero). By triggering SCRs 1 and 2 while SCRs 3 and 4 are still conducting, the bypass and inverter are paralleled for a short time. Such short term paralleling ensures a break-free transfer between the two supplies and it is for this reason that the two supplies must be synchronised before the transfer can take place. If the transfer was allowed regardless of the synchronisation status of the two supplies then the load would almost certainly be subjected to a power disturbance.

> To avoid a power disturbance to the load, if the system is **not** synchronised, a static switch should not allow a transfer from inverter to bypass, or vice versa.

The manufacturer's specification should provide details of the synchronisation limits of the UPS (*see "Introduction" on page 283*).

As a general rule, the mains voltage supply frequency in the UK is very stable. However, if a standby generator is feeding the UPS then it is important to ensure the generator's output frequency is stable enough for use with a UPS system (*See "UPS Compatibility" on page 149*).

Isolation in a UPS System

There are three distinct types of isolation in a UPS system:

- the galvanic isolation between input and output
- the input isolation between mains and battery, and
- the isolation between the dc circuit and the UPS output.

It is important to understand the distinction between these types of isolation in order to avoid misinterpretation of specifications.

Galvanic Isolation between Input and Output

In transformer-based UPS systems the transformer is used to step up the voltage at the output of the inverter to a voltage compatible with the utility or generator supply voltage.

A common misconception is that the transformer is also used to provide galvanic isolation, which is not the case. In transformer-based UPS systems, the neutral line passes through the bypass line and therefore no galvanic isolation between UPS input and output is provided. If total galvanic isolation is required in transformer-based or transformerless UPS, an additional transformer is necessary at the output of the UPS, so that a galvanic isolation from the load is provided for both the inverter and bypass. The transformer must be designed with adequate insulation to prevent the high voltages present at the UPS output from jumping between windings.

Input Isolation between Mains and Battery

In the early 60s, when only open lead-acid batteries where available, galvanic isolation was required for safety reasons. Since the late 80s, when the maintenance-free lead-acid or nickel-cadmium batteries came into use, input galvanic isolation was abandoned.

Today this isolation is very rare.

DC-Component Output Isolation

Transformer-based technology

As mentioned above, in transformer-based UPS systems the transformer is used to step up the voltage at the output of the inverter to a voltage compatible with the utility or generator supply voltage. Furthermore, the transformer isolates DC components, and therefore the inverter transformer isolates the DC circuit from the output load. In older designs, where the PWM profile was not as well controlled, the output transformer also assists with the reduction of noise components on the output waveform.

Figure 5.25 shows a block diagram of a transformer-based, double-conversion UPS system. It can be seen that the transformer is on the output of the inverter and not on the output of the UPS.

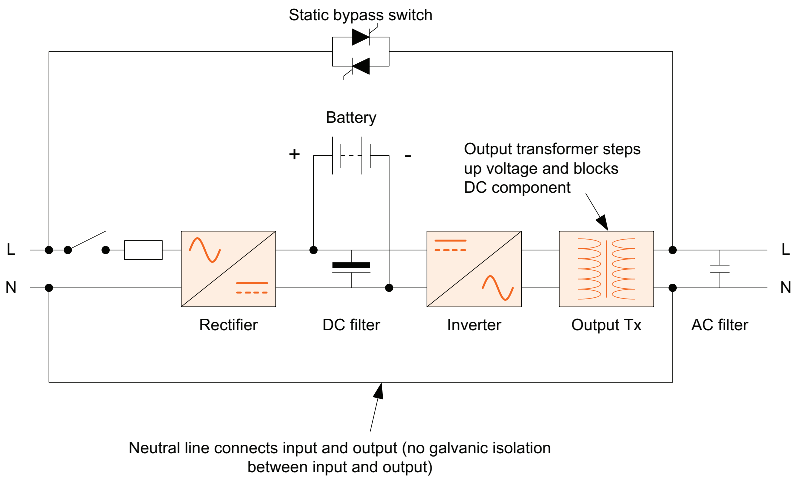


Figure 5.25: Transformer-based UPS

There are two possibilities for the DC component to pass from the UPS to the load – when there is an inverter IGBT fault or a bypass thyristor fault.

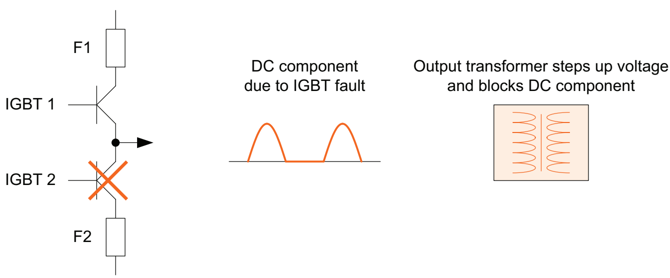


Figure 5.26: Effect of an IGBT fault in a transformer-based UPS

In the event of an inverter IGBT fault – if, for example, IGBT 2 of the inverter does not conduct – a DC component will be generated, and in the transformer-based UPS the output inverter transformer will isolate the inverter DC component from the load (Figure 5.26).

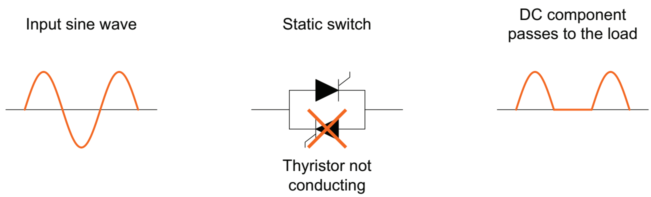


Figure 5.27: Effect of a bypass thyristor fault in a transformer-based UPS

In the event of a bypass thyristor fault – if, for example, one of the thyristors does not conduct – a considerable DC component will feed the load as the transformer does not isolate the bypass. The transformer-based UPS does not control this DC component (Figure 5.27).

Transformerless Technology

As transformerless UPS technology (Figure 5.28) does not provide an inverter output transformer, the DC-component issue must be handled differently. The DC component is blocked at the output by hardware and software regulation and control so that it cannot be fed to the load. The transformerless UPS behaves as follows in the two cases.

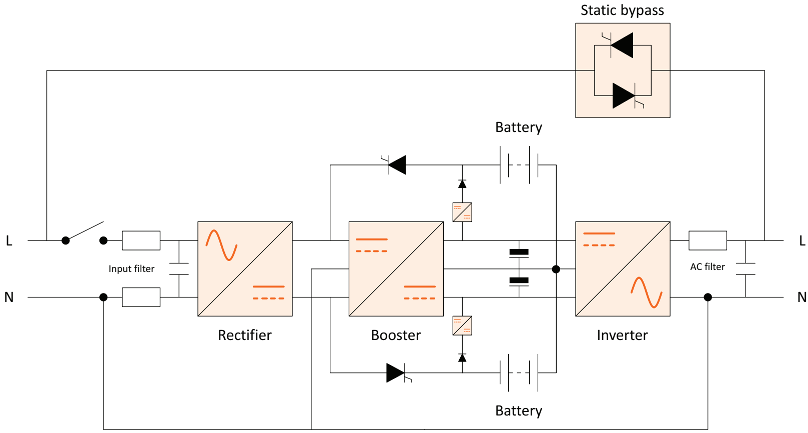


Figure 5.28: Transformerless UPS

In the case of an inverter IGBT fault – if, for example, IGBT 2 of the inverter does not conduct – a DC component will be generated. Transformerless UPS technology handles the DC component by means of a fully-redundant EDCP (electronic dc protection) system, so that the probability of a DC component appearing at the inverter output is practically zero (Figure 5.29).

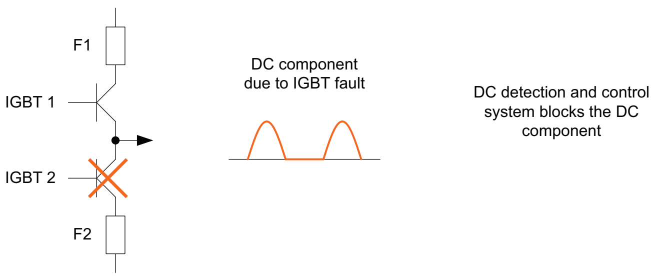


Figure 5.29: Effect of an inverter IGBT fault in a transformerless UPS

DC Component Protection in Modern UPS

Recent UPS designs provide fully-redundant DC component protection systems on the inverter side consisting of three parts:

Firstly, redundant DC-component regulation continuously detects and regulates the DC component within a tolerance of ±10mV - a normal mains supply to which all non-protected equipment is exposed has a DC-component tolerance of ±300mV.

Secondly, redundant DC-component control continuously detects the DC component, and if it is higher than 4V, the DC-component control circuit automatically and instantly transfers the load to bypass. The inverter, rectifier and booster are switched off, the battery is disconnected and alarms are signalled. To ensure the DC component does not appear on the load side, the protection system operates at all times, even if the UPS is on but switched to bypass. The DC-component detection, regulation and control circuits in modern UPS are redundant, making the system very safe and secure.

Thirdly, a DC component may appear on the output if one IGBT fuse blows and the other IGBT continues to conduct. Modern inverter bridges are designed in such a way that if one of the two fuses (F1 or F2 in Figure 5.29) blows the other fuse will also automatically blow, preventing the DC component flowing to the load.

The probability of a DC component passing through a modern transformerless UPS system is no higher than the probability of a transformer going short circuit (and allowing the DC component to pass).

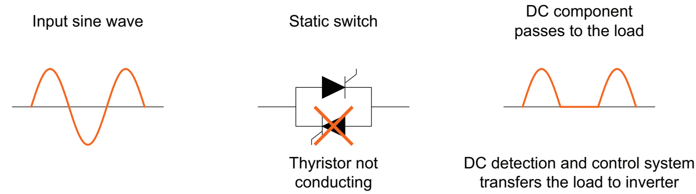


Figure 5.30: Effect of a bypass thyristor fault in a transformerless UPS

In the case of a bypass thyristor fault similar protection, on the bypass side, detects if one of the static bypass SCRs is not conducting. In this event, the load will be automatically transferred to the inverter within 2 to 5ms in order to avoid a DC component on the load side.

6 Transformerless UPS Systems

Introduction

The transformer-based static, double conversion, on-line UPS, utilising an internal step-up transformer, was first introduced during the seventies and was widely produced, especially at the very top of the output power range. However, with advances in power semiconductor technology and improved PWM based waveform generation, the UPS industry has generally moved towards transformerless technology, with individual modules now available up to 500kVA.

The examples shown throughout this section are for single phase UPS but apply equally to three phase systems.

Transformer Based Solution

Figure 6.1 shows the topology of a typical conventional transformer-based, double-conversion, on-line UPS. The transformer is used to step up the voltage at the output of the inverter to a voltage compatible with the utility or generator supply voltage (*refer to page 37 which describes the transformer-based technology in more detail*). A common misconception is that the transformer is also used to provide galvanic isolation, **which is not the case**.

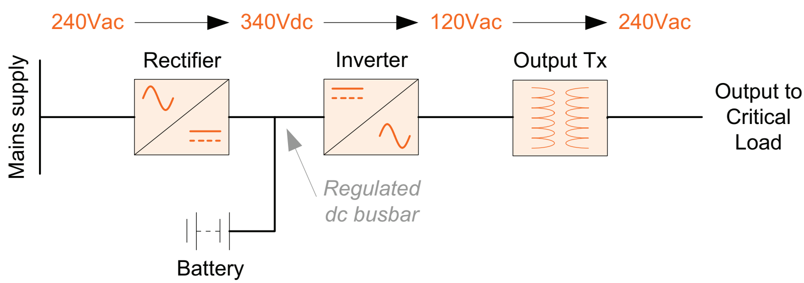


Figure 6.1: Conventional Transformer-based UPS.

Transformerless Solution

Recent advances in power semiconductor technology and the introduction of the Insulated Gate Bipolar Transistor (IGBT) device has made the transformerless UPS a viable proposition. One such design is shown in Figure 6.2.

In this design the phase controlled rectifier shown in the previous design example *(see 'Rectifier Power Block' on page 40)* has been replaced by a fixed rectifier followed by a dc converter which boosts the rectifier output to a much higher level, thus allowing the inverter to directly produce an output r.m.s voltage compatible with the rectifier input voltage. The diagram shows the dc busbar to the inverter input to be 700Vdc.

The rectifier is a standard full-wave diode bridge and its output is therefore unregulated. Although the figure of 340Vdc shown on the diagram is once again the theoretical off-load maximum voltage, in practice this value will be somewhat less.

The dc boost converter is a form of switching regulator circuit which provides a constant (700Vdc) output over a fairly wide range of input voltages from the unregulated dc busbar – *(see 'Boost Converter – (Transformerless UPS)' on page 46)*. The regulated busbar is therefore unaffected by mains supply aberrations within the UPS's specified limitations.

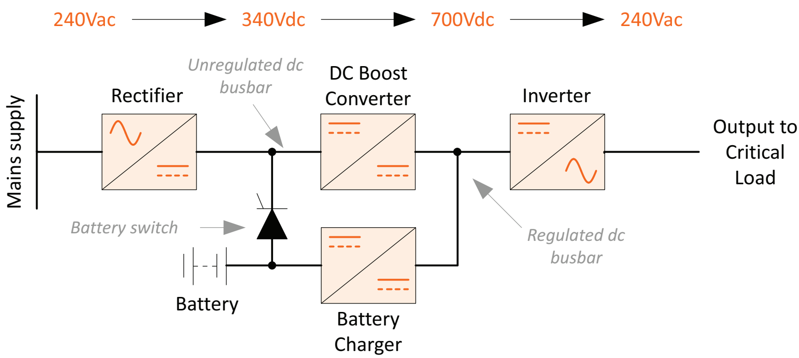


Figure 6.2: Transformerless UPS Block Diagram

A separate battery charger is shown connected to the regulated dc busbar. The charger acts as a dc-dc buck converter, reducing the high voltage present on the regulated dc busbar to a suitable battery float charge voltage.

When the mains supply fails the battery is instantaneously connected to the unregulated dc busbar by some form of switching device – this typically carried out using an electronic switch such as a fast-acting SCR. The dc boost converter continues to supply the regulated dc busbar from the discharging battery and the inverter operation is unaffected. As with the transformer based design, during a long term mains failure the battery will eventually reach its end-of-discharge voltage and the inverter will shut down.

One advantage of using an independent battery charger rather than connecting the battery directly to the inverter's input bus is that it provides greater flexibility over the number of battery cells used in the system which allows 'fine tuning' of the system's autonomy time, if necessary, by the addition/subtraction of a cell or two. Another advantage is that the dc-dc battery charger eliminates any ac ripple on the battery charging voltage. AC ripple is a prime cause of premature battery failure.

Advantages

The impetus towards the transformerless UPS over recent years has been brought about by the many advantages this design offers over the traditional transformer-based UPS.

- Improved efficiency
- Higher input power factor
- Lower input current harmonic distortion (THDi)
- Reduced operating costs
- Reduced physical size and weight
- Lower audible noise
- Enhanced battery life
- Reduced capital cost

Improved Efficiency

Eliminating the transformer has a significant impact on overall UPS efficiency, increasing it by around **five** percent to yield a substantial reduction in heat loss and electricity running costs. Figure 6.3 shows typical efficiency curves for transformerless and transformer-based UPS according to output loading. It can be seen that the efficiency improvement applies to the whole load spectrum.

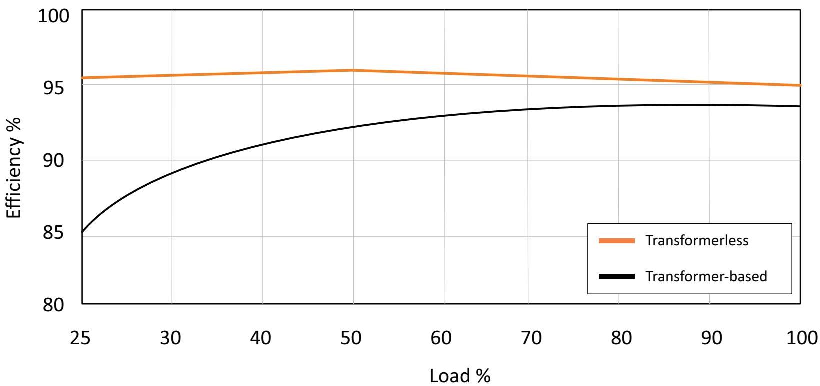


Figure 6.3: UPS Efficiency curve (a.c. to a.c.)

Higher Input Power Factor

Transformer-based UPS use a phase-controlled input rectifier to provide a regulated dc battery charging voltage and a regulated dc supply to the inverter. The effect of the phase-controlled rectifier is to present a lagging power factor load to the incoming supply, which falls further from unity as the UPS is lightly loaded as a result of the rectifier conduction angle phasing back.

It is always advisable to install UPS equipment with an input power factor close to unity since this will reduce the magnitude of the input currents which in turn minimises the size of the cabling and switchgear and, in some instances, reduces the electricity running costs.

The transformerless UPS has a free-running rectifier which, coupled with the very high frequency switching characteristics of the dc to dc boost converter, inherently produces an input power factor much closer to unity and less load dependant than the transformer-based UPS. Figure 6.4 shows the comparison between the transformer-based and transformerless input power factors and how they change according to the UPS loading.

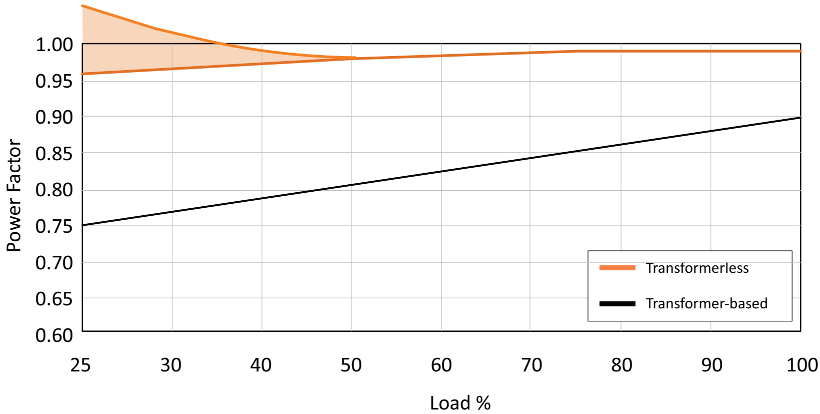


Figure 6.4: UPS Input Power Factor Comparison

Lower Input Current Harmonic Distortion (THDi)

Replacing the phase-controlled full-wave bridge rectifier with a free running full-wave bridge rectifier reduces the total input current harmonic distortion (THDi) in a three-phase UPS from around 30% to <3%, making a considerable contribution, through limiting harmonic emissions, to meeting the Energy Networks Association, G5/4-1 recommendations on page 264.

Reduced Operating Costs

Figure 6.5 shows a parallel redundant power protection system supporting a 100kVA load, with two 120kVA UPS modules equally sharing the load *(see 'Parallel UPS Systems' on page 83)*. In normal operation, each UPS will be supplying 42% of its rated output, and is therefore operating at a relatively disadvantageous point on its efficiency curve.

The table of "Comparative Costs" on page 79 compares the transformerless and transformer-based UPS alternatives when operating in the parallel redundant configuration shown in Figure 6.5. It demonstrates the importance of selecting UPS equipment which will maximize system efficiency to reduce heat losses and consequently the running costs, not only of the UPS, but also of the associated air conditioning plant.

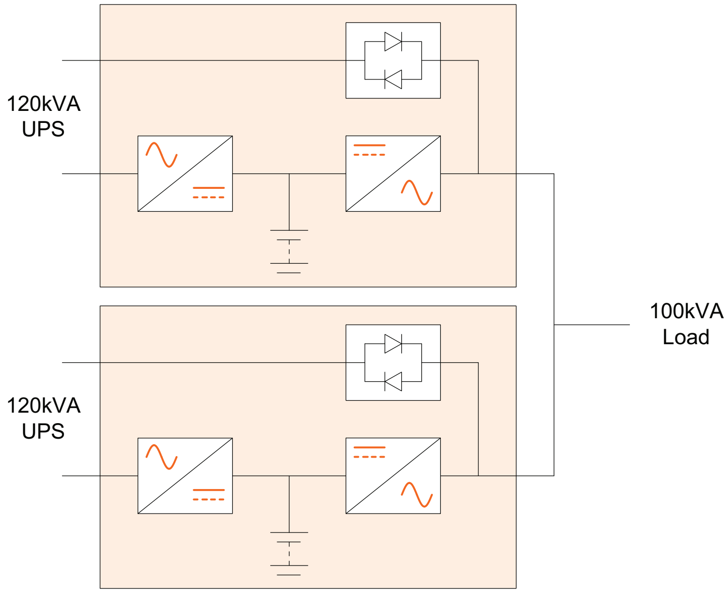


Figure 6.5: Parallel Redundant UPS System

UPS details	Transformer Based	Transformerless Design
UPS modules in parallel	2	2
UPS module rating (kVA)	120	120
Percentage load	42%	42%
Efficiency	91%	96%
Input power factor	0.8	0.98
User's load (kW@0.8p.f.)	80	80
Total UPS input (kW)	88	83
Total input current/phase (A)	159	123
Total UPS heat loss (kW)	7.9	3.3
Total UPS losses cost/year	£6,228	£2,602
UPS in an air-conditioned room?	Yes	Yes
Additional air conditioning running costs/year	£2,047	£862
Total UPS losses + cooling Cost per year	**£8,275**	**£3,464**
Cost of Ownership SAVING over Five Years		**£24,055**
Assumptions: User's actual load (assumed 0.8p.f.) **100kVA** Electricity cost (typical commercial premises) **9.0p/kWh**		

Table of Comparative Costs

Reduced System Size and Weight

The most far-reaching effects of transformerless technology are the substantial reductions in the size and weight of UPS systems. This is achieved not only by eliminating the transformer itself but also by removing the need for the 12-pulse rectifier previously required to improve input THDi performance *(see 'Twelve-Pulse Rectifier' on page 45)*. Figure 6.6 compares the space and weight characteristics of transformer-based and transformerless UPS systems.

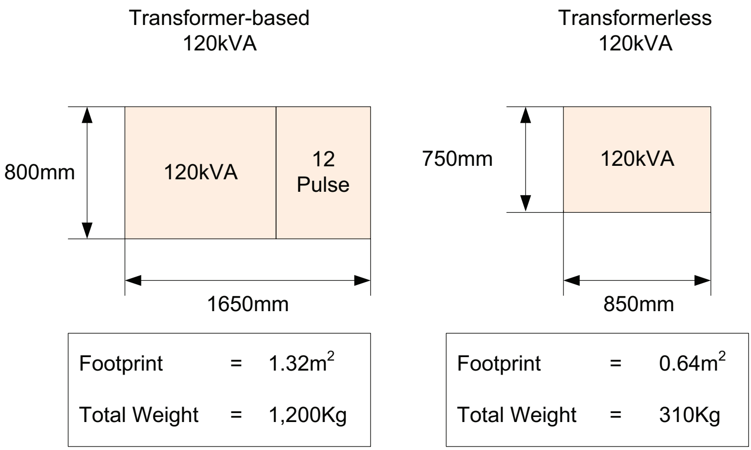


Figure 6.6: Size and Weight Comparisons

In the same way that computers have developed from large cumbersome mainframes into smaller often rack-mounted modules, so modern UPS systems have evolved from being perceived as plantroom equipment into computer peripherals.

The size factor has had a profound effect on the development of the UPS and the entire power protection culture, since it has substantially reduced the footprint and cost of parallel installations for redundancy, availability and scalability, and has enabled the development of the ultimate in flexibility and space-saving, the rackmountable three-phase UPS.

The modern three-phase rack-mounted UPS is based on individual modules with up to 100kVA output. Such systems offer major benefits in terms of parallel redundancy and unlimited upgradeability. The capabilities and advantages of modular systems are examined in Chapter 7*"Parallel UPS Systems"*.

Conclusion

Within the UPS industry, it is accepted that as a result of the many intrinsic benefits resulting from transformerless UPS topology, this design has become the standard for all modern day static, double conversion UPS systems, eventually replacing the traditional transformer based design.

The maximum rating of larger, single unit, transformerless UPS systems is currently limited by the availability of higher power, higher frequency, semiconductor devices. However, whilst 500kVA is the largest single unit transformerless UPS available today this does not preclude larger capacity UPS installations from being considered to take advantage of transformerless technology. It is relatively easy, and in some cases advantageous, to connect multiple transformerless UPS units in parallel to obtain larger capacities or gain modular redundancy. This can often be accomplished without compromising floor space or capital cost when compared with single, higher powered, transformer based UPS systems. For some manufacturers the number of UPS modules which can be connected in parallel is limited (typically to a maximum of six for transformer based systems) however, transformerless UPS are now available where there is no practical limitation on the number of units which may be connected in parallel.

7 Parallel UPS Systems

Introduction

This type of system comprises two or more UPS modules operating in parallel to feed a common critical load bus.

Units forming part of such a multi-module system are almost identical in operation to that of their corresponding single module counterparts. In fact, some manufacturers design their UPS modules such that they can be used as either standalone or parallel modules without the need for complex modification.

UPS modules are paralleled for two reasons:-

1. to increase the power rating of a UPS system because of an increase in the size of the critical load. Such parallel systems are known as capacity systems.
2. to increase the availability of a UPS system because of the importance of the critical load. Such parallel systems are known as redundancy systems.

The overwhelming majority of parallel UPS systems are designed to provide parallel redundancy.

Capacity Systems

A capacity system is implemented by using the appropriate number of modules of a particular rating necessary to supply full load power when they are all operating and connected in parallel – for example three 100kVA units might be used to serve a 270kVA load (*see Figure 7.1*).

Under normal circumstances each module will supply a maximum of approximately 90kVA. However, if one module fails the remaining two modules will each be expected to supply 135kVA and would be substantially overloaded. In this situation the load will immediately transfer to bypass via the simultaneous operation of the static switch in each module.

If the faulty module is unable to operate its bypass-side static switch, the static switches in the remaining healthy modules will ideally be rated to sustain the full load supply (e.g. 135kVA), as illustrated in Figure 7.2. When the faulty module has been repaired and all three UPS modules are again operational, the load is automatically transferred from bypass back to the inverters.

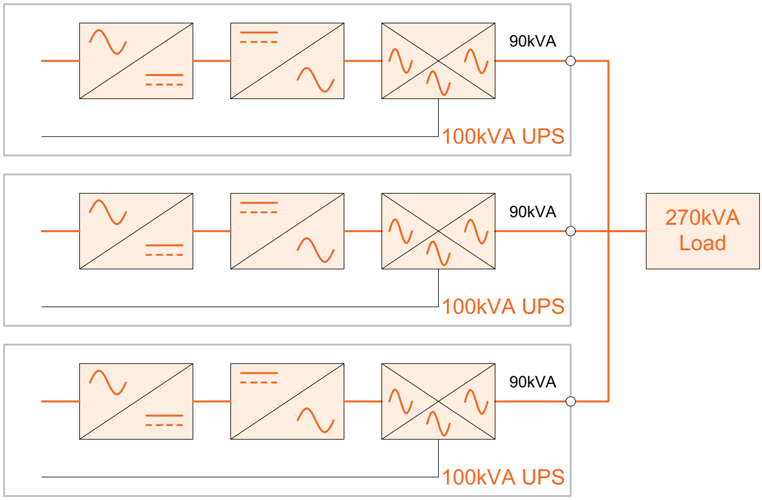


Figure 7.1: Parallel Capacity System.

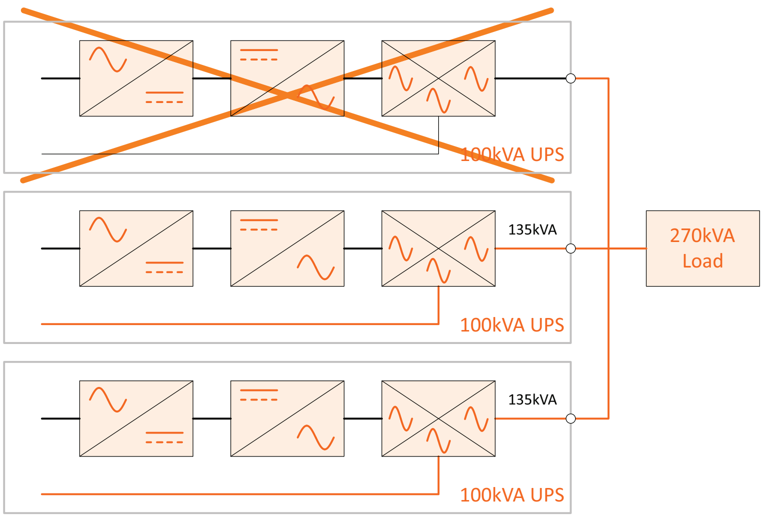


Figure 7.2: Capacity System On Bypass

Redundancy Systems

In a parallel redundant system the number of modules forming the system is a minimum of one module over and above that required by the 'capacity' system (e.g. 4 x 100kVA modules used to serve a 270kVA load – Figure 7.3). This allows the system to support the load with inverter power if any one module shuts down, and thereby increases the system reliability.

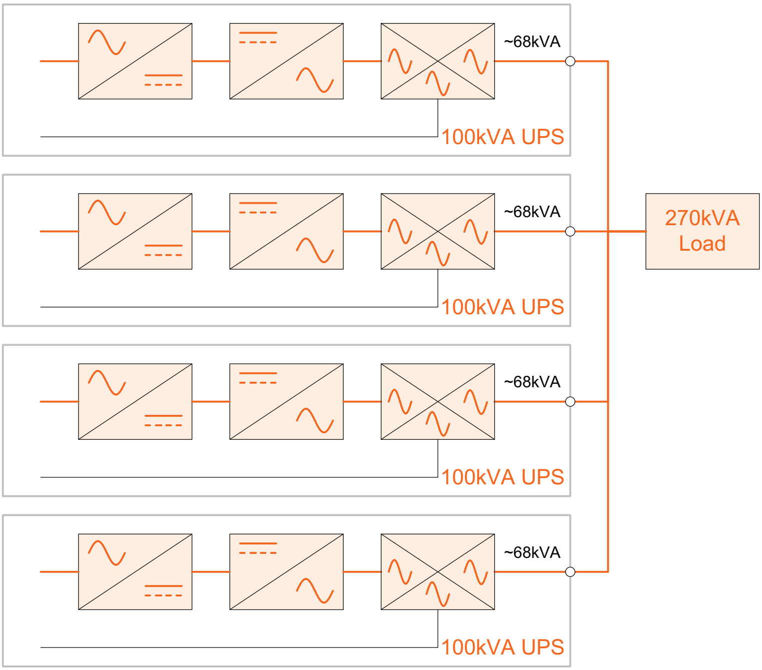


Figure 7.3: Parallel Redundant System

In a four module system operating with one redundant module, the load can be maintained on inverter power if one module fails and will only automatically transfer to bypass only on the failure of a second module. If extra security is required, the number of redundant modules can be increased to two (or more). This configuration is sometimes referred to as an 'N+1' (or 'N+2') system – where 'N' signifies the minimum number of modules needed to supply the load and '1' or '2' signifies the number of redundant modules (i.e. the coefficient of redundancy) in the system.

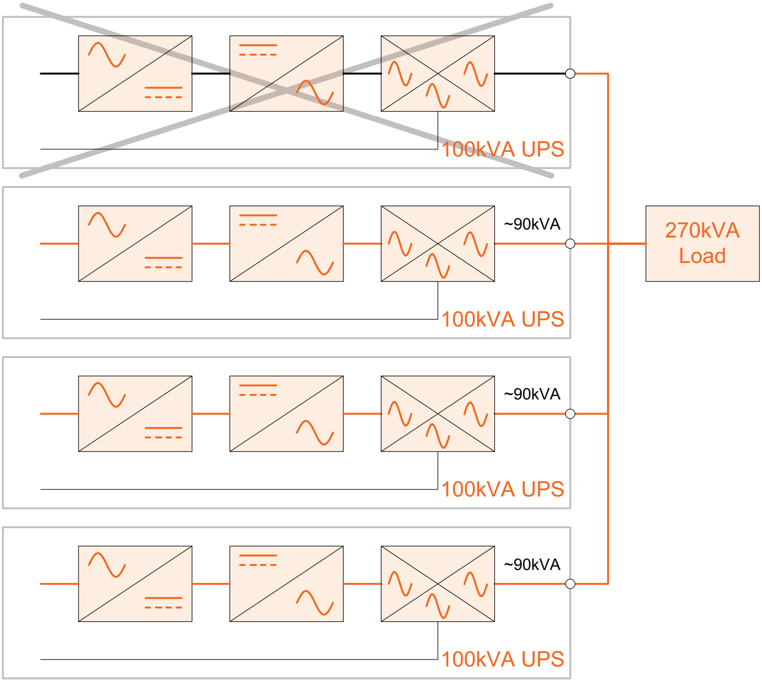
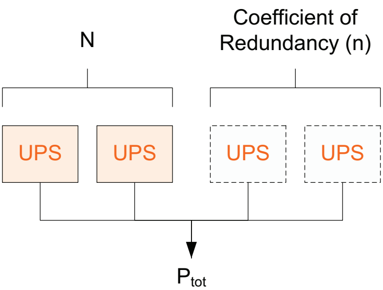


Figure 7.4: Redundant System with Failed Module

Definition of a Parallel Redundant UPS System



Total number of UPS modules = $N + n$

$$N = \frac{P_{tot}}{UPS_{min}}$$

Where:

UPS_{min} = Min. power rating of each UPS module

P_{tot} = Total load power requirement

N = Min. number of UPS modules needed to supply P_{tot}

n = Min. coefficient of redundancy

Centralised and De-centralised Systems

Note: In this discussion the term 'De-centralised System' is used to describe the UPS architecture, in that each UPS module incorporates its own static switch. This should not be confused the interpretation of the term 'De-centralised System' often used in data centres to describe the situation where individual power systems are provided alongside the various load equipment – e.g. as part of an IT equipment rack.

Introduction

Parallel UPS systems comprise UPS modules that either share common components with other UPS modules (i.e. they CANNOT operate as a "stand alone" UPS) or of completely independent UPS modules (i.e. the modules CAN operate as a "stand alone" UPS).

Parallel UPS systems whose UPS modules operate as a system by sharing common components are "centralised" systems and are described as having Centralised Parallel Architecture (CPA). The major benefit of CPA systems is cost as expensive components such as those used in module control circuitry and static switches, for example, can be used by all of the modules in the system at the same time, thereby negating the need for each module to have its own control circuitry and static switch. The major drawback of CPA systems is that the "centralised" nature of the control and power switching components introduces a number of "single points of failure" into the system which adversely affects the system's availability.

Parallel UPS systems whose UPS modules share no common components are "de-centralised" systems and are described as having De-centralised Parallel Architecture (DPA). The major benefit of DPA systems is very high availability as there are effectively no single points of failure in the system. The major drawback of DPA systems is cost as each module in the UPS system has its own, independent, control circuitry and static switch etc.

Centralised Systems

This type of parallel system configuration typically has all the UPS modules feeding the critical load via a single, centralised static switch (CSS).

Sometimes the CSS is built into the cabinet housing the various UPS modules. This is often the case with single phase and small three phase UPS systems. For large three phase systems the CSS is almost always housed in a separate cabinet.

For ease of explanation, the remainder of this chapter will assume that the CSS is housed in a separate cabinet.

Figure 7.5 shows three UPS modules working in parallel with a centralised static switch (CSS) which is connected between the UPS outputs and critical load. The total system capacity depends upon the ratings of the individual UPS modules and the number of modules used. Additional modules can be added to the system to cater for future load expansion, provided that the combined module capacity does not exceed that of the CSS.

UPS modules in centralised parallel systems differ from single UPS modules as the internal static switch is either disabled or, as shown in Figure 7.5, is configured to have only one input (the UPS inverter). In this case the internal static switch effectively becomes a static isolator ensuring very fast isolation of a faulty UPS from the CSS which provides central control of all system synchronisation and load transfer functions.

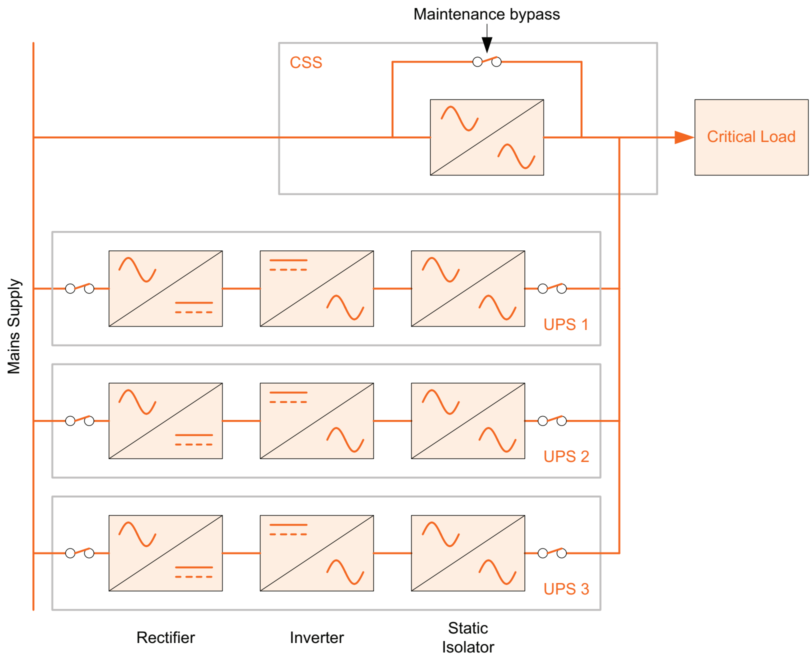


Figure 7.5: Three Module Centralised UPS System

Central Static Switch (CSS)

The CSS in Figure 7.6 provides three possible power paths to the critical load:

- the UPS inverter output.
- raw standby mains via the static bypass switch/contactor.
- raw mains via the maintenance bypass.

Static bypass isolator CB1 connects the standby mains supply to the static switch and is normally closed enabling the static bypass supply to be instantly available when required.

System output isolator CB2 is also normally closed allowing either the UPS output or the static bypass supply to feed the critical load.

The maintenance bypass switch is normally open and is only closed during CSS maintenance. Control electronics within the CSS and each UPS module sense the status of all the system's isolators to prevent the back feeding of mains power, via the maintenance bypass and CB2, to the UPS module terminals.

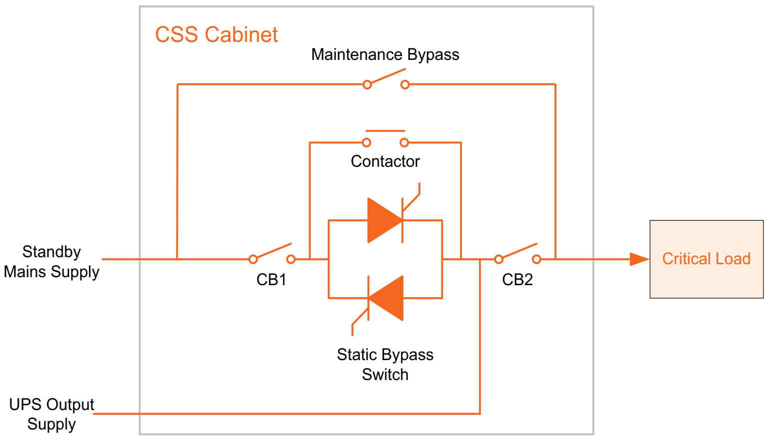


Figure 7.6: Typical CSS

UPS Output Supply

During normal operation all the UPS modules are on line (i.e. all modules' static isolators closed), they are synchronised to one another and also to the standby mains supply (if present) and share the critical load current equally.

If a UPS module develops a fault, it automatically isolates itself from the system by opening its static isolator, the critical load will continue to be supplied by the remaining healthy modules provided that it does not exceed the available system capacity. If the critical load is too great for the remaining modules to handle they will transfer the load to the standby mains via the central static bypass switch.

If the modules and standby mains are synchronised when the load transfer is required, the modules' static isolators are opened (turned off) at the same time as the central static bypass switch is closed (turned on) to provide a "no-break" load transfer. If however the system is not synchronised at the point of transfer then the modules' static isolators are opened before the central static bypass switch is closed which will result in an unavoidable brief power break and possible loss of the critical load.

If the standby mains supply is unavailable during an overload critical load loss may occur.

Central Static Bypass Switch Supply

When activated, an electronically controlled central static switch similar to that fitted to the UPS modules is used to connect the load to a raw "standby" mains supply. This supplies the load when the UPS modules are unable to do so, for example due to overload or inverter failure etc. As this supply is connected via solid-state switching components, it is known as the "Static Bypass" supply.

Depending upon the power rating of the CSS, the static bypass devices may be paralleled by a contactor which closes when the devices are turned on. This reduces the time that the static bypass devices actually pass load current meaning that relatively low powered (and therefore lower cost) devices can be used in relatively high powered static switches.

Interlocking circuitry between the CSS and each UPS module prevents the static bypass turning on while the static switches in each module are on. This is important because if the static bypass switch and module static switches were to turn on simultaneously, damage would occur in the modules caused by a back-feeding of power from the standby mains through the static bypass into the UPS module output terminals.

To obtain a clean load transfer between the UPS modules and static bypass, the UPS output and the standby mains supply frequencies must be synchronised. This is achieved by forcing the inverter frequency to track that of the standby mains within preset parameters. Furthermore, as the module AC power outputs are paralleled, it is also necessary to maintain synchronisation between the individual modules.

Maintenance Bypass Supply

The 'maintenance bypass' (also known as the manual bypass) is manually selectable. This switch makes it possible to maintain load power (unprotected) while the UPS system is completely shut down, and is designed to be used when maintenance or troubleshooting is carried out on the system.

De-centralised Systems

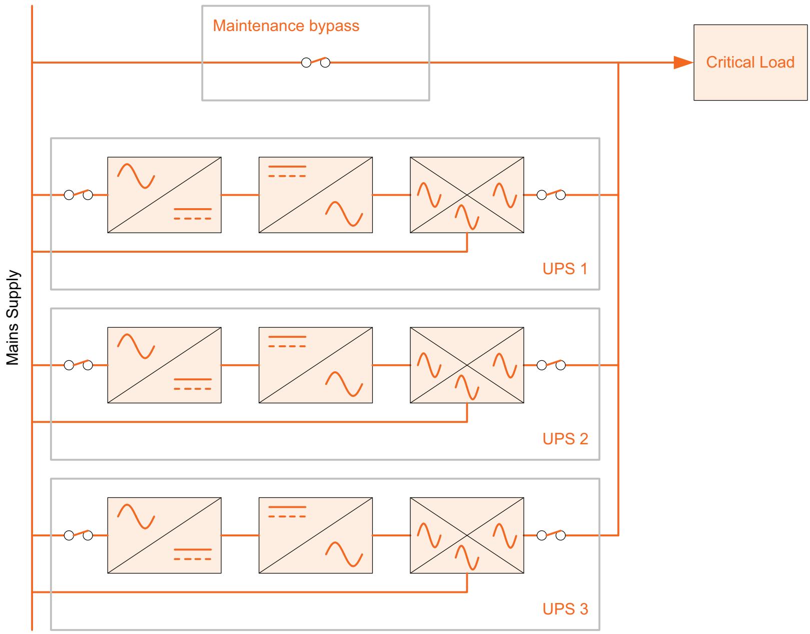


Figure 7.7: Three Module De-centralised UPS System

This type of parallel system configuration has all of the UPS modules feeding the critical load directly. A block diagram of a typical de-centralised parallel system is shown in Figure 7.7.

Figure 7.7 shows three UPS modules working in parallel directly feeding the critical load. The total system capacity depends upon the ratings of the individual UPS modules and the number of modules used. Additional modules can be added to the system to cater for future load expansion.

UPS modules in a de-centralised parallel system are practically identical to a stand alone UPS and, as previously mentioned, some manufacturers design their UPS to be used in either configuration without modification.

De-centralised parallel UPS systems always have one Master module with the other modules in the system being Slaves. If at any time the Master becomes faulty, or is isolated for maintenance etc., the next UPS in the system (former Slave) will immediately take over the Master function and the former Master will switch off.

De-Centralised Static Switch

In a de-centralised system every UPS module is provided with its own static bypass switch which is rated for the full load capacity (plus overload) of the UPS module. This means that there is more than one static switch in the system rather than the single static switch of the centralised system.

As with the centralised system, however, there are still three possible power paths to the critical load.

- the UPS inverter output.
- raw standby mains via the UPS static bypass switches.
- raw mains via the maintenance bypass.

During normal operation all of the UPS modules are on line and the UPS inverters are feeding the load via their internal static switches. All of the inverters are synchronised to each other and to the standby mains supply (if present) and share the load equally.

If a UPS module develops a fault then it automatically isolates itself from the critical load by inhibiting the operation of the inverter side of the static switch (*See "Static Switch Operation" on page 67*). The critical load will continue to be supplied from the remaining healthy modules provided that it does not exceed the available system capacity.

If the critical load is too great for the remaining modules to handle, all of the modules (including the module with a fault) will transfer the critical load to the standby mains via their internal static switches. If the system is synchronised the transfer is break-free and is achieved by enabling the operation of the bypass side, inhibiting the operation of the inverter side of each module’s static switch. If the system is not synchronised the UPS modules will not allow any transfer to take place and will attempt to supply the overload for as long as possible before switching off to protect themselves.

Conclusion

Originally, centralised parallel systems were the only type of parallel systems available due to the complexity of data and signal processing required to effectively control a de-centralised system.

The need for a separate CSS cabinet makes a typical centralised parallel system physically larger, more complicated to install and more expensive than its de-centralised counterpart. When this is coupled with the fact that the static switch and system control components of the CSS provide single points of failure to the critical load it is clear to see why de-centralised parallel systems are now the most popular choice.

One argument sometimes advanced in support of the centralised parallel system is the fault clearing capacity of the Central Static Switch. However, modern de-centralised systems incorporate internal static bypass switches capable of matching the fault clearing capacity of the Central Static Switch.

Modular UPS Systems

It was the development of transformerless three phase UPS technology as discussed in chapter 6 that enabled the development of rack mounted, modular three phase UPS systems. Transformer based three phase UPS modules would be far too large and heavy to be considered viable in a truly modular system. For example, excluding batteries, a typical transformer based 50kVA three phase UPS weighs 400kg whereas the latest modular three phase UPS weighs only 60kg.

It is widely recognised that the introduction of transformerless three phase UPS in the mid 1990s revolutionised three phase UPS design. This is borne out by the fact that all major UPS manufacturers now have three phase transformerless UPS within their product portfolios. It is also widely recognised that modular three phase UPS technology is revolutionising three phase UPS system design. This is because only modular UPS systems have the potential to simultaneously offer the benefits of very high availability, easy scalability and total system flexibility.

Hot Swappability

A modular UPS system that needs to be either switched off or manually bypassed to allow the addition or removal of a module (for example, in the event of a module failure or system upgrade) is undesirable because the overriding objective of any UPS system is to NEVER expose the critical load to unprotected power. With this in mind, some manufacturers have designed their UPS modules to be “hot swappable”.

A module is hot swappable if:

1. It can be inserted or removed from the host UPS system without:
   a. removing power from the critical load
   b. transferring the critical load to the raw AC mains supply
2. It can be safely electrically disconnected from its host system using electrically safe connectors.
3. It can be isolated from the rest of the host system without the risk of human error that may cause damage to the module, the host system or the critical load.

Modular UPS systems that contain modules that are not hot swappable as defined above are often described as being “warm swappable”.

The single most important benefit of hot swappable UPS modules is the affect that they have on system mean time to repair (MTTR) and the impact that this has on system availability.

Availability

Earlier in this chapter it was established that UPS system availability was significantly increased if individual UPS modules were connected to each other in a de-centralised, parallel redundant configuration. When the benefit of significantly reduced MTTR provided by hot swappable modules is added to such a configuration the result is maximised availability.

The subject of system availability is covered in greater depth in Chapter 11 on page 189. To avoid excessive duplication of information it is sufficient in this chapter to simply state that hot swappable modular UPS systems increase overall system availability by a factor of 10 compared to free standing (non-modular) UPS systems that are not hot swappable.

Scalability and Flexibility

7.8a 7.8b 7.8c

Figure 7.8: Rackmounted, Transformerless UPS Configuration

Figure 7.8 shows a rack cabinet containing alternative UPS configurations.

Figure 7.8a shows a three module UPS system with integral battery banks.

Figure 7.8b shows an alternative configuration with five UPS modules. In this configuration the batteries would be housed in a separate cabinet or on a rack.

Figure 7.8c shows a five module system with 100kVA modules.

Both the above arrangements automatically operate in a redundant or capacity mode according to the size of the load and significantly reduce the required floorspace.

Example 1

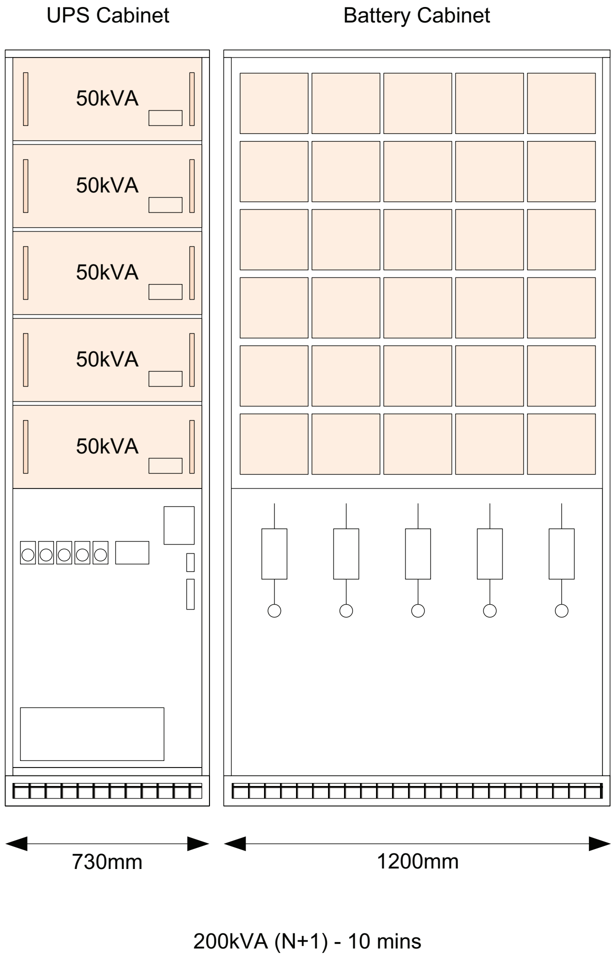


Figure 7.9: Vertical Scalability

Figure 7.9 shows 5 x 50kVA UPS modules used to support a 200kVA load with N+1 redundancy. Alternatively, the user could have employed 4 x 50kVA UPS modules to support a 200kVA load, and could have taken advantage of the vertical scalability opportunities of the system to upgrade to 250kVA cost-effectively, and with no disruption to the critical load or footprint penalty, by adding a further 50kVA module at a later date.

Figure 7.10 illustrates a modular UPS system able to support a 300kVA load with N+1 redundancy, with the ability to expand to 450kVA N+1 or 500kVA capacity in cost-effective increments and with no extra footprint requirement. Such a system may be expanded indefinitely by adding relatively small-footprint UPS and battery cabinets.

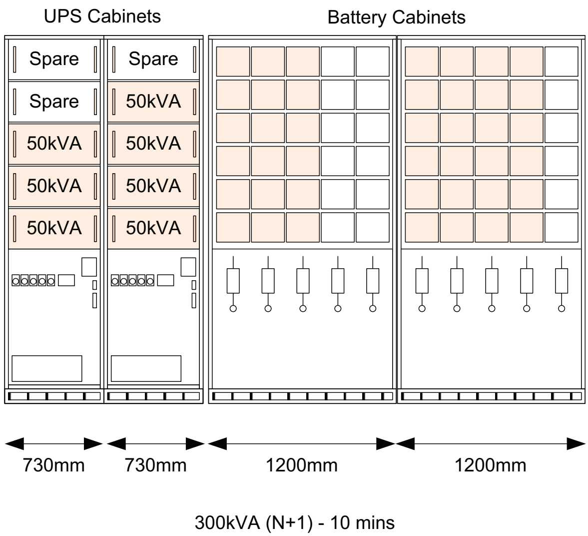


Figure 7.10: Horizontal Scalability

Figure 7.11 shows a sophisticated UPS installation utilising rack mounted UPS modules. On the first floor, a three module UPS is configured with 3 x 50kVA UPS modules, with redundancy, supporting two server/comms racks. On the ground floor, 4 x 50kVA modules, with redundancy, support three server/comms racks and has two spare slots to allow for expansion.

The user decides to move one of the server/comms racks to the ground floor, overloading the existing power support system there (Figure 7.12).

It is a simple matter to move one UPS module and respective battery to the ground floor to restore the balance (Figure 7.13). There are spare slots within the ground and first floor UPS cabinets to allow for future expansion of the protected system. Further capacity can be obtained by simply introducing additional UPS modules as and when required. The important point is that all of these changes can be made with minimum effort, low incremental cost, no disruption to the critical load and without using any more floor space.

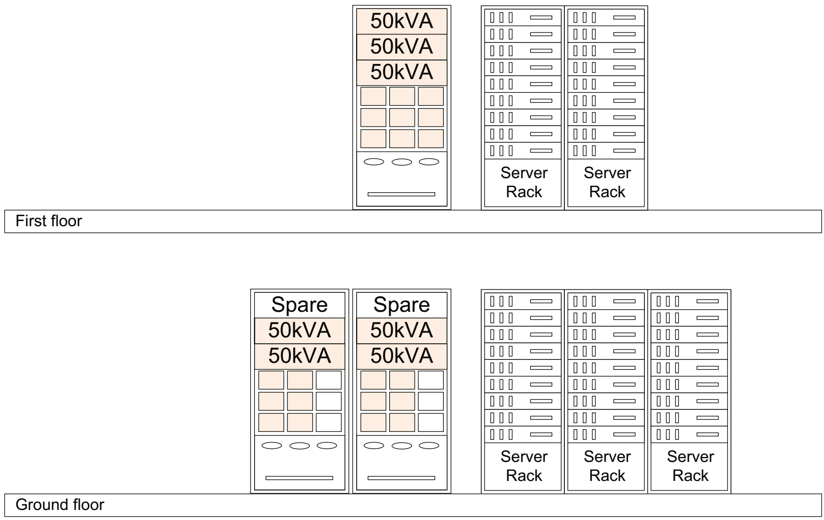


Figure 7.11: A Flexible and Upgradeable UPS System (a)

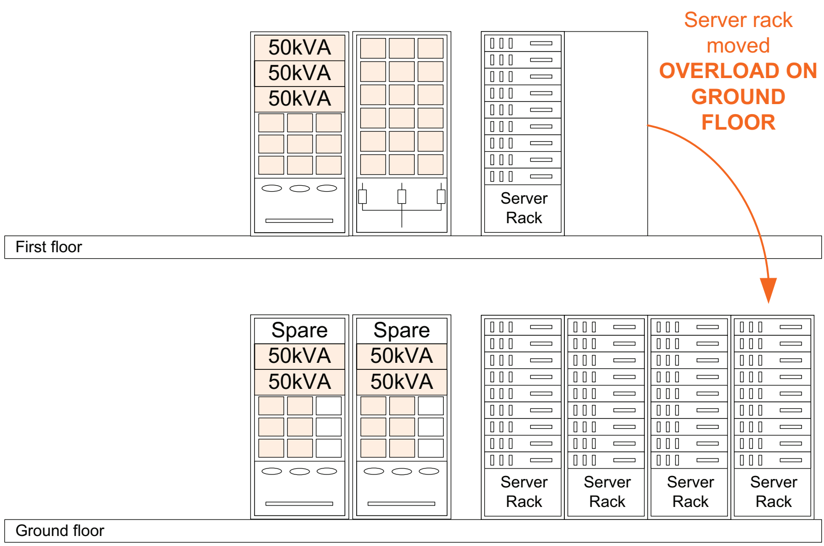


Figure 7.12: A Flexible and Upgradeable UPS System (b)

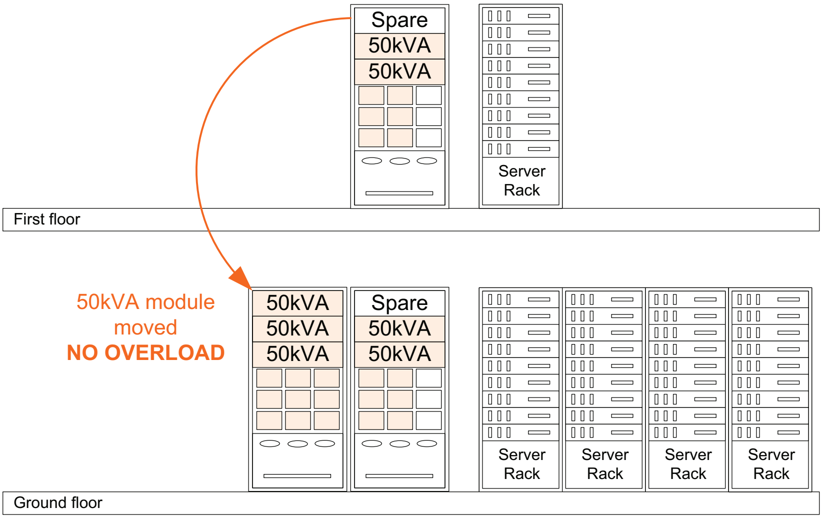


Figure 7.13: A Flexible and Upgradeable UPS System (c)

As an added bonus, if one UPS module should develop a fault, the user can easily arrange for a module to be moved from one floor to the other as an emergency measure pending service, albeit by temporarily sacrificing redundancy.

Serviceability is substantially improved by this modular technology because UPS modules can be swapped out for service and access is only required to the front of the UPS cabinet. As a result MTTR is significantly reduced.

Example 2

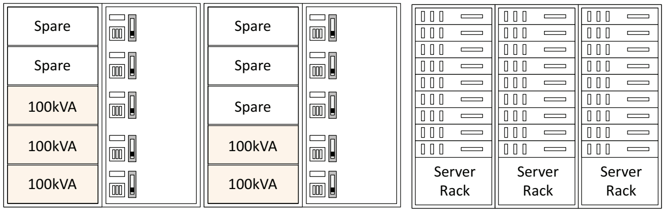


Figure 7.14: Expandable 1 MVA Modular System

Figures 7.14 and 7.15 illustrate the same flexibility and upgradable facility using 100kVA granular steps rather than 50kVA.

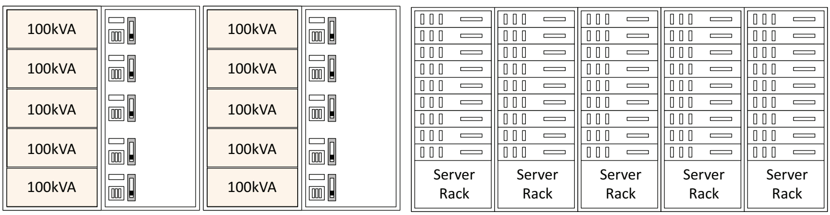


Figure 7.15: Fully Populated 1 MVA System

Managing a Parallel System

In the past, parallel systems were managed in a manner less ideal than is possible today using the latest technology. For example, in some older systems the module redundancy was often based on 'module availability' rather than the prevailing load itself – i.e. once the number of out of service modules exceeded the designed number of redundant modules the load transferred to bypass irrespective of the load current demand and available remaining module kVA.

Modern systems are able to treat the matter of redundancy more intelligently and effectively.

For example, reconsider the four module (one redundant) system in Figure 7.4. This shows the situation with one module shut down and the remaining healthy modules sharing the 270kVA load equally between them at around 90kVA each. If a second module were to fail the remaining two modules clearly could not support the load as each would exceed its 100kVA rating. However, if the load were only 160kVA at the time of failure of the second module there is no reason why the remaining two modules could not continue operating and maintain the load on their combined inverters operating at 80kVA each – (*see Figure 7.16*).

These examples illustrate that when planning a parallel system the effects of future load requirements should be taken into account, and the choice of UPS modules must take into consideration the ease of system expansion if and when necessary.

Traditionally, parallel systems were configured as either 'capacity' systems or 'redundancy' systems. If a single module failed in a capacity system the critical load would be transferred to bypass irrespective of the size of the critical load and the ability of the available module(s) to handle it. Similarly, if the critical load exceeded the available 'non-redundant' power, it would be transferred to bypass irrespective of the amount of 'redundant' power available.

The example shown in Figure 7.3 would be considered a 'capacity' system if the load were between 300kVA and 400kVA, an 'N+1' system if the load were between 200kVA and 300kVA, an 'N+2' system if the load were between 100kVA and 200kVA and an 'N+3' system if the load were less than 100kVA.

A modern parallel system will automatically adjust its 'N+n' status to accommodate the prevailing load.

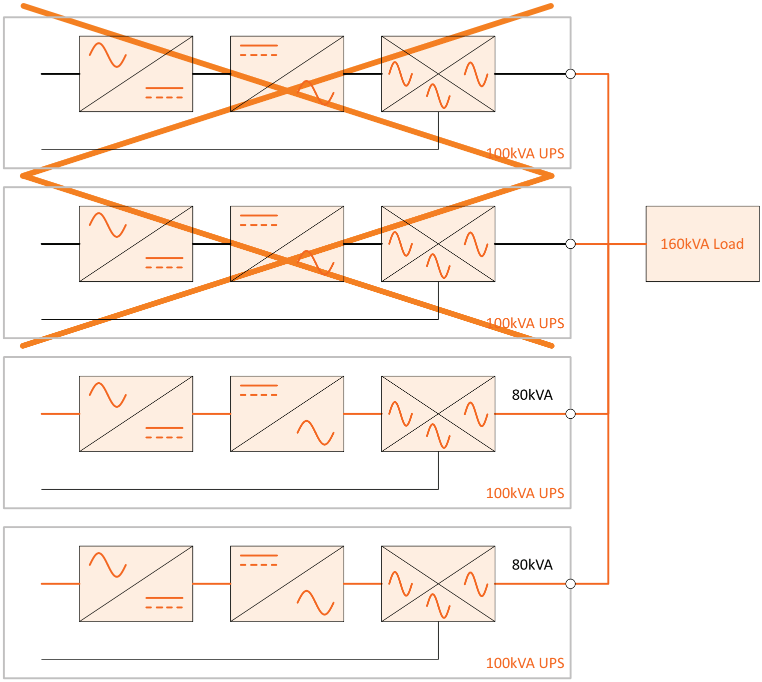


Figure 7.16: Redundant System With Two Failed Modules

Examples of De-centralised UPS Systems

System Requirements

In the following examples the UPS system specification required a 600kVA parallel redundant UPS with an upgrade path to at least 800kVA parallel redundant to accommodate potential future growth.

Example 1 - Using Free-Standing UPS Modules

The system proposed comprises 4 off 200kVA UPS modules configured as a 3+1 (i.e. 600kVA parallel redundant) system with a fully integrated switchgear panel providing all of the required UPS input and output switchgear and associated electrical and mechanical interlocks with a spare way to enable the addition of a fourth module at a later date.

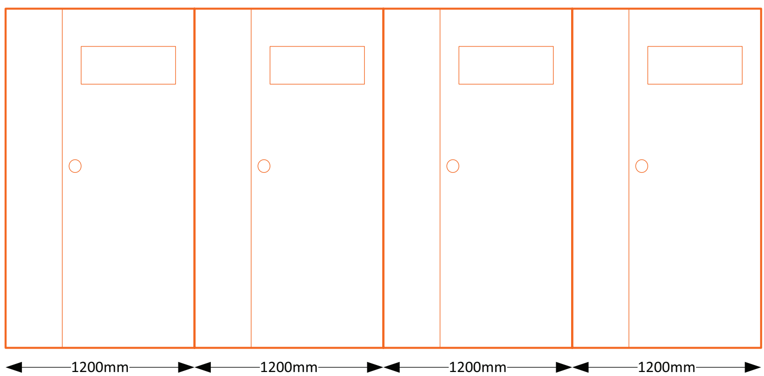


Figure 7.17: UPS System Layout (4 off 200kVA UPS)

System and Switchgear Panel Description

Figure 7.18 is a schematic diagram of a 5 way 800kVA "N+1" UPS switchgear panel in which 4 off 200kVA UPS modules are configured as a "3+1" system to provide 600kVA parallel redundancy. A spare way is designed into the panel for the addition of a further 200kVA UPS module to permit future system upgrade to 800kVA 'N+1'.

With reference to Figure 7.18 it should be noted that each UPS module has its own input protection which is sized to ensure adequate discrimination between the main panel input fuses and the UPS input. The protection also acts as an input isolator when the respective UPS module requires maintenance etc.

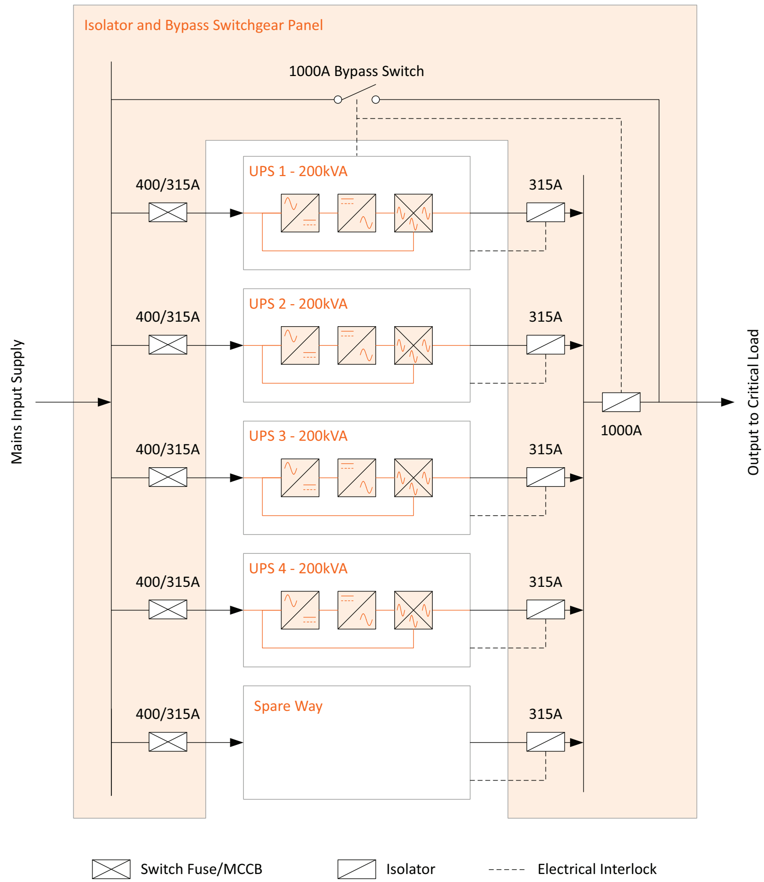


Figure 7.18: UPS Switchgear Panel Schematic

It should also be noted that each UPS module has an output isolator that is electrically interlocked to the UPS system. In any parallel system it is necessary to electrically interlock the output isolator to its associated UPS because whenever the output isolator is open the current sharing circuitry within all of the UPS modules that form the parallel system need to be aware that one of the UPS modules is not required to supply current.

The 5 off UPS output isolators all feed the parallel bus and connected between the parallel bus and the load is the main UPS output isolator. This isolator is required to facilitate full system testing and/or site electrical testing as, in conjunction with the “wrap around” manual bypass switch, it allows the UPS system to be completely electrically isolated from the load without a break in power to the load. The UPS system output isolator and the “wrap around” manual bypass switch are also electrically interlocked to the UPS system. The manual bypass switch is electrically interlocked to prevent accidental damage to the UPS system caused by unauthorised operation of the “wrap around” manual bypass (if the manual bypass switch is closed whilst the UPS system inverters are running, the inverters will be stopped and the system will automatically transfer to static bypass without any break in the supply to the load in order to prevent inverter damage caused by back feeding). By interconnecting the UPS output isolator and wrap around manual bypass switch interlocks, it is possible to fully functionally test the entire UPS system, complete with all paralleling features, without risk to the load.

Another major benefit of the switchgear panel is that it is possible to individually electrically isolate any UPS module connected to the panel, thereby allowing its physical removal and/or physical introduction to the UPS system whilst the load is running and still fully protected by the UPS system. Using such a switchgear panel therefore increases the system flexibility and eliminates the need for the load to ever be exposed to raw mains.

Example 2 - Using Rack Mounted Modular UPS

The proposed system comprises 7 x 100kVA rack mounted UPS modules configured as a 6+1 (i.e. 600kVA parallel redundant) system with a fully integrated switchgear panel providing all of the required UPS input and output switchgear and associated electrical and mechanical interlocks. Note that a spare way is not required in the switchgear panel as the addition of a module takes place within the already installed UPS cabinet. This also means that the system can be upgraded without the requirement for additional floorspace.

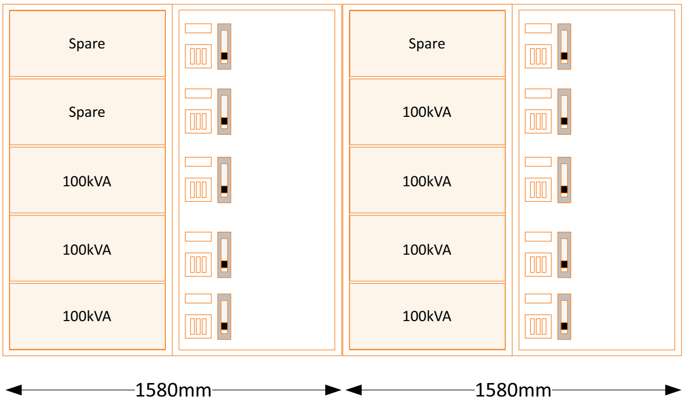


Figure 7.19: UPS System Layout (7 off 100kVA rack mounted UPS)

Figure 7.20 is a schematic diagram of a 2 way, 500kVA modular UPS switchgear panel in which 2 off UPS system cabinets, each capable of housing up to 5 off 100kVA UPS modules, are configured to provide up to 600kVA "6+1" parallel redundancy.

The UPS system is shown with 7 off 100kVA modules to provide 600kVA "6+1" parallel redundancy and has a spare way available to facilitate the addition of another 100kVA module if system upgrade is ever required.

It should be noted that the UPS switchgear panel in Figure 7.20 is considerably simpler than the one shown in Figure 7.18. This is because the majority of input and output switchgear needed by the individual UPS modules is provided within each of the system cabinets housing the UPS modules. For example, the UPS system cabinets themselves contain all of the input protection and input and output isolation required by the UPS modules.

The UPS switchgear panel shown in Figure 7.20 will be physically smaller, less expensive to purchase and easier to electrically install than the switchgear panel shown in Figure 7.18. It should also be noted that no additional electrical installation works will be required to upgrade the system.

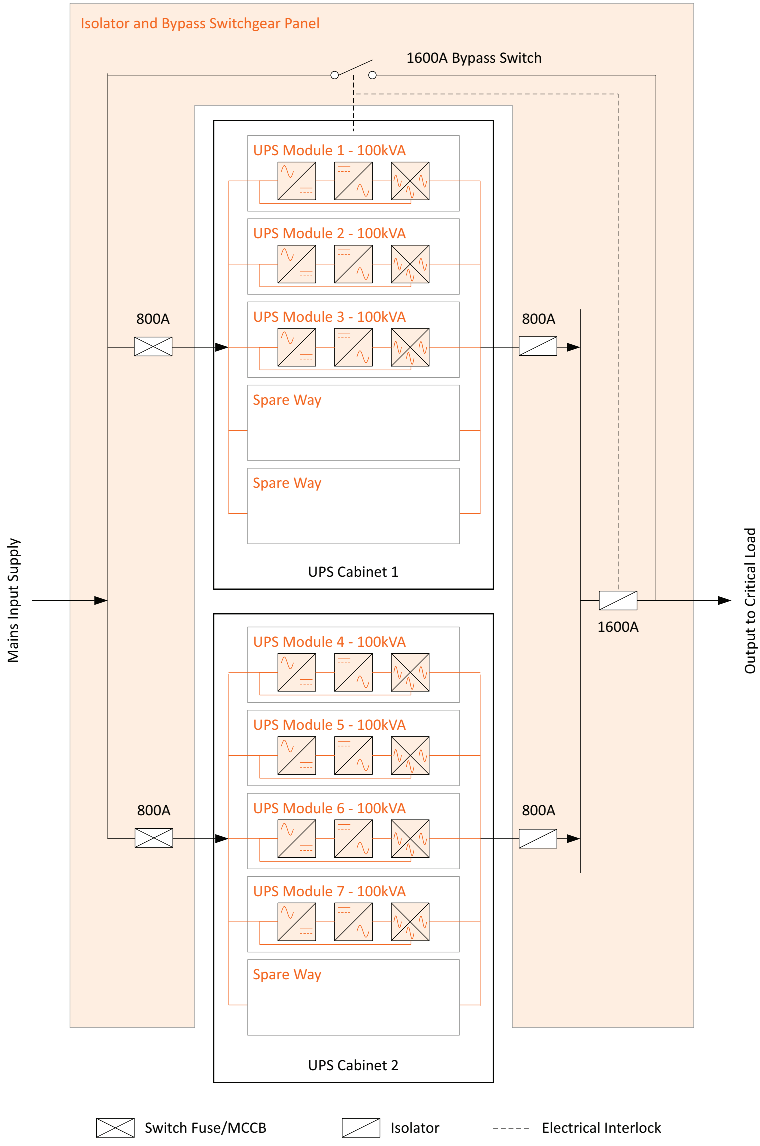


Figure 7.20: UPS Switchgear Schematic

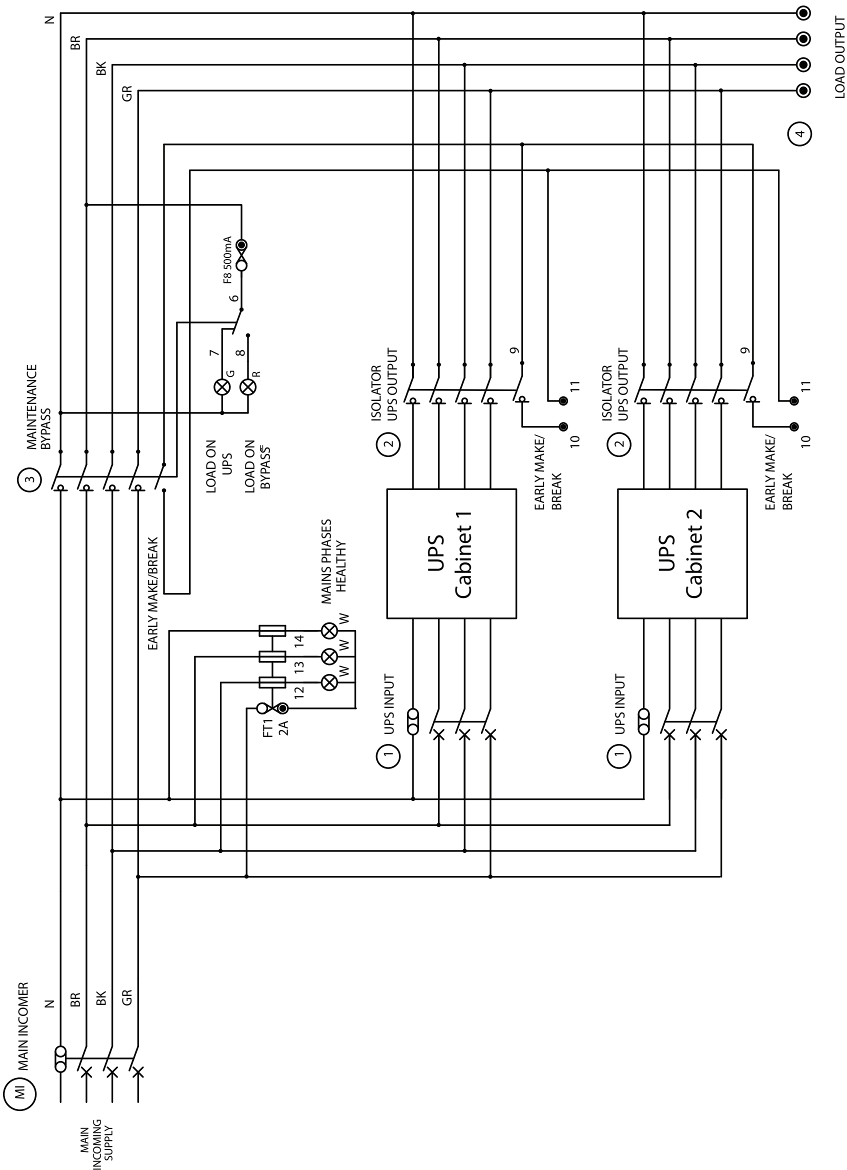


Figure 7.21: A Typical Paralleled UPS System Bypass Panel

Figure 7.21 illustrates a flexible yet tidy way of implementing an expandable parallel UPS system by using a purpose designed panel incorporating input and output switchgear for each UPS cabinet together with a 'system' output isolator and a wrap-around bypass switch. Whether paralleling is required for redundancy or scalability, this panel reduces the system design burden, simplifying cabling and shortening cable runs. It also minimises design and implementation complexity, saving time and costs.

Spare ways can be made available on the panel to permit the addition of further UPS modules to provide extra capacity or redundancy at a later date, and additional UPS can be connected and commissioned without any need to disrupt the load.

The panel enables electrical and physical isolation of individual UPS modules for service and maintenance without a break to the load.

Electrical interlocks should be included to prevent the UPS modules from being 'back-fed' due to incorrect switching.

Parallel UPS System Battery Configuration

The successful design of any parallel UPS system involves the minimisation of all the single points of failure.

A potential single point of failure in any UPS system is the battery bank. If a UPS has single strings of batteries and any one battery cell in the string is faulty then the batteries may fail to support the load in the event of a mains power failure. To overcome this problem multiple strings of batteries connected in parallel are used.

Chapter 8 discusses various battery configurations including parallel strings of batteries and the use of transition boxes when paralleling batteries. In summary, parallel strings are used to increase the capacity of a battery system and/or its resilience (by providing battery redundancy) and transition boxes are used to simplify wiring and to individually protect each string in the battery system.

Ideally, each UPS module in a parallel UPS system should have its own set of separately fused paralleled strings of batteries. With large, high powered parallel UPS systems this could be prohibitively expensive and take up too much space within the UPS/computer room. Such cost and space pressures can be partially overcome with careful design of the battery systems by, for example, using more individual strings of lower capacity battery blocks to achieve the required total battery capacity. It is invariably cheaper, however, to have a single string of large batteries rather than multiple strings of smaller batteries.

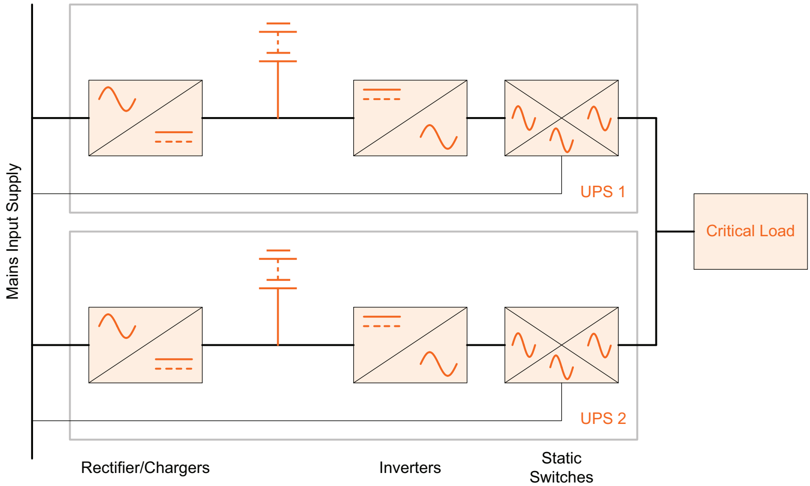


Figure 7.22: Parallel UPS System with One Battery String

Figure 7.22 shows a 2 module parallel UPS system where each UPS module has a single string of batteries. In such a configuration, if any one battery cell is open circuit in either of the battery strings only one UPS module will be able to operate in the event of a mains power supply failure. In a capacity parallel system this may result in the overloading of the UPS module with good batteries potentially resulting in a load loss. However, in a parallel redundant system the battery failure will result in redundancy being lost, but the critical load will be maintained without interruption.

Figure 7.23, shows the same 2 module parallel UPS system but this time each UPS module has 2 strings of batteries connected in parallel to the UPS. If any one battery cell in such a configuration is open circuit both UPS modules will still be able to operate. As both UPS modules equally share the load, the UPS module with only one good battery string will discharge its good batteries quicker than the other UPS module but with appropriately rated batteries and correctly configured auto-shutdown software (*See Chapter 10*) the critical load will be protected.

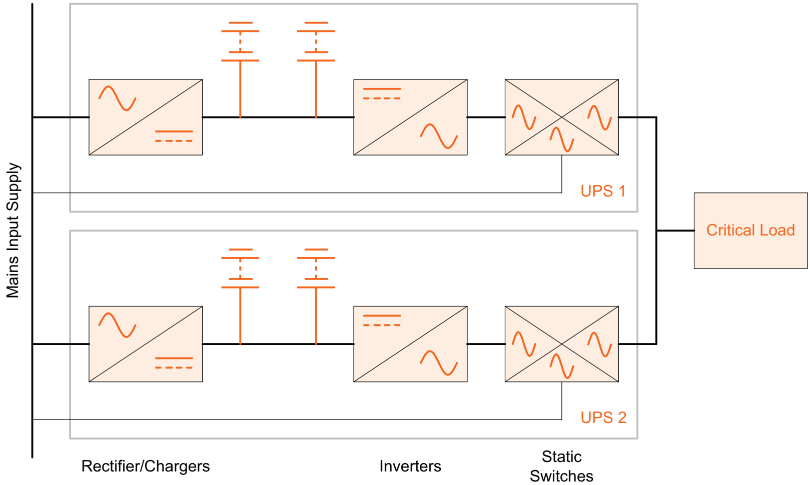


Figure 7.23: Parallel UPS System with Dual Battery Strings

Common Battery Configuration

Both the systems shown in Figure 7.22 and Figure 7.23 have batteries that are configured as "separate batteries" i.e each UPS module has its own set of batteries and no other UPS module in the system has access to these batteries. It is possible to configure the same batteries as "common batteries" i.e. all of the batteries are physically connected to all of the UPS modules in the system.

Common battery configurations utilising multiple strings overcome the problems presented by open circuit cells as discussed in the earlier paragraphs but, unless great care is taken with the common battery's DC distribution system, such a battery configuration can present a single point of failure (e.g. a short circuit on the DC bus of one of the UPS modules may cause all of the battery fuses in the system to fail).

An example of a DC distribution system designed to connect all of the system batteries to all of the UPS modules in the system is shown in Figure 7.24.

Figure 7.24 shows the DC distribution system for a 6 module parallel UPS system with 4 strings of batteries configured as a common battery. For illustrative purposes the UPS DC input protection has been rated at 250A and the battery string protection has been rated at 630A. In a practical application the actual rating of the protection would depend upon the power rating and quantity of UPS modules and batteries.

It can be seen that a short circuit on the DC bus bars within any of the UPS modules will not affect any of the other UPS modules or any of the battery protective devices. It can also be seen that a short circuit within any of the battery strings will not affect any of the other battery protective devices or any of the UPS modules.

The only single point of failure of this system are the DC bus bars themselves but as these are solid copper bars protected and enclosed within a bus bar chamber it is highly unlikely that a short circuit will be presented here. It is still, however, a single point of failure within the overall system and if such a single point of failure is considered unacceptable to the UPS user the batteries must be configured as separate batteries.

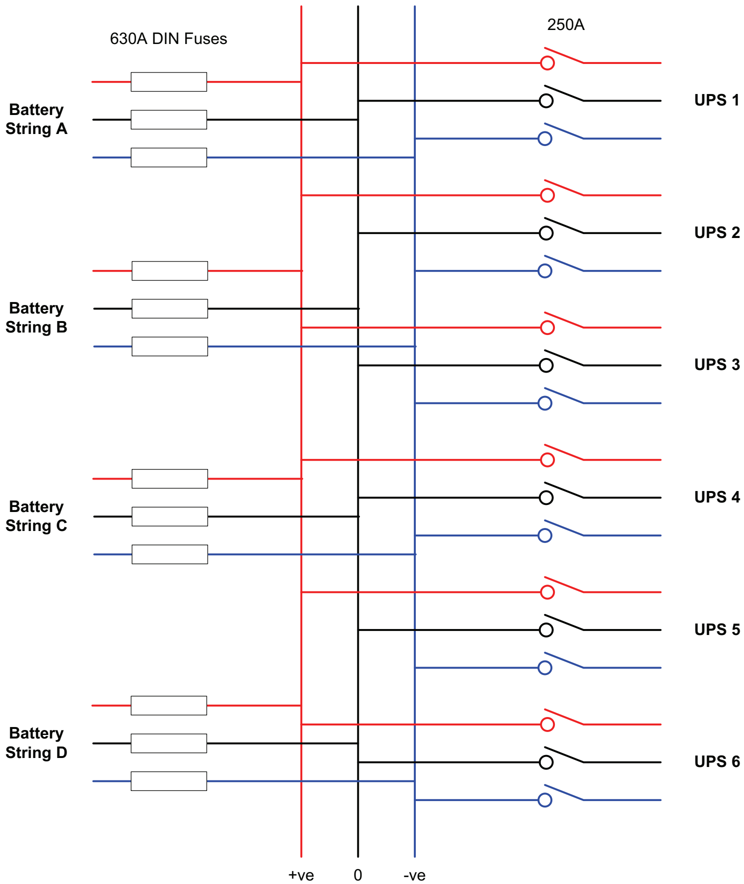


Figure 7.24: DC Distribution System for a Common Battery

Optimum Battery Configuration

The optimum battery configuration for a parallel UPS system will vary depending upon the site facilities (standby generator, available space etc.) and the load requirements. A good UPS supplier will be able to discuss all of the options available to allow the UPS user to make an informed decision on the configuration that best suits their requirement and budget.

8

Energy Storage Devices

Introduction

When mains power fails a UPS must call upon another source of power if it is to continue providing power to the critical load. This power, or more accurately energy, has to be safely stored and instantaneously available for use whenever required. It must also be easily replenishable when mains power returns. With all this in mind, it is no real surprise that the options for energy storage devices capable of being used by UPS systems is limited.

Traditionally, batteries have been the energy storage devices used by almost all UPS manufacturers. There are, however, a couple of technologies that are still very much in their infancy but may well develop into commercially viable alternatives to batteries. These technologies are flywheels and hydrogen fuel cells.

Flywheels

A flywheel is a device that uses mechanical means to store kinetic energy (the energy of motion). When mains power is available a motor-generator is used to rotate the flywheel which acts as the storage vessel for the kinetic energy. When mains power is not available the flywheel's kinetic energy is converted into electrical energy that supplies power to the UPS DC bus. A typical DC flywheel and UPS configuration can be seen in Figure 8.1.

The capital cost of a UPS system incorporating a flywheel is likely to be significantly higher than that of a UPS using more traditional forms of energy storage devices and, because of physical constraints, is unlikely to ever provide more than 30 to 45 seconds of “back-up” time. However, flywheels are an environmentally friendly alternative to devices such as batteries and, unlike most batteries, can continuously operate at ambient temperatures from 0 to +40 Celsius.

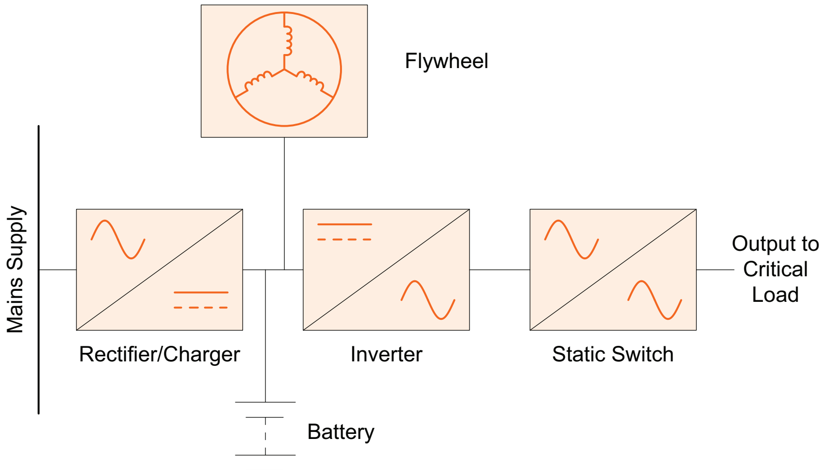


Figure 8.1: A typical DC flywheel and UPS

Hydrogen Fuel Cells

When hydrogen and oxygen combine to produce water a chemical reaction occurs, one by-product of which is electrical energy. Hydrogen fuel cells can therefore be said to convert hydrogen gas into electrical energy.

Each hydrogen fuel cell has two electrodes, an anode and a cathode, that are separated by a polymer electrolyte membrane. Oxygen is passed over the cathode and hydrogen is passed over the anode. The hydrogen molecules are converted into electrons and protons when they pass over a catalyst (typically platinum) on the anode. The electrons flow out of the fuel cell as electrical energy whilst the protons flow through a membrane to the cathode where they combine with the oxygen to produce pure water. Figure 8.2 shows a typical hydrogen fuel cell.

Hydrogen fuel cells are significantly more expensive than batteries and, because hydrogen is an explosive gas, great care has to be taken with its storage. Also, because hydrogen is currently manufactured from natural gas and energy is required to make the hydrogen the “environmentally friendly” credentials of hydrogen fuel cells are currently questionable. Having said this, hydrogen fuel cells are smaller and lighter than batteries and the research and development currently taking place into the use of hydrogen fuel cells in automotive applications will have spin-off benefits for “standby” fuel cell applications.

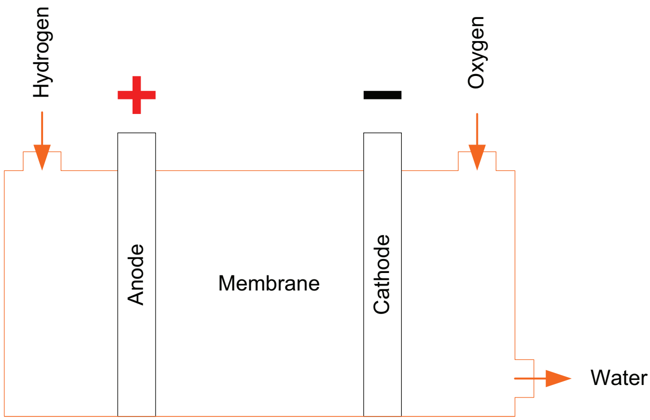


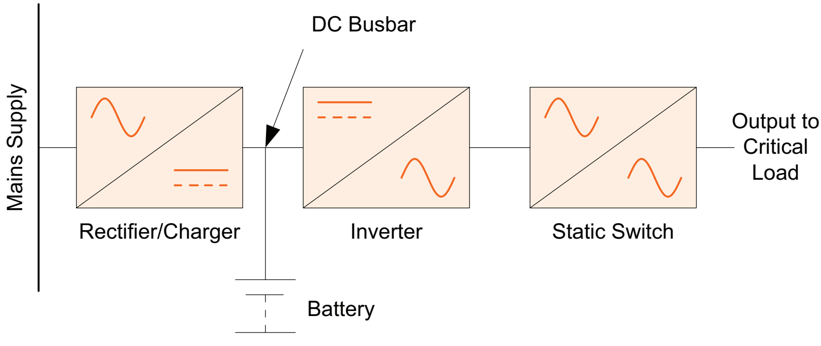
Figure 8.2: A typical hydrogen fuel cell

Summary

Whilst the ongoing development of flywheel and hydrogen fuel cell technologies are of great interest to UPS manufacturers they must be viewed as emerging technologies as it is unlikely that either of these technologies will be commercially viable within the next 5 to 10 years. With this in mind, this book will focus on the use of batteries as energy storage devices for UPS.

Batteries

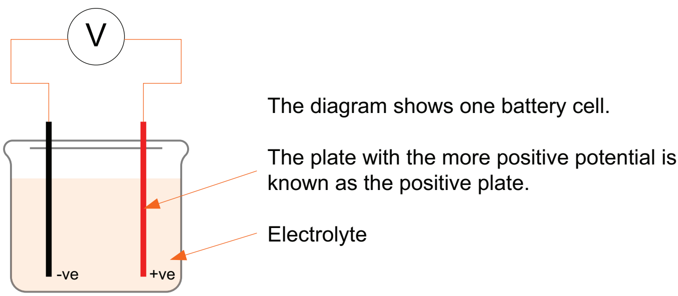
Batteries are an essential part of any UPS. They provide the reserve or alternative power source which is used when the mains supply fails or when it is outside certain limits (*See "What is a UPS?" on page 11*).



Batteries may be contained within the UPS cabinet, in separate cabinets or on racks. The actual location depends on site conditions and restrictions and on both the capacity of the battery and the required back-up or autonomy time. *See "Size and Location" on page 120.*

What is a Battery?

A battery is a device that uses chemical means to store electrical energy and can be found in any number of shapes, sizes, voltages and capacities.



When two materials (usually dissimilar metals) are immersed in a solution (electrolyte) they conduct electricity between the 'plates' causing an electrical potential. The value of the potential (or voltage) is dependent on the plate materials and the electrolyte used. Examples are lead acid, nickel cadmium (Nicad), lithium, silver alkaline.

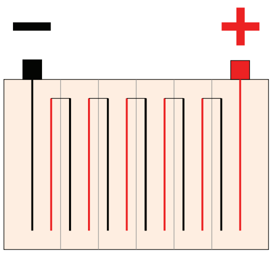
Nickel-Cadmium (Ni-Cad) Batteries

Ni-Cad batteries are rarely used in modern UPS applications because of their high cost and the impact that their Cadmium content has on the environment. When they are used it is almost always in applications that require the batteries to operate in extremes of temperature (e.g. from -20 to +40 Celsius) or where useful working lives in excess of 20 years are essential.

Because of the relative rarity of Ni-Cad batteries in UPS applications this book is concerned only with the lead acid battery as this type of battery is the most suitable for general UPS applications within the UK.

The Lead-Acid Battery

The lead acid cell uses lead and lead oxide plates immersed in sulphuric acid electrolyte. Using this combination each cell develops a nominal 2 volt potential.



The diagram shows six, 2 volt cells connected in series to form a 12 volt block.

A battery is simply a number of cells connected together with a given voltage and capacity. The capacity is defined in Ampere hours (Ah), i.e. the power of the battery or its capability to produce 1 Amp for a certain number of hours. As a general rule the more cells the higher the battery voltage and the larger the plates the higher the battery capacity.

For convenience, batteries are made in 12 volt blocks using six cells but are also available in 6 volt (three cell), 4 volt (two cell) and 2 volt (single cell) blocks.

There are two main types of lead-acid batteries which may be used in UPS applications:

- open - vented
- sealed or Valve Regulated Lead Acid (VRLA)

Open - Vented	Sealed - VRLA
Older technology	Environmentally friendly
Separate battery room	Suitable for office environments
Regular routine maintenance	Low regular routine maintenance
Separate safety requirements	Self-contained. Safe
Store/use in vertical position	Store/use in any orientation
The VRLA Lead-acid battery is now the battery of choice for modern UPS systems.	

Size and Location

UPS suppliers offer a range of standard batteries, all designed to support the full UPS load but with various back-up/autonomy times.

- UPS suppliers often accommodate the batteries in the UPS cabinet.
- Additional cabinets, which match the UPS, are usually available for larger battery installations – these may need to be built to order.
- Larger or 'non-standard' installations may require separate battery racks. UPS suppliers may offer cladded or open types to suit a particular installation. Open racks usually require the batteries to be kept in a separate battery room with controlled access arrangements.

The table below gives some sample battery sizes and weights.

UPS Rating (kVA)	Autonomy (Minutes)	Size Inc. UPS H x W x D (mm)	Weight (kg) inc. UPS
5	5 45	One off*- 690 x 200 x 690 Two off - 690 x 200 x 690	77 226
15	20	Two off - 690 x 200 x 690	353
30	6 25	One off*- 1400 x 580 x 750 Two off - 1400 x 580 x 750	490 1055
60	8	Two off - 1400 x 580 x 750	1060
120	15	Three off - 1800 x 580 x 750	2960

* Batteries located within the UPS cabinet

Configuration

The configurations shown in this section are samples – on-site arrangements will obviously differ from site to site.

In any battery configuration, all of the cells used in a serial string must be identical to each other.

Serial Strings

A serial string is a single series of blocks connected 'end-to-end' to form the battery. The positive terminal of the first block is connected to the negative terminal of the second block, the positive terminal of the second is connected to the negative of the third, etc.

The overall voltage of the battery is the sum of the individual block voltages and must be arranged to match the float voltage setting of the UPS.

The capacity of the battery is unchanged with this arrangement, being the same as each individual block.

For example:

> If 12 x 12V 10Ah blocks are connected in series, the resulting battery is 144V with a 10Ah capacity.

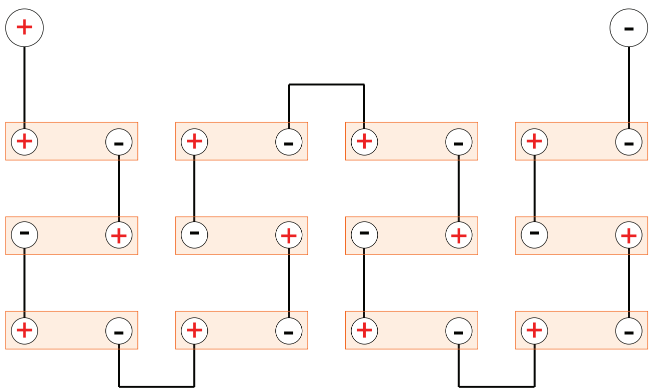


Figure 8.3: Serial Battery String

Parallel Strings

A parallel string is a combination of two or more serial strings, and each string must contain the same number of blocks. Batteries are paralleled for two main reasons: either to increase the resilience of the battery bank so that a single faulty battery will not cause all of the batteries to be unavailable to the UPS, or to increase the total capacity (Ah rating) of the battery bank.

The positive terminal of the first battery string is connected to the positive terminal of the second battery string, the positive terminal of the second is connected to the positive of the third, etc. The negative terminal of the first battery string is connected to the negative terminal of the second battery string, the negative terminal of the second is connected to the negative of the third, etc.

The overall voltage of the battery is the same as the voltage of each string.

The capacity of the battery is the sum of the capacities of the individual strings.

For example:

> If 3 strings of 12 x 12V 10Ah batteries are connected in parallel, the resulting battery is 144V with a 30 Ah capacity.

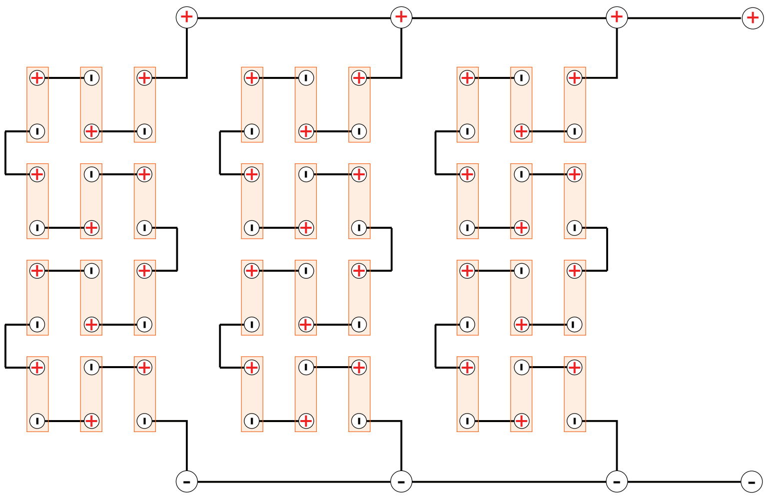


Figure 8.4: Parallel Battery Strings

Due to potential equalisation problems (i.e. unequal charge being taken on by individual batteries), it is unusual for more than six battery strings to be connected in parallel.

Battery Monitoring

Equalisation problems can be minimised using a modern battery monitoring application, such as the patented Battery Analysis & Care System (BACS), which can provide integrated battery monitoring and management over an Ethernet network.

Using web-management technology, the system sequentially checks the internal resistance, temperature and voltage of each individual battery block and corrects its charging voltage as required to obtain a balanced charging condition across the battery string.

By constantly monitoring and controlling the individual charging voltages for each battery block it ensures they are kept in their optimal voltage operating range and guarantees the availability of the battery at all times.

Other benefits from using the BACS equalisation system include:

- Avoid overcharging:
  Through the equalisation process the unnoticed overcharging of individual batteries (gassing, dry-out, thermal runaway) is prevented.
- Avoid undercharging:
  Through the equalisation process the unnoticed undercharging of individual batteries (sulphation, loss of capacity) is prevented.
- Indication of battery problems:
  Typical battery problems such as sulphation, corrosion, gassing, dry-out, thermal runaway etc. are visible through a rise of impedance and temperature.
- Avoid sulphation :
  Sulphation is a typical problem for UPS batteries because they are consistently held at a float charge level for a long time. Its not guaranteed that ALL batteries have really been fully charged when the UPS charge switches from boost charging to float charging. The result maybe that some batteries are overcharged, while others have never been fully charged. Equalisation avoids sulphation through the process of bringing the overcharged and undercharged accumulators to a balanced voltage level.

- Show stratification:
  BACS warns of a possible stratification of the electrolyte through detecting increasing impedance and drifting voltages. The stratification can be removed through a discharge process and the BACS will indicate this effect through a lower impedance and improved equalizing.
- Early warning to replace batteries:
  Through impedance trending you can see in the early stage that some battery blocks are damaged or simply weaker than others. The earlier accumulators are replaced the better for an increased lifetime of the complete battery system.
- Extension of service life up to 30%:
  The service life of all the batteries in a string depends on the weakest member – i.e. the weakest battery. By equalizing, all batteries are kept constantly in their ideal voltage window so that all negative influences of wrong charging voltages and currents within the string are eliminated.
- Improved maintenance:
  A BACS system improves the service quality by providing remote monitoring through Internet, VPN or other network for downloading real time data and battery history for analysis. Single, individual battery tests are now possible without the need to disconnect batteries from the group. Maintenance and battery testing are able to take place at any time, under real operating.

Transition Boxes

Transition boxes are used to simplify the connection of a battery to a UPS. In addition to providing space for the correct termination of battery cables they also contain suitable fuses to protect the individual battery strings and associated cabling.

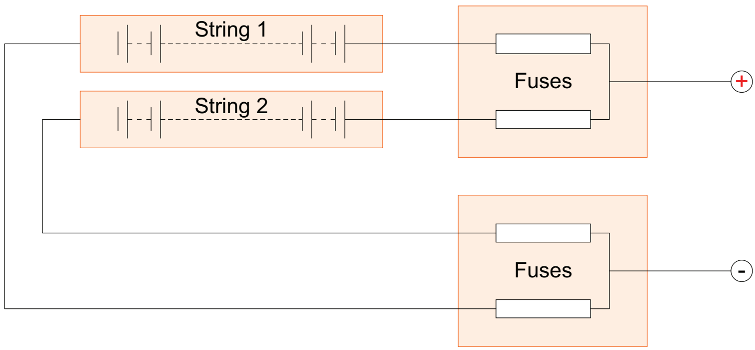
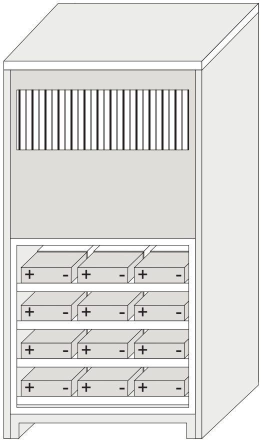


Figure 8.5: Fused Transition Boxes for Two Battery Strings

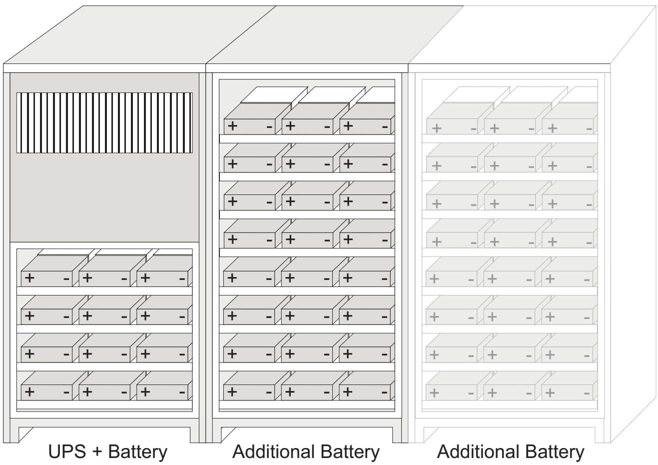
When two or more parallel battery strings need to be connected to the same UPS, it is common to use transition boxes. Fused transition boxes allow individual battery strings and cables to be protected and also enable an individual battery string to be safely isolated for maintenance or repair without completely disconnecting the UPS equipment.

It is important to keep the lengths of cables within each battery string approximately the same to ensure that the impedance (and hence the current share) of each battery string is approximately the same.

UPS with Internal Batteries



Additional Battery Cabinets



Open Battery Racks

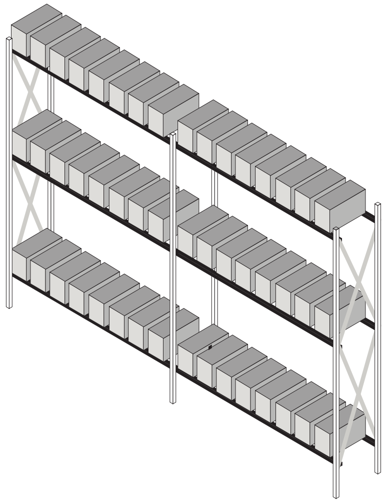


Figure 8.6: A 3 Tier, 1 Row Open Battery Rack

Cladded Battery Racks

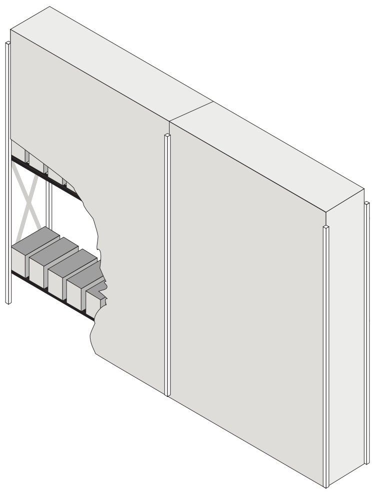


Figure 8.7: A Fully Clad Battery Rack

Storage, Care and Maintenance

Batteries should be considered a weak link in any UPS application because they have a finite useful working life and, if left in service long enough, will definitely require replacement. How the battery is used and the environment in which it is kept have an effect upon the useful working life of the battery. For this reason, great care must be taken when selecting and sizing batteries in a UPS installation.

The factors which most affect the useful working life of a battery are discussed below.

Storage

Depending on manufacturer, the storage or shelf life of a VRLA battery is usually between 3 and 6 months at 20°C, starting from a charged condition.

VRLA batteries must NEVER be stored in a discharged or partially discharged state.

Always store batteries in a dry, clean, cool environment in their original packaging.

If storage of 6 months or longer is required supplementary charging will be necessary.

Design Life

All batteries have a ‘design life’ and this is a figure quoted by the battery manufacturer based upon certain assumptions about how the battery will be used and the environment in which it will be kept. Unfortunately, the ‘ideal world’ of the battery design engineer cannot be matched by the ‘real world’ application of the UPS system.

The battery manufacturer will specify that under certain charging conditions and at certain temperatures, with a set number of charge and discharge cycles, their battery will last X years. In a UPS application, the ambient temperature is unlikely to be exactly that specified by the battery manufacturer and the frequency and depth of discharge will be determined by the quality of the site mains voltage. For these reasons the useful working life of the battery is invariably less than the ‘design life’ of the battery.

Sulphation/Undercharge

If a battery has an open-circuit voltage lower than its rated value, then sulphation may well be the cause.

When a battery is left in a discharged state or for prolonged periods of storage, lead sulphate crystals begin to form, acting as a barrier to recharge and preventing normal battery operation.

Depending on the degree of sulphation, a battery may be recovered by constant current charging at a higher voltage than the standard charge voltage with the current limited to one tenth of the battery capacity, and for a maximum of 4 to 10 hours.

Note: The applied voltage will exceed the normal recommendation and so the battery must be monitored (not left unattended) and removed from charge if excess heat is dissipated. The voltage required to 'force' this maximum current into the battery will reduce as the battery recovers until normal charging can take place.

In extreme circumstances a battery may never fully recover from sulphation and must therefore be replaced.

Overcharge

Optimum charging relies mainly on voltage, current and temperature factors which are interrelated and all of which can cause overcharge.

Excessive charge voltages will force a high overcharge current into the battery, which will dissipate as heat, and may cause gas emission through the safety valve (hence the term 'Valve Regulated'). Within a short period this will corrode the positive plate material and accelerate the battery towards end-of-life.

Temperature

Most manufacturers recommend a battery operating temperature of 20°C.

Figure 8.8 shows how high temperatures will reduce the battery service life and in extreme cases will cause *thermal runaway*, resulting in possible oxygen/ hydrogen gas production and battery swelling. VRLA batteries cannot be recovered from this condition and should be replaced.

Extreme temperatures will destroy batteries.

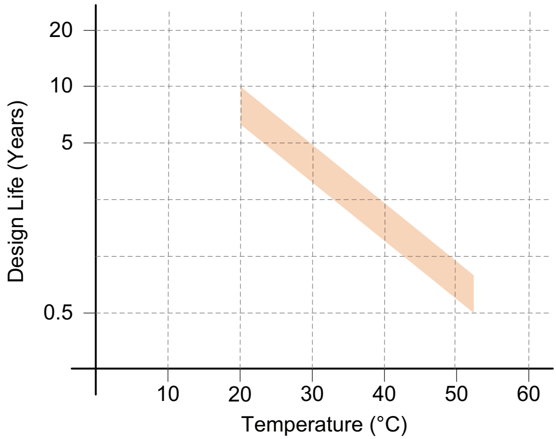


Figure 8.8: Temp./Life Characteristics of a Typical VRLA Battery

Low temperatures will have little effect on the battery service life but will reduce the battery performance. Figure 8.8 shows the extrapolated service life for a typical VRLA battery at different ambient temperatures. As can be seen, higher ambient temperatures will significantly reduce service life.

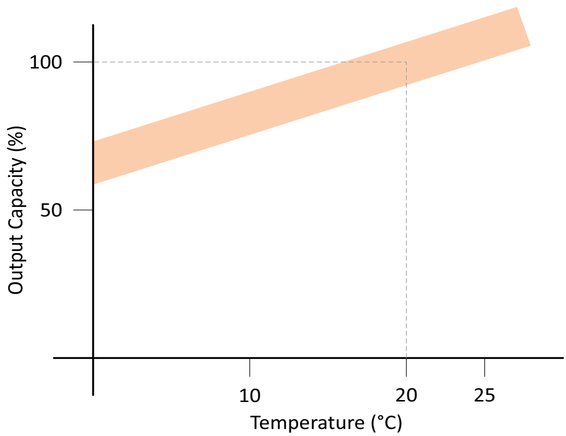


Figure 8.9: Temp./Capacity Characteristics of a Typical VRLA Battery

High temperatures give increased performance but reduced service life
Low temperatures give reduced performance but increase service life

Over or 'Deep' Discharge

When a battery is discharged to the extent that its on-load voltage falls below a predetermined limit, the battery is considered to be over discharged. Where extreme over discharging occurs the battery is said to be deep discharged and both the battery's capacity and its useful working life will be adversely affected. Over discharging will cause sulphation of the plates within the battery which results in an increase in the internal resistance (impedance) of the battery. In extreme cases of deep discharge the battery may be unable to accept a recharge and, as such, will be at the end of its useful working life. Depending upon the depth of over discharge, it may be possible for the battery capacity to be recovered by very careful recharging. In the majority of critical UPS applications, however, any battery that has been over discharged will require replacement.

AC Ripple

Batteries are dc power storage devices and require charging with dc voltage. Any ac voltage superimposed upon the dc charging voltage is known as ac ripple and will adversely affect the useful working life of the battery.

UPS Design and Battery 'Useful Working Life'

UPS design engineers understand how batteries need to be used in a UPS application, so it is reasonable to assume that the design of the UPS will protect the batteries from under charging, over charging and over discharging etc. Modern UPS have battery charging systems that completely eliminate ac ripple. They also have temperature compensated charging to prevent over charging at higher than normal temperatures.

The only area of battery life optimisation that the UPS design engineer cannot directly address is the ambient temperature that the battery will experience during service. Control of the UPS ambient temperature is entirely the responsibility of the user. The high efficiencies of the latest generation UPS assist in the battle against high ambient temperatures by minimising the thermal effect (heat output) of the UPS on its environment and therefore the batteries. However, the UPS user must always pay attention to the UPS and battery ambient temperatures.

Battery Maintenance

VRLA batteries require periodic maintenance, see *"System Maintenance" on page 239* for more details.

Choosing the Correct Battery Size

UPS batteries are sized to provide emergency back-up power to the UPS in the event of a total or partial loss of ac input supply.

> Statistically 95% of all mains disturbances last for less than 5 minutes with anything longer likely to last for many hours.

A typical UPS battery must be able to support the load for the time determined by the user and have sufficient additional capacity to allow time for a generator to start (*See "Generators" on page 137*), or for an orderly shut down of the critical load or application (*See "UPS Communications" on page 155*).

Considerations

The length of back-up time (autonomy) required is primarily a function of the process being protected. However the following should also be considered:

- what is the history of mains supply problems on the site?
- is there a standby generator and, if so, does it have auto-start capabilities?
- does the critical load have automatic shutdown software or facilities?
- how long will an orderly shutdown take?
- is the site 'manned' 24 hours a day, 7 days each week?
- how much space is available for the batteries?
- are there any budgetary constraints?
- where will the batteries be located?
- does the load have regular step changes – for example are large parts of the load regularly switched on and off?

Calculations

To select the correct size of battery requires, as a minimum, two pieces of information:

- battery load and
- required back-up or autonomy time.

Battery Load

The load on a UPS battery can be calculated by adding the actual UPS load to the losses in the UPS inverter section.

Example:

If the load connected to the UPS is 40kVA at a power factor of 0.8,
then UPS load = 32kW.
If the UPS Inverter efficiency is 90%,
then the inverter losses = 3.5kW
The battery must then supply 32 + 3.5 = 35.5kW (dc) to support the load.

The very latest generation of on-line UPS have inverter efficiencies of up to 97%, producing longer battery autonomies than could previously be achieved from the same battery connected to a UPS with a less efficient inverter.

Back-up or Autonomy Time

This is the time that the battery must support the load described above and is often called autonomy or discharge time – typical systems are sized for 5 to 10 minutes autonomy.

Batteries are sold in discrete sizes with various Ampere hour ratings (Ah) so a calculation must be performed to establish the correct battery blocks to be used. The required DC power and autonomy from the battery system will be used to calculate the capacity (Ah) and number of battery blocks required.

The UPS supplier will normally compute the battery configuration required for the particular application.

Charging

Correct charging of a VRLA battery is essential in order to maintain optimum performance and a long useful life.

Circuitry within the UPS will ensure the correct charging method is used. In most UPS systems the battery is 'float charged' in which case the battery is continuously on charge with a voltage of between 2.25 and 2.3 Volts/cell with minimal, or zero, voltage ripple.

Battery Safety

Batteries are electrically live at all times, take great care never to short-circuit the battery terminals.

High dc voltages can be more dangerous than the mains.

Batteries are heavy – take care when lifting and transporting them. With weights above 24 kilos lifting aids should be used.

Do not attempt to remove the battery lid or tamper with the battery internal workings. VRLA batteries are 'maintenance-free' requiring no electrolyte top-up or measurement of Specific Gravity.

Disposal/Recycling

When a battery has reached the end of its useful working life it must be returned to the point of sale or to a licensed battery dealer for recycling.

'Old' batteries are classified as 'hazardous waste' and must be disposed of in line with current legislation. The originator of the waste is responsible for the correct (certified) disposal of the batteries and a large fine and/or imprisonment is the penalty for non-compliance with the legislation.

VRLA batteries contain substances harmful to the environment.

Do not throw batteries in a bin at end-of-life.

Never bury in the ground or incinerate VRLA batteries at end-of-life.

Return expired VRLA batteries to the supplier.

9 Generators

Introduction

For modern critical business activities having a large number of high-value online transactions, a standby power generator may very well be an essential requirement.

In the event of a power failure in a critical power system without a standby generator, the only source of standby power is the UPS battery. The length of time the load can be supported is entirely dependent on the size of the load and the capacity of the battery.

During a prolonged mains interruption, the UPS will support the load equipment for the battery autonomy time and then signal the load to perform an orderly shutdown (*See "UPS Communications" on page 155*), assuming that suitable shutdown software is available and running. The applications will then be closed and shut down with no loss of data. However, as the data processing and communications equipment is no longer available, there will be some loss of productivity and business activity.

If the critical power system includes a generator with automatic mains failure (AMF) detection, when the mains supply fails the battery will support the load for the time it takes the generator to start, stabilise, and be switched over to supply the UPS. Assuming the generator has been correctly sized for the application, the UPS will accept the generator as a ‘mains replacement’ and start to recharge the battery and continue to supply the critical load for the duration of the interruption.

What is a Generator?

In very simple terms, a generator is a machine that converts a stored energy source (fuel) into electrical energy.

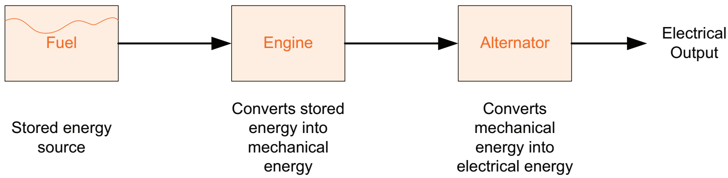


Figure 9.1: Block Diagram of a Simple Generator System

The stored energy could be either gas or diesel fuel. Gas powered generators are typically only used in Combined Heat and Power (CHP) applications. Diesel generators are normally used for both base load (continuous) and standby applications. As this chapter is primarily concerned with the role of the generator in the event of a site power failure (i.e. as a standby power source), only standby diesel generators will be considered from now on.

Diesel Engine

The engines used in diesel generators are very similar to those found in large trucks and lorries. Instead of the engine driving a gearbox and prop-shaft in a motor vehicle it drives an alternator in a generator. Most vehicle owners understand the basic requirements of keeping their car reliable and ready to use and the same basic principles apply to the diesel generator. It must:

- be well maintained
- have a supply of fuel
- have a healthy battery for starting
- have sufficient coolant and oil.

Alternator

Alternators convert the mechanical power of the engine into ac electrical power. In the UK the alternator will typically produce either single phase (230V) or three phase (400V) voltages and the value of the output voltage is determined by how the alternator is ‘wound’. The amplitude and stability of the alternator output voltage is controlled by an Automatic Voltage Regulator (AVR). The frequency of the output voltage (typically 50Hz in the UK) is determined by the engine speed. It is usual for an engine speed of 1500rpm to equate to an output frequency of 50Hz although the speed/frequency relationship is a function of the design of the alternator. The engine speed and therefore output frequency are controlled by a 'governor' which regulates the amount of fuel going into the engine (*more fuel = higher engine speed = higher output frequency*).

Governing

There are two basic methods of generator governing; mechanical and electronic.

A mechanical governor uses springs and spinning weights to regulate the supply of fuel. Mechanical governors are less expensive than electronic ones but because of their mechanical nature they are less responsive (slower) and provide less stable engine speed (frequency) regulation.

An electronic governor works by counting the teeth on the flywheel of the alternator as it rotates and regulates the fuel flow accordingly. Electronic governing is highly responsive and offers very stable engine speed regulation. For this reason it is almost without exception a pre-requisite for any standby generator being used with a UPS system.

A Generator as a Standby Power Source

As mains power failures cannot be predicted, the generator must always be ready to start and to support the required load. For this reason the generator is referred to as a 'Standby Generator'.

To ensure that the generator is always ready to start it must be kept warm, have a fully charged battery and sufficient fuel. It must also 'know' when the mains has failed and when it has returned so that it 'knows' when to start and stop.

Standby generators are kept warm by 'engine water heaters' (sometimes referred to as jacket heaters) that are powered by the mains supply, and batteries are trickle charged by a mains powered battery charger. The generator is started and stopped by signals from its Automatic Mains Failure (AMF) panel (*see page 143*). The alternative to an AMF panel is a manually started generator which relies on someone starting and stopping it whenever it is used.

As a minimum all generators used in UPS applications must have:

- an AMF panel
- an electronic governor
- an engine water heater
- a battery charger.

Do I Need a Generator?

A standby generator with automatic mains failure (AMF) detection and changeover facilities is the only practical source of long term back-up power during an extended mains outage.

The decision to install a standby generator as part of a critical power system should be made after considering:

- business implications if the critical application is unavailable for an extended period
- the reliability of the mains supply
- the UPS battery autonomy
- the physical constraints e.g. suitable space requirements.

Business Implications

If the critical application must be available at all times without interruption then a standby generator is essential.

As the mains supply is generally quite reliable, there may be situations where the business can tolerate a loss of application/service on rare occasions (*See "Mains Supply Reliability" on page 141*). In this case a UPS fitted with a standard or extended autonomy battery may provide the required system integrity. Only the management of the business concerned can make the decision whether or not generator support is essential.

If the critical application must never be interrupted, a standby generator must be installed as part of the protected power supply system.

The decision whether or not to install a standby generator is often defined by the critical application.

There is no point in having several hours UPS battery autonomy if the air conditioning system cannot keep the computer room cool enough to continue operating for an extended period when the mains supply fails. In these circumstances generator support is essential.

Mains Supply Reliability

The utility mains supply in the UK is generally very reliable. However, figures regarding continued supply ***without disturbance*** are not available as factors such as critical load sensitivity and the proximity of other equipment cannot be determined on a national basis.

Statistically 95% of all mains disturbances last for less than five minutes with anything longer likely to last for many hours.

Once the need for a UPS has been established (*See "Why do I Need a UPS?" on page 3*), the next considerations should be:

- can a UPS with batteries fully protect the critical load? or
- is the load so '*business critical*' that a standby generator is essential to keep the load operational during extended periods without mains supply?

UPS Battery Autonomy

UPS batteries are sized to provide emergency back-up power to the UPS in the event of a total loss of ac input supply.

As a minimum, a UPS battery must have enough capacity to allow time for a generator to start or for an orderly shutdown of the critical load or application (*See "UPS Communications" on page 155*).

Most UPS suppliers can provide battery solutions which will allow the UPS to support the critical load for longer periods. For example a 10kVA UPS may be supplied with a 10 minute battery as standard. However by adding another, matching, cabinet it is possible to extend the autonomy time to 30 minutes. Some systems allow many external battery cabinets to be connected to achieve autonomy times extending into several hours.

Figure 9.2: External Battery Cabinets on a 10kVA System

Additional cabinets and batteries obviously take more space and will require both periodic maintenance and end-of-life replacement (*See "System Maintenance" on page 239*).

Mains Failure Detection and Changeover

When a generator is used as part of a secure power supply installation it is essential that it is fitted with control equipment which, in the event of a mains power failure, will enable it to start automatically. The generator output supply should then be connected to take the place of the failed mains. Both operations are usually controlled by an Automatic Mains Failure (AMF) Detection panel.

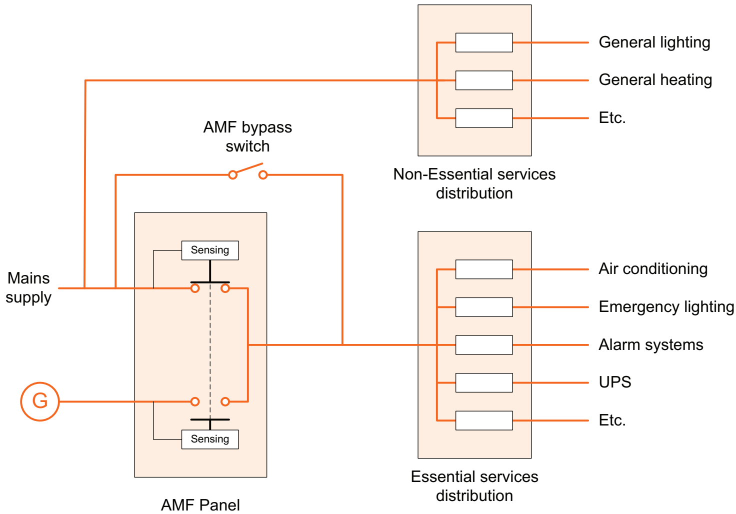


Figure 9.3: Typical Protected Power Installation with Mains Failure Detection and Change Over

To avoid the AMF panel starting the generator every time the mains is disturbed, it is usual to set it to operate only if the mains supply fails for an extended time. The time delay chosen is typically 2 to 10 seconds.

It is also important to set the AMF so that it does not stop the generator and switch the UPS equipment back to mains supply as soon as the mains supply is restored. The mains supply may have been reconnected as part of the utility company's fault location procedure or be the result of an automatic breaker operation – the fault may still exist, in which case the supply will be disconnected again almost immediately.

Most AMF controlled generators start within 10 seconds of a mains failure and continue to supply power for a minimum of two minutes after the mains supply is restored.

In a fully protected system, when the utility mains supply fails:

- the UPS continues to power the load using energy from its battery
- the AMF panel senses the mains failure which, if the interruption continues for longer than the preset delay, starts the standby generator and switches its output supply to the UPS
- the UPS system senses that its input mains supply is restored (albeit now from the generator) and continues to supply the load and recharges the depleted battery.

The system remains in this state until the utility supply is restored.

When the mains is restored:

- the AMF panel senses the restoration of the mains supply and, after a preset delay, assumes that the mains is now stable, and switches the mains supply to the UPS input
- during the transfer back to mains the UPS sees another short power interruption and supports the load from its battery
- the UPS system then senses that its input mains supply is restored and continues to supply the load and recharges the depleted battery.

The only user intervention needed during this sequence is to reset or accept the prevailing alarm indications.

Note that the changeover contactors in the AMF panel (one contactor for the mains and one for the generator) are electrically and mechanically interlocked as both contactors must NEVER be closed at the same time.

The AMF bypass switch is required to allow maintenance of the AMF panel without the need to disturb the power to essential services distribution. The AMF bypass switch must be interlocked with the generator output circuit breaker to prevent the generator feeding the load or backfeeding the mains supply while the AMF bypass switch is closed.

Switching the Neutral Conductor

When considering a mains changeover solution, it is very important to consider the method used to switch the neutral conductor during the mains failure.

It is normal to employ 4-pole switching in the U.K. Short interruptions in the neutral plane are accepted as many sites these days have generators and hence 4 pole changeover.

General advice is to keep the changeover time to a minimum. Advice varies from manufacturer to manufacturer, and product to product; but experience shows that it is best to aim to keep the changeover to less than 30 seconds. 10-20 seconds is therefore permissible, although if this can be reduced it would of course be better. This is especially true in the case of a single phase UPS where, by definition, there is normally a non-zero current flow in the neutral, hence increasing the N-E potential during 4 pole changeover.

The site should also consider that during the changeover period the electrical circuit configuration will be modified from TN-S or TN-C-S to an IT or TT arrangement. This will therefore influence fault and other circuit behaviour during this time.

It is advisable to contact the local electricity supply company at the planning stage, as there may be regulations which prohibit or control paralleling and/or earthing of the neutral conductor.

Solutions available can be grouped into three categories (illustrated in Figures 9.4, 9.5 and 9.6).

The chosen solution is dependent on:

- the requirements of both the UPS and other connected loads,
- local electricity supply regulations.

This section looks at the options available for the UPS. The effects of neutral interruption on other items of connected load are beyond the scope of this book.

Option 1 - Broken Neutral

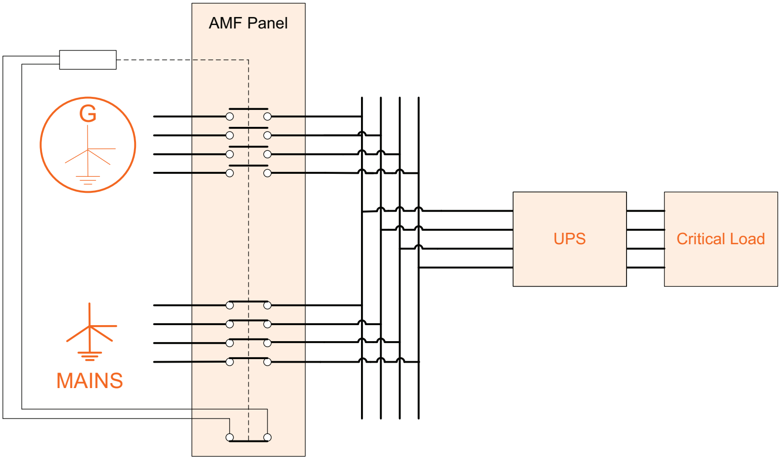


Figure 9.4: Auto-Changeover with a Break in the Neutral Supply

The solution illustrated in Figure 9.4 is normally the "least cost" option as it assumes the connected load, which includes the UPS module(s), can operate normally with a momentary break in both the phase and the neutral connections during any supply changeover.

Option 2- Maintained Neutral

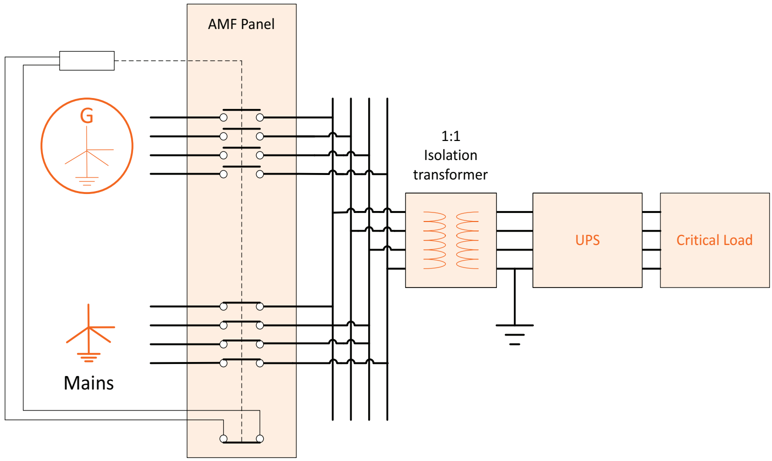


Figure 9.5: Auto-Changeover with No Break in the Neutral Supply

The operation of the AMF panel in Figure 9.5 is identical to that shown in Figure 9.4 however, in this case, the UPS input neutral is provided by connecting the neutral to the earth on the secondary side of the isolation transformer. As this "re-grounded" neutral is a solid connection there is no break in the UPS (and therefore the UPS load) neutral during any mains failure or mains restoration.

As the isolation transformer is in series with the UPS it must be rated to supply the overload rating of the UPS plus any battery recharging requirements.

The costs of the isolation transformer and neutral earthing along with the additional space requirements may make Option 3 more attractive.

Option 3 - Overlapped Neutral

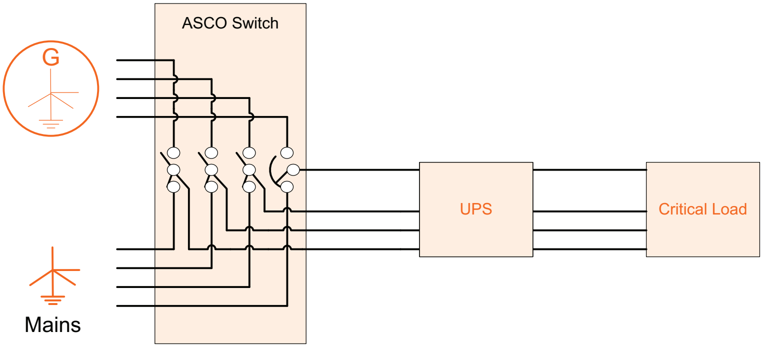


Figure 9.6: Auto-Changeover with an Overlapping Neutral Supply

The overlapping neutral solution shown in Figure 9.6 relies on a special "ASCO Switch" which maintains a neutral connection by momentarily paralleling the Mains supply and the Generator neutral conductors during any changeover operation – the phase conductors are disconnected normally, as with the previous examples.

The ASCO Switch can be operated automatically on mains failure or return.

Note that an overlapping neutral would not normally be allowed in the UK without the local distributor's permission.

UPS Considerations

Constant voltage and frequency are directly proportional to the size and type of generator. The generators used by the power generation companies produce consistent power because they are huge. A standby generator, by comparison, is quite small and cannot supply such consistent power. Any increase in electrical load requires an instantaneous increase in mechanical power to supply it and whereas in a large generator many of these variations are 'absorbed' by the inertia of the rotating parts, a small generator set with less inertia will actually slow down until the engine governor compensates.

UPS Compatibility

There can sometimes be compatibility problems between the generator and the UPS system.

The generator output voltage may be acceptable to the UPS, but often the generator's frequency range is wider than the UPS is designed to accept. In the worst case the frequency variations of the generator will be such that the UPS cannot synchronise with it, either because the frequency is outside limits or it is varying too quickly for the UPS to follow (slew rate) without putting the load at risk. In this situation most UPS systems will signal a warning alarm to inform the operator that in the event of a fault the load will not be transferred from the UPS to the raw generator supply.

This problem can be overcome by ensuring that the generator manufacturer is aware that the generator will be supplying a UPS and making sure it is fully tested during commissioning. As previously discussed, modern standby generators should be fitted with electronic governors that allow the generator to operate within tight frequency tolerances.

On-line UPS systems can accommodate most generator frequency variations while a properly sized generator will absorb most load variations. An electronic governor on the generator will minimise or completely remove potential problems.

Generator Sizing Guidelines

There should be an expectation to oversize the generator. In practice, it is usually necessary to size the generator to handle more than just the UPS. While the UPS is typically running data processing equipment, the air conditioning power to cool the equipment must be maintained. Emergency lighting, communications and alarm systems must also stay operational.

As a ‘rule of thumb’, when sizing a generator:

1.5x the nominal UPS capacity should be allowed for a transformerless UPS.

2.0x the nominal UPS capacity should be allowed for a transformer based UPS.

3.0x the nominal air conditioning running capacity should be allowed for the air conditioning.

The nominal capacity of all other items to be powered by the generator can be either read from the manufacturer’s specification (or rating plate) or measured using a current clamp.

The above are only guidelines and it is recommended that advice should be sought from the UPS and generator supplier if independently attempting to size the generator.

Generator Power Ratings

Generators have two power ratings, namely a standby and a continuous (or prime) rating. A generator's standby rating is typically 10% higher than its continuous rating because in standby applications the generator is only expected to be occasionally brought into use and is not expected to be continuously run. Because standby generators used in a power protection solution can be called upon at any time and for any duration (depending upon the frequency and duration of mains power problems) the continuous rating of the generator is the most appropriate rating to use.

Step Loading

Most generators cannot accept 100% of their load rating in one single step i.e. an AMF panel cannot present a 100kVA load to a 100kVA generator in one single “hit”. A generator's ability to take large load steps is a function of its design and turbo charged generators can, typically, take larger load steps than standard generators.

It is good practice to not introduce the entire load to the generator when this load is >50% of the generator's standby rating. This can be achieved by either over-sizing the generator, which is a potentially expensive option, or by ensuring that load equipment such as the UPS and air conditioning has a “soft start” (also known as “walk-in”) facility or by the clever use of time delay contactors on the essential services distribution board (see Figure 9.3).

Environmental and Physical Constraints

The following must be considered when planning a standby generator installation:

Fuel Storage

In England the Control of Pollution (Oil Storage) (England) Regulations 2001 require oil storage tanks to have a secondary containment facility such as a bund or drip tray to prevent oil escaping into the water environment. The regulations apply to all oil storage containers greater that 200 litres located above ground at an industrial, commercial or institutional site.

In Scotland the Water Environment (Oil Storage) (Scotland) Regulations 2006, which are different to the English regulations, apply.

In Northern Ireland the DOE Guidance Document for The Control Of Pollution (Oil Storage) Regulations (Norther Ireland) 2010, which are different to the English regulations, apply.

There are currently no equivalent regulations in Wales.

For space saving reasons, the majority of standby generators have a “base tank” that, as the name suggests, forms the base of the generator. This base tank would typically be double bunded to 110% of the fuel tank capacity to accommodate the capture of any spilt fuel and would typically be sized to provide between eight and twenty four hours of full power run-time. A fuel tank of this size is also known as a “day tank”. If continuous full power run-time of greater than eight hours is required then either a larger base tank or a bulk fuel tank would be required.

A generator supplied with a standard double bunded day tank is relatively straightforward to site and install, however, the siting of bulk fuel tanks with their associated fire valves and fuel pumps will require specialist advice.

Acoustic Noise

Mains supply disturbances can occur at any time and, consequently, standby generators may be called upon at any time of the day or night.

During the day the sound of a generator starting and running may not cause any problems in either the workplace or in adjacent properties but at night the same sound level will appear ***much*** louder and will seem to carry for a ***much*** greater distance. It is also likely that, once the generator has started, it will be operational for some hours.

Acoustic housings with various noise attenuation ratings are available for standby generators, but the higher the attenuation rating the higher the cost.

Heat Generation

When a standby generator is running it will produce heat as well as electrical power. Almost all standby generators are air cooled, so provision for enough cooling air must be made. For this reason, the majority of standby generators are housed outside the building in weatherproof (and acoustic) enclosures.

Exhaust Fumes

Provision must be made to vent generator exhaust gases in a responsible way. All generators are fitted with exhaust systems, but consideration must be given as to how and where the system will be fitted in order to avoid disturbance to others and to ensure that fumes are minimised and vented safely. Where long exhaust pipe runs or bends in the exhaust pipe are required, it will be necessary to increase the cross-sectional area of the pipe. If part of the exhaust pipe passes through a building, it must be lagged to minimise the problems of heat and fumes. Specialist advice will be required when exhaust pipes pass through, or attach to, a building.

Planning Permission

Local authority planning permission requirements vary from area to area. It is essential to check the local regulations before installing or operating a standby generator. If fuel is to be stored on the site then the local fire officer may also need to inspect the proposed generator and fuel locations.

It is also necessary to advise the local electricity supply company that a generator is to be fitted on the site.

Delivery

A ‘small’ standby generator of only 100kVA or so will weigh several tonnes and be the size of a small car, so consideration must be given to where the generator is to be positioned and how it is to be delivered into such a position.

For the delivery of large generator systems, special delivery vehicles and lifting equipment will be required.

Electrical Installation

As a minimum, a power cable rated to carry full generator power and a signal cable to carry generator start/stop signals must be run between the generator and the AMF panel and/or the essential services board.

If the cable from the generator is long then it may be necessary to increase the cable rating to reduce the 'volt drop' along it. This increases the electrical installation costs of the generator, so the generator should be located as close as practically possible to the AMF panel and/or the essential services board.

Siting

The generator must be installed on a flat and level surface and it may need to be securely fixed to the floor. It is therefore common for the generator to be positioned on a purpose built concrete slab.

10 UPS Communications

Introduction

A UPS provides essential uninterrupted power during a utility mains disturbance or failure but it is also important that it communicates its status and activity to monitoring facilities and the critical load.

Computer networks with file servers or clusters of file servers will often depend upon alarms from the UPS system to invoke orderly and unattended shutdown procedures, saving vital information and work. Many would argue that a UPS system that does not communicate with the equipment that it is protecting, is merely delaying the inevitable system crash in the event of an *extended* site power failure beyond the support time of the UPS battery.

UPS Status and Activity Signals

Modern UPS systems contain facilities to signal their operational status and activity to remote monitoring stations, building management systems and the critical load equipment.

Simple status information is usually provided by volt-free contacts, with more detailed information being supplied over an RS-232 serial connection. Modern systems might also implement these facilities using an internet protocol such as Simple Network Management Protocol (SNMP) or Modbus over IP. When used in conjunction with an SNMP adaptor (*see page 163*), the communication protocol allows the more detailed information to be sent directly on to a computer network, where it can provide management information and invoke shutdown procedures across the network.

Modern UPS systems can also detect failures, or potential failures, in their own components or sub-systems and are able to initiate automatic service calls to address the situation. Such calls may be made to land lines, mobile phones or pagers and will normally include details of the fault. Such capability clearly adds to the overall reliability of the UPS system.

Volt-Free Contacts

UPS alarms and status are usually signalled on the front panel display of the UPS. In addition, a UPS should have simple ‘volt-free’ contacts to allow interfacing with remote (but on-site) alarm panels and monitoring systems.

Volt-free contacts provide the simplest form of communication. They provide a ‘true/not true’ signal which is very useful when simple status information is all that is required for such alarm systems as a Remote Status Panel (RSP) or a site Building Management System (BMS).

With suitable network software, volt-free contacts can be used to initiate an orderly shutdown of the PC or network operating systems such as almost all Windows, Mac, Linux and Unix variants. The software required may be embedded within the system or purchased from the UPS supplier or the network operating system supplier.

Many software solutions are available but they all operate in similar ways:

- When the mains supply to the UPS fails the software detects (via the volt-free contacts) that the UPS is running on battery power and starts a timer that can be user configured.
- If the mains supply stays off for long enough for the timer to hit the user configured limit, or the software detects the UPS low battery alarm, a controlled shutdown of the computer software, hardware and peripheral equipment is initiated (*See "Computer Networks Auto Shutdown" on page 162*).
- If the mains supply returns before the low battery alarm is signalled, the software again detects this via the contacts and resets the timer.
- If the software is installed on a computer network server, that server can be designated as ‘master’ and can be used to relay UPS alarms to other network devices or ‘slaves’ which can also be configured to respond appropriately.

Contact	Signal	Function
	Alarm	Mains Failure
		Mains Present
		Common
	Message	Load On Inverter
		Common
	Alarm	Battery Low
		Battery OK
		Common
	Message	Load On Mains
		Common
	Alarm	Common Alarm
		No Alarm Condition
		Common
Volt-free contacts are typically rated for 60VAC max. and 500mA max.		

Figure 10.1: Sample 'Volt-Free' UPS Status Monitors

Older Communication Protocols

RS-232

The RS-232 connection provided with many UPS systems is designed to enable the UPS to be connected to a monitoring computer running suitable software.

Details of the standard RS-232 nine and 25 pin connections are shown in Figure 10.2 and Figure 10.3.

Serial data contained within the RS-232 signals allows for more information to be monitored than the 'volt-free' contacts. Instead of purely true/not true conditions, RS-232 systems allow analogue values to be monitored; for example, the following (and more) could be displayed on a remote terminal:

- inverter output voltage, frequency, current, kVA and kW
- bypass voltage, frequency, current, kVA and kW
- battery voltage, charge/discharge current and remaining battery time
- statistics regarding mains failures and UPS operation

Unfortunately there is no European Standard for UPS RS-232 protocol so each UPS manufacturer uses its own protocol. This means that the UPS user must normally obtain the relevant RS-232 shutdown software from the UPS supplier.

Using an RS-232 serial connection, a computer can monitor the UPS in real-time since its operational status can be continually polled for updates. However, in normal practice, only critical alarms are continually monitored with operational status being manually requested by a system administrator or supervisor.

The RS-232 signal from the UPS may be configured to provide a number of facilities. Most UPS suppliers will also provide proprietary software to make best use of the serial connection, although the features offered by each manufacturer may vary.

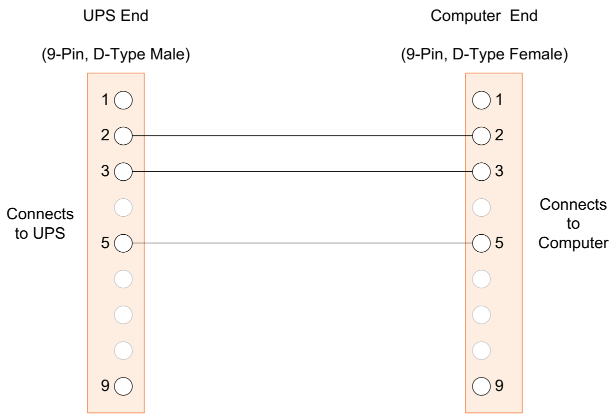


Figure 10.2: 9-pin to 9-pin RS-232 Interface Cable

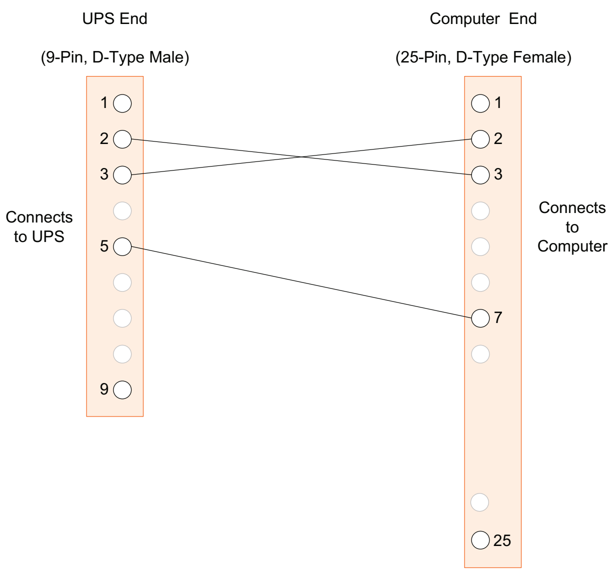


Figure 10.3: 9-pin to 25-pin RS-232 Interface Cable

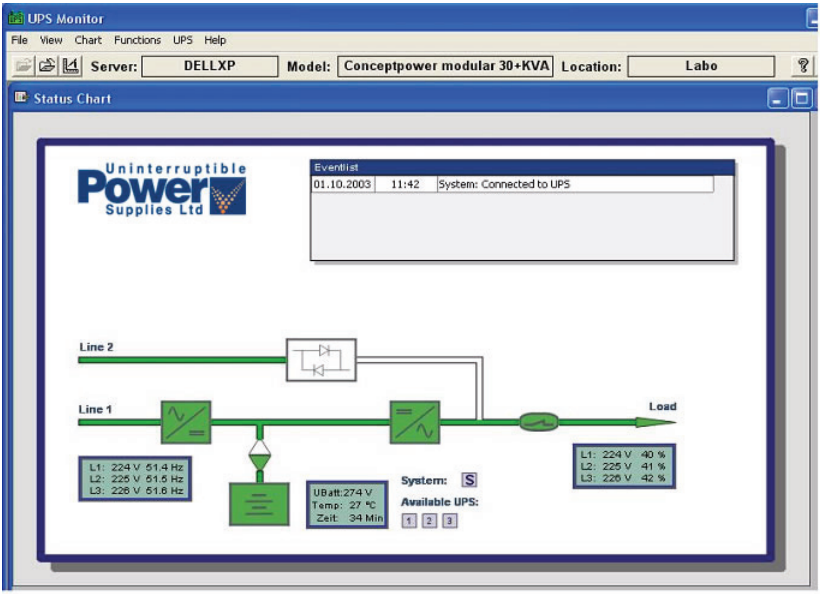


Figure 10.4: Typical UPS Monitoring Screen

Monitoring software is available for almost all computer operating systems and its facilities may include:

- a graphical display of UPS status, voltage, current, load, battery voltage and frequency etc. (*See Figure 10.4*).
- configurable responses to certain alarms – broadcasts to users etc.
- scheduled diagnostic checks and data logging.

For longer communications distances, RS485 or RS422 type interfaces are often used, although RS422 is generally favoured since it is a full-duplex system and introduces less problems.

Modern UPS equipment also incorporates a USB interface to enable real-time UPS monitoring.

Modbus (JBus)

Modbus is an application layer serial communications protocol that was originally designed for use with programmable logic controllers (PLC) and is commonly used to monitor and control a variety of industrial electronic devices.

It can be implemented over RS485 or IP (Ethernet) to communicate with up to 240 nodes (devices) connected to a common network.

When used in a serial (RS485) environment one node is designated as a ‘master’ device and becomes the only one able to initiate Modbus commands to the remaining ‘slave’ devices. The installation requires the master device to be connected via a remote terminal unit (RTU) and for this reason this type of system is sometimes referred to as “Modbus RTU”.

An RTU is not required when implementing Modbus over IP (Ethernet) – which is sometimes described as “Modbus TCP”. In this type of installation any of the connected devices can send a Modbus command; however, although it is possible to have multiple master devices in this system it is usual to employ a single master only.

In both Modbus RTU and Modbus TCP systems each slave device is configured with an individual ID or IP address which allows the master device to access each one individually.

Data is stored on the slave devices in a number of 16-bit or 1-bit registers that can be written to, or read, by the master device. For example, in a UPS system, the 16-bit registers can contain digitised values relating to the existing input voltage, input current, battery charge current etc., and alarm status data can be stored in the single-bit registers. These registers can then be polled by the master device and provide a data feed for a centralised UPS Management station. Note that the registers can also be configured to receive control inputs from the master device.

When Modbus is employed in a typical parallel UPS system which incorporates a centralised UPS Management system, each module is individually addressable by the UPS Management system, as explained above. Any ‘read’ or ‘write’ command transmitted by the UPS Management system will therefore only be acted upon by the intended UPS module, even though it might have been detected by them all.

It is however possible to ‘broadcast’ a command to a base address which is simultaneously processed by ALL modules – for example to transfer all the UPS modules to bypass or effect an emergency power off.

Computer Networks Auto Shutdown

During a power failure, the monitoring software collates the UPS remaining battery time and will initiate a local or network shutdown of the UPS protected computers.

Remote Control Command (RCCMD) is the most commonly used shutdown client solution for UPS supported network environments. Many UPS systems and manufacturers can be supported by a proprietary monitoring solution. RCCMD will match this diversity and is available for many different operating systems.

In simple terms, the monitoring software, which can be resident in either a PC or in an SNMP adapter card, will send out an RCCMD shutdown signal at a pre configured level of remaining battery run-time. Any remote PC/server with an installed RCCMD client licence will “recognise” the shutdown signal and initiate its own shutdown procedure.

By configuring the IT system so that less essential items of equipment are automatically shut down earlier, the electrical load on the UPS battery can be reduced, therefore increasing the available back-up time for critical items.

Therefore, with considered planning between the UPS system and the auto-shutdown facility, the electrical supply can be extended for the longest possible period to the most essential equipment.

UPS Management Across Networks

Networks that are spread out over a large area, Wide Area Networks (WAN), can cover hundreds, even thousands, of miles. WANs create great advantages for their users because they allow people to share information that in the past would have been faxed or mailed. However, a disadvantage of the WAN is that it is difficult to monitor, manage, and maintain all the computing equipment that is spread over such a wide area.

Management of unmanned sites has become a big issue on these large networks. Typically, multiple site networks will not have a network manager at each site. If a problem should occur while a network manager is not there, irreparable damage to system hardware and software could occur. SNMP cures this problem because now a network manager can monitor and control all network devices from a central location.

SNMP

A modern UPS should come with SNMP compatibility as standard for interfacing with major Network Management Systems such as HP OpenView or IBM Tivoli NetView.

Simple Network Management Protocol (SNMP) was created to address the problem of wide area network management. SNMP is a standard protocol that is part of the Transmission Control Protocol/Internet Protocol (TCP/IP) suite which allows all network devices to transmit management variables across enterprise wide networks. By creating one standard, SNMP allows a network manager to monitor all remote sites from one central location (*See Figure 10.5*).

A UPS with SNMP capability becomes an intelligent UPS that can, for example:

- log events
- continuously monitor power quality
- report on battery status, load and temperature
- perform self-diagnostics.

SNMP is vendor and platform-independent and establishes guidelines for what information will be collected, how it will be structured and how the messages are formed from the network device to the manager and back. Network devices then gather information into a management information base (MIB).

A user's operating system software uses SNMP management software to collect and display the MIB data in an easily understood format.

An intelligent UPS might have a provision for individually controlling the devices to which it is connected - for example, turning them off or on. This could enable the system manager to isolate sections of the system for security purposes, shut down devices to achieve electrical savings and manage redundant portions of the system.

Because intelligent UPS systems can condition power as well as provide battery backup to attached devices, system disruption due to power outages or disturbances can be dramatically reduced. The system's microprocessor can log power disturbances, keep track of battery usage, alert system managers to low battery problems and track the history of power levels. Through SNMP, this information is available to managers for immediate analysis and to detect potential problems before they occur.

SNMP allows system managers not only to control the UPS, but also to more efficiently manage its load. By linking several dozen UPS systems (possibly from different manufacturers) into the network and feeding status data to the central network console, power protection and network control becomes that much more efficient.

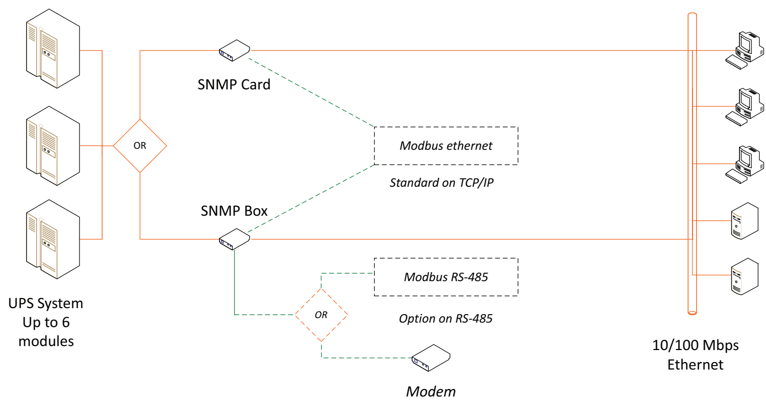


Figure 10.5: SNMP Network Interfaces

SNMP Adaptors

An SNMP adaptor connects the UPS system directly to the computer network so that the UPS system becomes a network peripheral device.

SNMP adaptors can be either separate enclosures or slot-in cards (*See Figure 10.6*) and are usually fitted between the UPS serial communications port and the computer network, although adaptors are available that can interface between the UPS volt-free contacts and the network. These convert the contact information to the correct protocol which can then be read by the rest of the network. Offering HTTP, SNMP, SMTP, WAP, Telnet, SSL, SSH compatibility and a console port, SNMP adaptors enable dynamic support for a large variety of system configurations.

SNMP Software Facilities

Levels of control, monitoring and shutdown facilities vary from manufacturer to manufacturer, so it is important to understand exactly what functions are required by a particular installation before choosing an adaptor.

At best the adaptor will allow UPS connection to the network without the use of a proxy agent, such as a master server, and will therefore not be reliant on the server to relay information to other devices on behalf of the UPS, thus increasing system integrity.

The software used with the adaptor needs to be selected carefully as it must be designed for use with the network operating system. Most major UPS manufacturers provide versions for use with Windows, Apple, Linux and Unix.

As a minimum, the selected SNMP software should offer:

- Remote control and rebooting of UPS-protected devices over the network/internet
- Protection of information through automatic and graceful shutdown of multiple UPS-protected devices during an extended power failure
- Real-time email, mobile phone or SMS alarm notification capability
- SSL and SSH data encryption and authentication
- Web pages served automatically in the selected local language
- Activity and alarm logging

Figure 10.6: SNMP Adaptors

SNMP Compatibility

As SNMP is an established and accepted standard, it is possible to control and monitor UPS from different manufacturers and to display an integrated status report of all equipment.

Other Network Solutions

While the SNMP/ethernet is the most common networking solution for UPS systems in a computing or office environment, other solutions do exist.

Manufacturing and industrial facilities often employ other solutions which may dictate the monitoring and alarm system chosen. Fortunately, these can usually be interfaced directly using the standard RS-232 ports provided on the UPS.

Parallel UPS Management

Special consideration must be given to parallel UPS installations when selecting an appropriate communications protocol. It is not sufficient to simply install independent communication software for each UPS module since the correct operation of the parallel system as a whole needs to be monitored rather than the status of each individual module. Likewise in a parallel redundant UPS configuration, system shutdown should not be initiated as a result of a redundant UPS module failure.

The UPS manufacturer should be able to provide bespoke hardware and software to enable the correct communication and management of a parallel UPS system.

Key requirements are:

- Real time value monitoring of the combined, overall, parallel UPS system as well as each independent module (See Figure 10.7).
- Intelligent communication software control at system level and not at UPS module level.
- Auto-shutdown software procedures should recognise redundancy status and only be initiated at system level and not at UPS module level.
- A single interface port for the overall parallel UPS configuration.

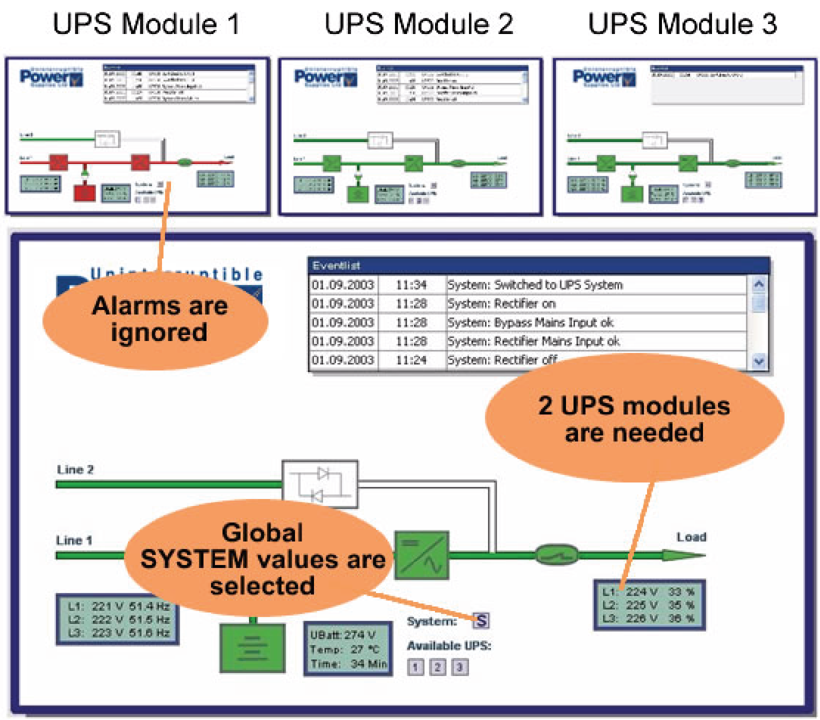


Figure 10.7: Parallel UPS Management

Off-Site Alarms and Remote Management

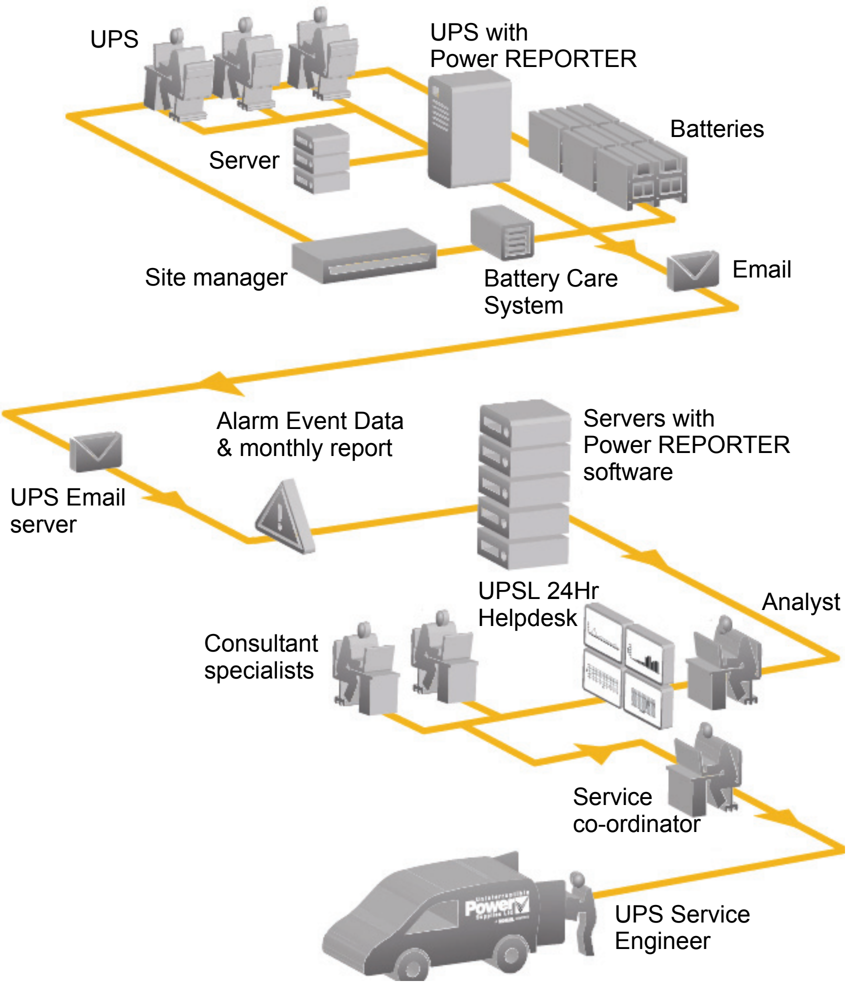


Figure 10.8: Automatic Call Out Facility

In addition to on-site alarm monitoring via volt-free contacts and RS-232 or network wide monitoring via SNMP connections, some modern UPS offer additional facilities which enable fault indications to be signalled to remote monitoring points. Remote management may effectively be used to:

- alert the client's on-call engineer via SMS, mobile phone, or over network
- allow remote, basic UPS interrogation by a service engineer
- automatically signal maintenance requirements

The Management Software can be programmed for extensive alarm dispatching so when a critical alarm is received, a dedicated customer response can be initiated. For example, when an alarm is detected, the client's representative, or the manufacturer's service technician, is immediately contacted.

Using a laptop and a simple browser, the on-call service technician is able to connect to the UPS Management Centre, gain detailed information regarding the alarm and, if necessary, respond to the fault quickly and fully prepared.

Emergency Power Off (EPO)

For Health and Safety reasons, all modern UPS systems have an Emergency Power Off (EPO) port that can be connected to a suitable fire alarm panel or push button switch etc.

Emergency stop is usually a normally closed contact which, when opened in the event of a fire or other emergency, completely turns off the UPS **with immediate loss of supply to the load**.

The EPO facility is often:

- connected to a large red mushroom push-button that can be hit easily by the last person exiting the room in a fire or disaster situation,
- connected to a suitable relay port in a site fire alarm or building services management panel.

As emergency stop contacts must be closed during normal UPS operation, multiple emergency stops must be wired in series – that is, the operation of any emergency stop button or relay will open the connection to the UPS and initiate the emergency shutdown.

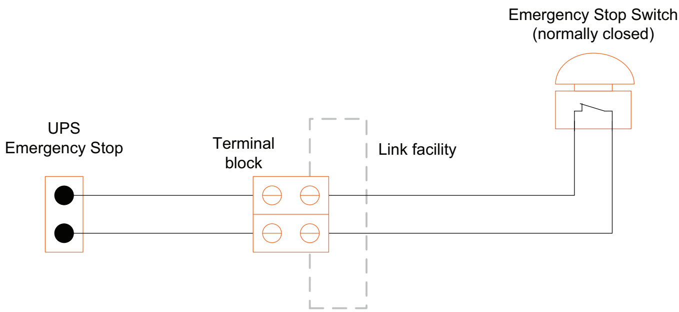


Figure 10.9: Typical Emergency Stop Wiring

It is advisable to include a link facility in the EPO wiring as this enables a switch to be replaced without interrupting the supply to the load.

Note: In most cases the EPO facility turns off the UPS electronically under software control and is often called "Remote Power Off" (RPO). If total electrical isolation of the UPS is required as part of the EPO operation it must be implemented using additional contactors.

11

Planning a UPS Installation

Introduction

This chapter assumes the need for a UPS system has been established.

There are now six main stages which must be completed in order to achieve a successful UPS installation:

- Sizing and selecting the correct UPS
- Reliability considerations
- Environmental considerations
- Total cost of ownership considerations
- Installing the UPS
- Using and maintaining the UPS

In the text which follows, each of these points is expanded to provide comprehensive information on all aspects of UPS installation planning.

Sizing and Selecting the Correct UPS

Collating and Calculating Load Data

When planning a UPS installation it is important to gather as much information as possible about the proposed load and make allowances for future load expansion. Most items of electrical equipment have labels which carry information regarding the electrical characteristics of the item.

It is important to collate information for items of the proposed load – you may find the form *'Collecting Load Details'* on page 182 useful.

In order to correctly size the UPS certain information about the load is needed - these include:

- Supply voltage
- Supply frequency
- Number of phases
- Load current
- Power factor
- Power consumption.

Supply Voltage

The ac supply voltage in Volts (V) is normally stated on the label or in the manufacturer's literature. In the UK, single phase equipment will normally have a supply voltage of 230/240Vac and three phase equipment will be 400/415Vac. Some equipment is designed for international use and the labelling may give a range of operating voltages.

Supply Frequency

The ac supply frequency in Hertz (Hz) is normally stated on the label or in the manufacturer's literature. In the UK, equipment will normally have a supply frequency of 50 Hz. Some equipment is designed for international use and again the labelling may give a range of operating frequencies.

Number of Phases

The number of phases will be either single (one) or three. If the equipment label or literature does not give a value, 230/240Vac devices can be assumed to be single phase and 400/415Vac three phase.

A three phase UPS can supply three phase and single phase loads.
A single phase UPS can **ONLY** supply single phase loads.

Load Current

The device load current in Amperes (A) is normally stated on the label or in the manufacturer's literature.

Power Factor

In some electrical loads such as motors or computers, current flows into the equipment without being usefully converted to energy. This happens when the current drawn by the equipment is not in phase with the applied voltage.

Some equipment draws current which is always in phase with the voltage, however almost all the equipment likely to be connected to a UPS draws additional current which is not in phase with the voltage.

Power factor expresses how much of the supply current is in phase with the voltage and is effectively used.

Equipment which draws out of phase current has a power factor of less than 1.0. The power factor value will usually be between 0.8 and 1.0, and if no figure is stated it is traditional to assume a value of 0.8.

See *"Power Consumption" on page 174* for an example of how to use the power factor value.

Typically, loads have tended to present a lagging (inductive) power factor to its supply. Modern Switched Mode Power Supplies (SMPS's) within items such as blade servers have shifted this power factor to near unity, and in some cases to a leading (capacitive) power factor. Care must be taken to ensure that any potential UPS system can supply leading power factor loads without any form of derating. In addition, SMPS manufacturers have increased the efficiency of the SMPS itself but at the expense of increasd harmonic content.

Power Consumption

Power consumption may be stated in Watts (W) or Volt Amperes (VA) but rarely both. As UPS manufacturers use VA (or kVA) it is useful to obtain the VA rating of all load items.

If the VA rating is not stated it can be obtained by:

- multiplying the supply voltage (V) by the load current (A) or
- dividing the power consumption (W) by the stated power factor (p.f.).

To calculate the VA rating for an item rated at 230V, 6A

VA Rating = 230 x 6 = 1380VA or 1.38kVA

To calculate the VA rating for an item rated at 240V, 130W

$$\text{VA Rating} = \frac{W}{pf} = \frac{130}{0.8} = 162.5\text{VA}$$

The VA rating will never be lower than the Watt rating as it is dependent on the Power Factor of the device (*See "Power Factor" on page 173*).

Measuring the Actual Load

Obtaining load details from product labelling will give a reasonable indication of the load power requirements but it cannot give an accurate view of the load variations over time. The only accurate method of establishing the load 'profile' is to perform a site survey.

Using label information gives an indication of expected load but takes no account of the load variation over time.

Many UPS suppliers offer a site survey service which may involve installing portable measuring and monitoring equipment to record information about the load over a period of time. The time the monitoring equipment is installed will be largely dependent upon the load applications. For example, there is little point in measuring the power demand of an office network after 5 pm or at a weekend when very few staff will have their PCs switched on.

Problem Loads

UPS equipment is generally resilient but there are certain types of load which require special consideration when connected to a UPS and these include:

- blade servers
- fluorescent/gas discharge lighting
- motors and compressors
- air conditioning equipment
- laser printers
- dimmable lighting systems.

The items above can draw high, or pulsed currents during normal operation or start-up. This may overload the UPS or cause unintended operation, during start-up in particular, causing intermittent alarms or possible transfer between inverter and static bypass mode.

Blade Servers

Data centres are dynamic computer environments. In recent years the increasing mix of old and new computer technologies has caused the overall power factor of the computers/servers to shift towards unity. Furthermore with the introduction of powerful blade servers the overall power factor may even become leading.

This server evolution is becoming a big challenge for IT managers as most of the installed legacy UPS systems, with PWM (pulse width modulated) inverter switching, are designed to provide maximum power at lagging power factors. These UPS systems are approaching their kW power limits due to the change of loads from lagging to leading power factors, or may even shift into an overload condition. The majority of legacy UPS topologies that are installed in IT environments experience a typical derating up to 30% compared with modern transformerless topologies.

Derating of UPS topologies with leading loads

Legacy UPS topologies are designed to provide maximum kW power for lagging loads, typically at 0.8 power factor. If the load shifts from lagging to leading power factor, legacy double conversion UPS will derate substantially and hence reach or exceed their rated power.

The PWM inverter switching in most transformer-based UPS systems is slower and cannot avoid derating when supplying loads with leading power factors.

Transformerless UPS with adaptive inverter switching do not experience derating at unity and small leading power factors.

	300kVA Transformerless UPS	300kVA Legacy double-conversion UPS
Power Factor (load)	kW Rating	kW Rating
0.80 lead	231kW	152kW
0.85 lead	249kW	166kW
0.90 lead	270kW	182kW
0.95 lead	285kW	214kW
1.00	300kW	240kW
0.95 lag	285kW	240kW
0.90 lag	270kW	240kW
0.85 lag	255kW	240kW
0.80 lag	240kW	240kW

Figure 11.1: UPS derating versus leading loads (300kVA)

Figure 11.1 shows typical values of power versus load power factor for both modern transformerless and legacy UPS topologies. Legacy UPS topologies (300kVA) typically provide 182kW at 0.90 leading power factors, which corresponds to 24% derating.

Transformerless UPS (300kVA) experience no derating up to 0.90 leading with respect to the nominal power at 0.8 lagging, and provide 270kW.

Figure 11.2 shows that the transformerless UPS can provide substantially more power than equivalent legacy UPS. The 300kVA transformerless UPS provides up to 88kW more power for a 180kW load with 0.90 leading power factor, than equivalent legacy UPS, which corresponds to 44% of the total load value.

When new data centre power requirements are assessed it is very important to evaluate the power that the specified UPS can provide at leading power factors. The shift to leading power factors gives a clear advantage to transformerless UPS with respect to legacy UPS. Due to the substantial derating of legacy UPS when powering loads with leading power factors, in many cases it will be possible to specify a smaller transformerless UPS against a larger legacy double-conversion UPS.

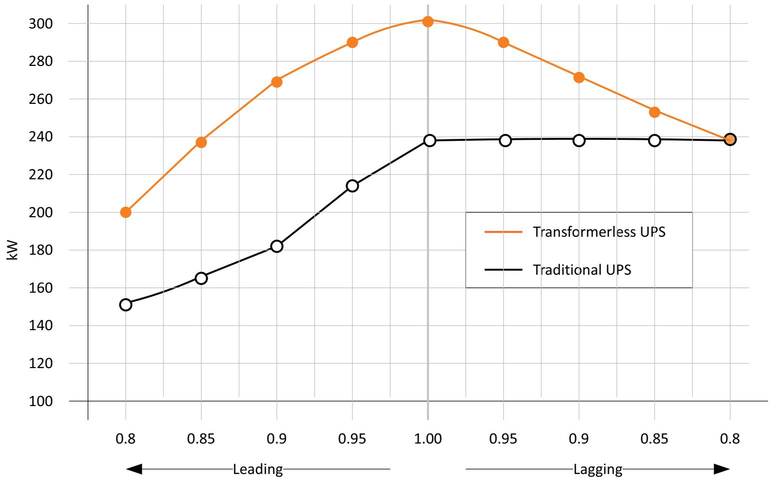


Figure 11.2: Power (kW) versus power factor

Figure 11.3 shows how two typical UPS topologies cope with blade servers with leading input power factor, which represents a major challenge for legacy double-conversion UPS.

	Transformerless UPS	Typical legacy UPS
UPS Rating	300kVA	300kVA
Available power at PF = 0.9 lead	270kW **(UPS 74% loaded)**	182kW **(UPS 10% overloaded)**
Losses at full load of 200kW (0.9 lead, non-linear)	**9kW (95.5% efficiency)**	**25kW (89% efficiency)**
Generator over-sizing factor	**1.5**	**2.5**
Note: Special care should be taken when sizing the generator for leading power factor loads. It is recommended that advice is sought from the generator manufacturer. When the generator is supporting the UPS, the power factor presented to the generator is close to unity (typical for a transformerless UPS). However, if the UPS operates in bypass mode the leading power factor is presented directly to the generator terminals.		

Figure 11.3: UPS performance with blade servers (assuming a 200kW load and PF = 0.9 lead)

It should also be borne in mind that, irrespective of the UPS topology, should the UPS system operate in bypass mode, the blade server load with leading power factor will be presented directly to the output of the standby generator — there is a risk that leading power factor loads could result in the generator AVR losing full control of the output voltage.

As data centre loads move towards leading power factors the technical advantages of transformerless UPS, particularly in the output power range from 60 to 300kVA, become evident.

Harmonic Currents

Harmonic currents result only in undesired reactive power and not as active power and therefore the power factor for this type of load is poor. Nowadays, many equipment manufacturers include a power factor correction stage, without which a typical power factor can be 0.7 or less. Another typical characteristic for this kind of load is the high peak current. This is the peak (or crest) factor which is the ratio of the peak value to the r.m.s. value of an AC current in steady state. A factor of 2.5 can be regarded as typical for computer loads. For a normal linear load the corresponding value is only $\sqrt{2}$ or 1.42. It is important to pay attention to these factors when designing a network for computers and especially when choosing UPS equipment for this purpose.

To comply with the EU standard EN61000-3-2, all computer power supplies must, at least, include passive power factor correction (PPFC). PPFC can achieve a power factor of about 0.7 - 0.75.

When calculating with power vectors (apparent, active and reactive) the difference between the reactive power Q caused by phase shift and D (distortion) caused by harmonic currents must be observed. Instead of the power triangle formed by the vectors P, Q and S, a figure in three dimensions also including the reactive vector of D should be used. The relations within this configuration are given in Figure 11.4.

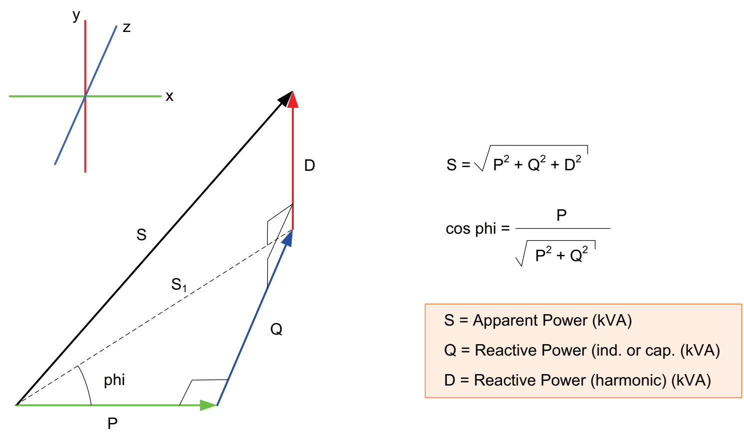


Figure 11.4: Three Dimensional Vector Diagram for Power Calculations

Neutral Current

In a three phase system the current in the neutral conductor is usually the result of the difference in the three line currents. Typically, in computer networks however, very high currents are present in the neutral conductor even when the three currents are equal and the arithmetic sum of their r.m.s. values is zero.

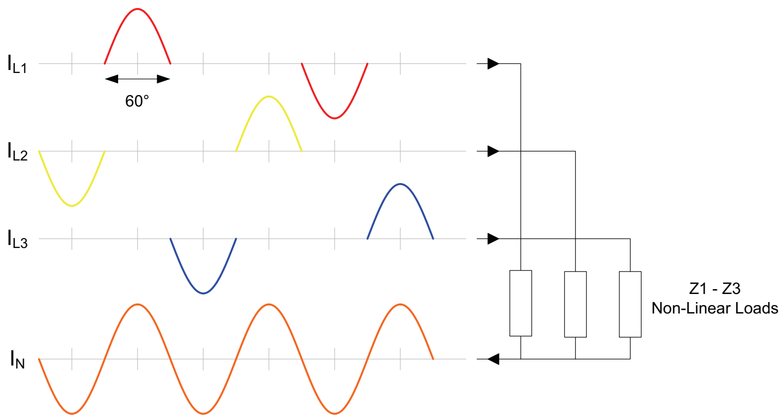


Figure 11.5: Currents in line conductors and neutral conductor

When single-phase computer units with their non-linear load characters are connected in a three-phase network from lines L1, L2 and L3 to the neutrals no current balance will take place as it would normally with linear sinusoidal currents. The situation is illustrated in Figure 11.5 which shows how the three line currents add-up into the neutral conductor. This results in a current which will be the root mean square of the three line currents and its frequency is 150Hz. At its maximum this current will be as high as $\sqrt{3}$ or 1.73 times the line current. This maximum takes place when the line currents are of the same magnitude, which they generally are at the optimized loading of a cable.

High peak line currents and the high current in the neutral conductor can cause over loading of feeders and transformers as well as voltage distortion (top-flattening of the sinusoidal voltage form) and common mode distortion. Special care is required – see *IEE Wiring Regulations 17th Edition.*

In-Rush Currents

Some computer units have a built-in soft-start circuit but most are switched on directly causing a high inrush current. In the latter case the situation is similar to a momentary short circuit, where the current limitation will only be provided by the line impedance in the power supply.

In-rush currents may also find their way through the neutral conductor and cause potential variations and transients affecting different areas of the connected computer network

Figure 11.6 shows typical in-rush current behaviour. These currents may have an amplitude of 15 to 20 times the nominal r.m.s. value.

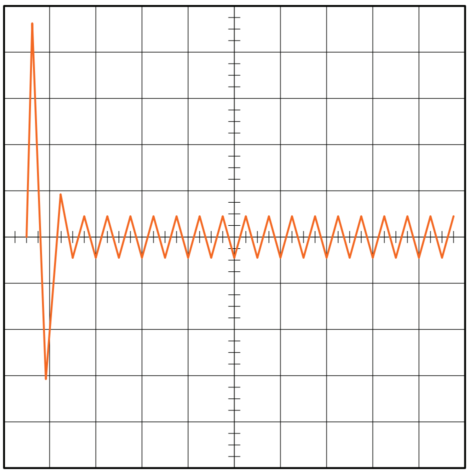


Figure 11.6: Typical Computer In-rush Current

Significant oversizing of the UPS system is required if high current loads such as laser printers and motors are to be powered.

Distributing the Load

If you are planning a three phase UPS installation, once you have collected the load details, you must decide how the individual items of load will be distributed across the phases. Balancing the load evenly across the three phases is good practise as this allows the rating of the UPS to be fully utilised and presents a balanced load to the mains (or generator – if fitted) whenever the UPS is bypassed.

For example, a 60 kVA three phase UPS can supply up to 20 kVA on each phase.

Most modern UPS have independently regulated phase voltages and do not require careful load balancing across the 3 phases in order to operate correctly. Even with these systems the load on any single phase must never exceed 33% of the total UPS rating.

It is permissible to have single phase loads, supplied by different phases of a three phase UPS, in the same vicinity providing regulation 514-10-01 of BS7671 is enforced - see page 228.

Collecting Load Details

You may find it useful to use the following table to collect and collate load information.

Description	Voltage (V)	Frequency (Hz)	Phases	Current (A)	Power		Power Factor
					W	VA	

Site Capacity

It is essential that the capacity of the site's incoming mains supply and its cabling and switchgear is taken into account when planning any UPS installation.

If existing equipment is merely to be transferred to a UPS protected supply there may be only minimal increase in load, but if the site is to be expanded to include, for example, a new data centre, the load increase will be significant and the effect on the site's supply capacity will be important and must be considered.

Increasing the capacity of the mains supply to the site is likely to involve considerable expenditure so it is important, at this stage, to plan for the future.

It is beyond the scope of this book to give specific advice about increasing the supply capacity of a site, but the local electricity supply company will be able to give advice and guidance.

Future Requirements

When all the load information has been collected and collated, the required UPS capacity will be established. However, it is important to make some spare capacity contingency when sizing the UPS — 20% is typical.

However, just adding allowance to the measured or calculated capacity is not enough to cater for any future expansion plans and the topology of the UPS system is also an important consideration (*See "UPS Topologies" on page 21*).

Example

If the load measurement and calculation has resulted in a total load requirement of 120kVA (including a spare capacity contingency) and the critical load/ process dictates that a parallel redundant system is required:

> Instead of just considering a 1+1 system comprising 2 off 120kVA UPS, a more cost effective solution may well be to specify an N+1 system, for example 3 off 60kVA UPS or 4 off 40kVA etc.
>
> In the 2 UPS 1+1 system, each unit can only ever carry 50% of its full load capacity while retaining redundancy and may therefore be operating at a low efficiency.
>
> In an N+1 system, each unit will be more heavily loaded while retaining redundancy and may well therefore operate at a higher efficiency (See *"Operating Costs" on page 211*).

The benefits of the N+1 system are:

- lower running costs
- smaller foot-print
- more easily expandible should the load grow.

An N+1 system may be configured for future expansion by ensuring that suitable switchgear facilities are included during the initial electrical installation stages (*See "A Typical Paralleled UPS System Bypass Panel" on page 109*).

Alternatively, the selection of a rack format, modular UPS configuration enables a very expedient and cost-effective solution for future capacity upgrades (See *"Modular UPS Systems" on page 94*).

Choosing a UPS Topology

The topology chosen (*See "UPS Topologies" on page 21*) for a particular UPS installation is largely governed by:

- the size of the load
- the load type
- resilience and required availability
- CAPEX
- OPEX

Size of Load

The size of the load will influence which type of UPS may be chosen (*See "What is Available?" on page 15*).

Examples

If just one PC is to be supported:
The load is single-phase and likely to be less than 250VA therefore a 'Micro' UPS would probably be adequate and on-line, off-line and line interactive designs are available.
If an office network, or communications centre is to be supported:
The load may be either single or three-phase and is likely to be between 3 and 20kVA. It may require a battery backup or autonomy time of perhaps 30 minutes – in this case a 'Medium' sized UPS system is probably most appropriate. A UPS of this power rating is likely to be available only as an on-line design.
If a major data centre is to be supported:
The load will almost certainly be three-phase and may be between 30kVA and several hundreds of kVA. The load process may also require power redundancy and a standby generator to ensure absolute supply security even in the event of a lengthy mains failure. The only solution in this case is a 'High-Power' parallel system which is only available in an on-line configuration.

Load Type

The assessment of load type may overrule the UPS type chosen in the *'Size of Load'* section. If, for example, during the initial load compilation of calculation just one piece of three-phase equipment is required then this dictates that a three-phase UPS **must** be installed.

A single-phase UPS can only support single-phase loads.
A three-phase UPS can support **both** single and three-phase loads.

If a load that **must** be connected to the UPS is listed in *"Problem Loads" on page 175*, then you must consult your UPS supplier as a special assessment will be required.

UPS equipment can support almost any type of electrical load but, installing a much larger UPS than was initially planned may avoid electrical disturbance to other connected loads and/or constant overload conditions and alarms if particularly 'hostile' loads are to be connected.

Consult your UPS supplier if any part of the planned load is listed in *"Problem Loads" on page 175*

Load Process Requirements

The degree of mains supply protection demanded by the load process will often govern which UPS topology is chosen.

Examples

If the business processes must be protected for the majority of minor mains disturbances and interruptions but would not be adversely affected if it could be shut down in a controlled way should the interruption continue for an extended period, then a solution may be to install:

- a UPS with auto controlled shutdown software facilities (*See "UPS Communications" on page 155*).
- an extended battery autonomy (*See "Additional Battery Cabinets" on page 126*).

If the supply to the critical load(s) may **never** be interrupted and the business process being protected **must** be available twenty-four hours per day, seven days per week, then the only viable solution is to install:

- an on-line UPS configured as an N+n parallel redundant system
- batteries to support the load during short mains failures
- a standby generator to protect the load during long outages.

Summary

The choice of UPS topology is a complex one and depends on the particular business process and load to be supported.

Consideration must be given to:

- the size of the load
- the load type
- resilience requirements
- CAPEX
- OPEX
- financial cost to business of any down-time

In addition to the main criteria listed above, two additional items remain – will the chosen UPS fit in the space allowed for it? and can the equipment be easily transported into the chosen position? These are discussed in *"Delivery and Positioning" on page 213*.

Reliability Considerations

The overall cost of your UPS system can be affected by the reliability of the equipment you choose to install. The most important consideration when comparing manufacturers' reliability figures is consistency. Make sure that each manufacturer is performing calculations to the same standards and fully investigate any figures which differ drastically from the others.

The definitions which follow are generally considered to be the standard.

Term	Definition
Reliability	The reliability of a UPS system is the probability that it can perform its designed function (supply of interruption-free, clean power) during a certain time period.
Failure	Failure denotes the inability of a UPS to perform its designed function. A failure is caused by internal or environmental faults. *Note:* Faults usually cause a degradation of the system but do not always cause a system failure.
Faults/Errors	A fault is an anomalous physical condition e.g. design error, manufacturing problem, bad material, damage, fatigue etc. An error is a manifestation of a fault in a system where the state of the system differs from the intended state.
MTBF	Mean Time Between Failures is a measure of probability and is the average failure-free time between subsequent failures.
MTTR	Mean Time To Repair is the elapsed time from the error acknowledgement until repair is completed. MTTR depends on many factors such as size and quality of the service organisation and the availability of spare parts etc.

Availability Considerations

Power Availability Index

High availability is one of the most important issues in computing today. Understanding how to achieve the highest possible availability of systems has been a critical issue in mainframe computing for many years, and now it is just as important for IT and networking managers of distributed processing. A certain amount of mystery surrounds the topic of power availability, but consideration of just a few important points leads to a metric which IT managers can use to increase their systems and applications availability and make a rational price/performance purchase decision.

High Systems Availability

Availability is a measure of how much time per year a system is operational and available. Usually, companies measure application availability because this is a direct measure of their employees' productivity. With critical applications, or parts of critical applications, physically distributed throughout the enterprise, and even to customer and supplier locations, IT managers need to take the necessary steps to achieve high applications availability throughout the enterprise.

Power availability is the largest single component of systems availability and is a measure of how much time per year a computer system has acceptable power. Without power, the system, and most likely the application, will not work. Since power problems are the largest single cause of computer downtime, increasing power availability is the most effective way for IT managers to increase their overall systems availability. Power availability, like both systems and applications availability, has two components: mean time between failures (MTBF) and mean time to repair (MTTR). The two most important issues in increasing power availability are therefore increasing the MTBF and decreasing the MTTR of the power protection system.

Increasing MTBF

MTBF Definitions

MTBF figures for a UPS ($MTBF_{UPS}$) have little value unless they are given with values for the mains supply ($MTBF_{MAINS}$) and the Mean Time To Repair for the UPS ($MTTR_{UPS}$).

Value	Definition
$MTBF_{UPS}$	Calculated using of field statistics and on calculations of the MTBF of all the UPS component parts based on a recognised standard e.g. MIL-HDBK-217F. A high quality UPS will have figures in the region of: $MTBF_{UPS}$ Single UPS = 125,000 hours Parallel Redundant (1+1) UPS = 1,250,000 hours Parallel Redundant (4+1) UPS = 500,000 hours $MTTR_{UPS}$ = 6 hours $MTBF_{MAINS}$ = 50 hours (*Refer to Chapter 2*)
$MTTR_{UPS}$	Is the elapsed time from the error acknowledgement until repair is completed. MTTR depends on many factors such as size and quality of the service organisation, availability of spare parts, UPS diagnostic system etc.
$MTBF_{MAINS}$	Mains quality is an important factor when calculating $MTBF_{UPS}$ values. An average good quality mains supply has an $MTBF_{MAINS}$ = 50 hours (*Refer to Chapter 2*)
Bath Tub Curve	Displays failure rate as a function of time. There are three distinct periods on the curve: Early Failure Period Constant Failure Period Wear Out Period
Reliability Diagram	An event diagram which gives an answer to the question “which elements of the system must continue to operate in order to maintain the desired function and which may fail?” (redundancy).

Failure Rate (λ)

Failure Rate is the probability that a system which has operated to a certain time t will not fail in the following time interval (t, t + Dt).

$$\lambda = \frac{1}{MTBF}$$

MTBF is the average number of hours it takes for the power protection system to fail. The MTBF of the system can be increased in two ways: by increasing the reliability of every component in the system, or by ensuring that the system remains available even during the failure of an individual component. There is a finite limit to how reliable individual components can get, even with increased cost. Today, typical power protection systems that rely only on high component reliability achieve MTBF between 50 000 hours and 200 000 hours.

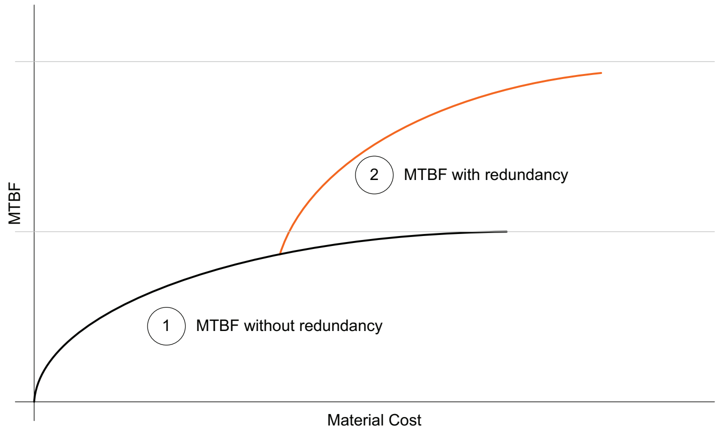


Figure 11.7: The diminishing returns of component reliability

By adding a level of redundancy to the system it is possible to achieve a three- to six-fold improvement in MTBF for power protection devices. Redundancy means that a single component of a power protection system can fail and the overall system will remain available and protect the critical load.

Of course, component reliability is a requirement of any system. However, Figure 11.7 shows the diminishing returns of increasing component reliability. Line 1 shows the plateau that occurs when MTBF is increased by using more reliable (and therefore more costly) components. Line 2 shows how redundancy, in addition to component reliability, can raise MTBF to the next plateau.

Decreasing MTTR

One way that systems downtime can occur is when both the power protection system and the utility power fails. A shorter MTTR can decrease the risk that both of these events will occur at the same time. By driving the MTTR towards zero, it is possible to essentially eliminate this failure mode.

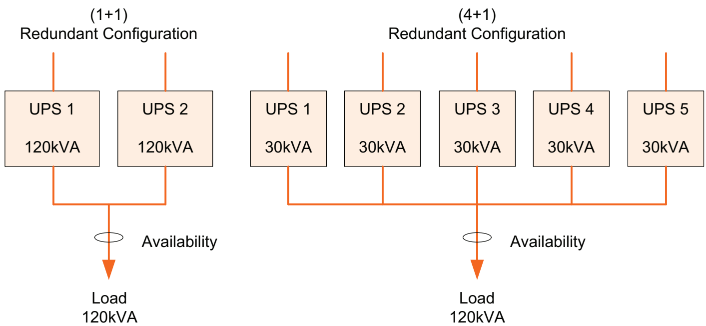
Adding hot-swappability to a power protection system is the most effective way of decreasing MTTR. Hot-swappability means that if a single component fails, it can be removed and replaced by the user while the system is up and running. When hot-swappability is used in conjunction with a redundant system, MTTR is driven close to zero, since the device is repaired when there is a component failure but before there is a systems failure.

Availability (A)

Availability is a useful measure (downtime per year) for systems subject to failure and repair; it is defined as the probability that the system is operational at time t.

$$A = \frac{MTBF}{MTBF + MTTR}$$

Sample Availability Calculations



This example compares the calculated Availability (A) of the two UPS system configurations shown above.

As stated previously the Availability (A) of a UPS is defined as:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Taking sample figures from page 190:

Example 1	**(1+1) Parallel Redundant Configuration Free standing UPS units**	**(4+1) Parallel Redundant Configuration Free standing UPS units**
MTBF	1,250,000h	500,000h
MTTR	6h	6h
Availability	99.9995%	99.9988
Assumptions: MTBF of the (1+1) system is higher than that of the (4+1). MTTR is 6 hours for each configuration. Results: Availability of the (1+1) system is higher than that of the (4+1).		

Example 2	**(1+1) Parallel Redundant Configuration Free standing UPS units**	**(4+1) Parallel Redundant Configuration Rack mounted UPS units**
MTBF	1,250,000h	500,000h
MTTR	6h	0.5h
Availability	99.9995%	99.9999%
Assumptions: MTBF of the (1+1) system is higher than that of the (4+1). MTTR of the (4+1) system is shorter than that of the (1+1), achieved using rack mounted modular UPS units. Results: Availability of the (4+1) system is higher than that of the (1+1).		

The examples show the importance of the MTTR figure if high availabilities are required. If a UPS module should fail in either of the samples shown, the systems are immediately non-redundant and rapid repair or replacement of the faulty UPS is essential.

Example 2 has a much reduced MTTR figure and hence higher availability as it uses modern, rack mounted modular UPS units (See Chapter 6 and Chapter 7).

This pair of examples illustrates the move away from the, rather futile, search for a total reliability to the more easily attainable, fault tolerant system.

High Nines

In the previous examples the availability figures are shown as percentages. Recent attention to availability calculations has resulted in an additional expression; "high nines". A lot of work in this area has been initiated by the Uptime Institute® (www.upsite.com) and "high nines" has become an accepted standard to express availability.

"Nines"	Availability (%)	Down Time per annum
Two	**99**	87.5 hours
Three	**99.9**	8.75 hours
Four	**99.99**	52.5 minutes
Five	**99.999**	5.5 minutes
Six	**99.9999**	32 seconds

Data Centre Tier Rating

The availability figures given previously relate only to the UPS components, which, when considering a complete installation, can only give part of the picture. The Uptime Institute® has suggested a tiered approach to data centre availability and this specifies various system attributes for each tier. A comprehensive white paper, "Tier Classifications Define Site Infrastructure Performance", is available from their website and some extracts are included here (see *"Further Reading" on page 279*):

Determining a Site's Tier Rating for Design Topology				
Tier Requirement	**Tier 1**	**Tier II**	**Tier III**	**Tier IV**
Source	System	System	System	System + System
System Component Redundancy	N	N+1	N+1	Minimum of N+1
Distribution Paths	1	1	1 normal and 1 alternate	2 simultaneously active
Compartmentalisation	No	No	No	Yes
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerance (single event)	No	No	No	Yes

Simply put, the Tier rating for an entire site is limited to the rating of the weakest subsystem that will impact site operation. For example, a site with a robust Tier IV UPS configuration combined with a Tier II chilled water system will yield a Tier II site rating. This is driven by the need to manage perception in senior management, as well as to factually report actual site capabilities. If a site is advertised within an organization as being fault tolerant and concurrently maintainable (Tier IV), it is intolerable to shut the site down at any time in the future—regardless of what subsystem may have required the shut down.
There are no partial or fractional Tier ratings. The site's Tier rating is not the average of the ratings for the 16 critical site infrastructure subsystems. The site's tier rating is the LOWEST of the individual subsystem ratings.
Similarly, the "Tier" cannot be imputed by using calculated Mean Time Between Failure (MTBF) component statistical reliability to generate a predictive availability and then using that number to "match" the actual measured availability results shown later in Figure 2. Even if statistically valid component values existed (and they don't because product life cycles are getting shorter and shorter and no independent, industry wide database exists to collect failures), this approach fails to include people which consistently are involved in 70% of all site failures. A calculated reliability of 0.9999 which ignores human interaction does NOT define a site as being Tier IV. The only way to determine Tier Level is to objectively determine a site's ability to respond to planned and unplanned events.

Tier I: Basic Site Infrastructure

The fundamental requirement

- A Tier I basic data centre has non-redundant capacity components and single non-redundant path distribution paths serving the site's computer equipment.

The performance confirmation test(s)

- Any capacity component or distribution path failure will impact the computer systems.
- Planned work will require most or all of the systems to be shut down, impacting the computer systems.

The operational impact

- The site is susceptible to disruption from both planned and unplanned activities.
- The site infrastructure must be completely shut down on an annual basis to safely perform necessary preventive maintenance and repair work. Urgent situations may require more frequent shutdowns. Failure to perform this maintenance work increases the risk of unplanned disruption as well as the severity of the consequential failure.
- Operation errors or spontaneous failures of site infrastructure components will cause a data centre disruption.

Tier II: Redundant Capacity Components Site Infrastructure

The fundamental requirement

- A Tier II data centre has redundant capacity components and single non-redundant distribution paths serving the site's computer equipment.

The performance confirmation test(s)

- A capacity component failure may impact the computer equipment.
- A distribution path failure will cause the computer equipment to shut down.

The operational impact

- The site is susceptible to disruption from both planned activities and unplanned events.
- Redundant UPS modules and engine generators are required.
- The site infrastructure must be completely shut down on an annual basis to safely perform preventive maintenance and repair work. Urgent situations may require more frequent shutdowns. Failure to perform this maintenance work increases the risk of unplanned disruption as well as the severity of the consequential failure.
- Operation errors or spontaneous failures of site infrastructure components may cause a data centre disruption.

Tier III: Concurrently Maintainable Site Infrastructure

The fundamental requirement

- A concurrently maintainable data centre has redundant capacity components and multiple distribution paths one distribution path serves the computer equipment at any time.

The performance confirmation test

- Each and every capacity component and element of the distribution paths can be removed from service on a planned basis without causing any of the computer equipment to be shut down.

The operational impact

- The site is susceptible to disruption from unplanned activities.
- Planned site infrastructure maintenance can be performed by using the redundant capacity components and distribution paths to safely work on the remaining equipment.
- In order to establish concurrent maintainability of the critical power distribution system between the UPS and the computer equipment, Tier III sites require all computer hardware have dual power inputs as defined by the *Institute's* Fault Tolerant Power Compliance Specifications Version 2. Devices such as point-of-use switches must be incorporated for computer equipment that does not meet this specification.
- During maintenance activities, the risk of disruption may be elevated.
- Operation errors or spontaneous failures of site infrastructure components may cause a data centre disruption.

Tier IV: Fault Tolerant Site Infrastructure

The fundamental requirement

- A fault tolerant data centre has redundant capacity systems and multiple distribution paths simultaneously serving the site's computer equipment.
- All IT equipment is dual powered and installed properly to be compatible with the topology of the site's architecture.

The performance confirmation test(s)

- A single worst-case failure of any capacity system, capacity component or distribution element will not impact the computer equipment.
- Each and every capacity component and element of the distribution paths must be able to be removed from service on a planned basis without causing any of the computers to be shut down.
- In order to establish fault tolerance and concurrent maintainability of the critical power distribution system between the UPS and the computer equipment, Tier IV sites require all computer hardware have dual power inputs as defined by the Institute's Fault Tolerant Power Compliance Specifications Version 2. Devices such as point-of-use switches must be incorporated for computer equipment that does not meet this specification.
- Complementary systems and distribution paths must be physically separated (compartmentalized) to prevent any single event from impacting both systems or paths simultaneously.

The operational impact

- The site is not susceptible to disruption from a single unplanned worst-case event.
- The site in not susceptible to disruption from any planned work activities.
- The site infrastructure maintenance can be performed by using the redundant capacity components and distribution paths to safely work on the remaining equipment.
- During maintenance activities, the risk of disruption may be elevated.
- Operation of the fire alarm, fire suppression, or the emergency power off (EPO) feature may cause a data centre disruption.

Work by the Uptime Institute shows beyond doubt that traditional reliance on manufacturers figures does not always provide the best approach to system reliability and availability.

Traditional non-redundant, non fault tolerant UPS systems and solutions **cannot** provide reliable power supplies at the availability levels currently demanded by business critical systems.

TIA-942 Standard
Reference can be made to the TIA-942 standard developed by the Telecommunications Industry Association (TIA) to define guidelines for planning and building Data Centres, particularly with regard to Data Centre infrastructure and power management.

Power Availability (PA) Chart

The relationship between power availability, redundancy, and hot-swappability is easily explained by using the PA Chart, which categorises power protection systems in quadrants according to how well they meet the requirements of high power availability – redundancy and hot-swappability. As more components in a system become hot-swappable, the system moves from the bottom to the top of the graph (Figure 11.8), and as more components become redundant, it moves from the left to the right of the graph. IT managers can choose the solution that is right for them, depending on the need for high availability and the amount of money they want to spend.

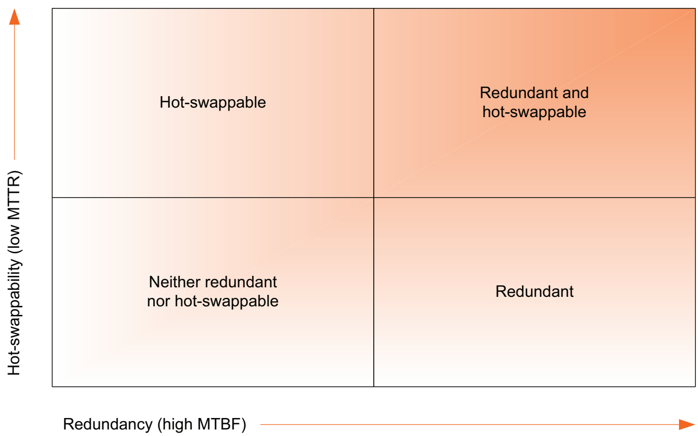


Figure 11.8: Systems categorised by how well they meet the requirement of high power availability

The PA Chart corresponds to the types of power protection systems available today as shown in Figure 11.9. The standalone UPS is neither hot swappable nor redundant. As shown in the table, a standalone UPS provides normal power availability because uptime is dependent on the reliability of the UPS itself.

The fault tolerant UPS is sometimes described as providing affordable redundancy. Systems of this type have redundant components but not all of the major components are hot-swappable. This type of system offers high power availability because the power protection system will continue to protect the load when a component fails. But because a failed component often results in the entire UPS needing replacement, this type of system can have serious drawbacks, including expensive and time-consuming repair with both systems downtime and a major inconvenience for IT managers. Fault tolerant UPS systems may have some hot-swappable components, such as batteries and a subset of power electronics, but in most cases a high number of critical components, such as the processor electronics, will not be hot-swappable.

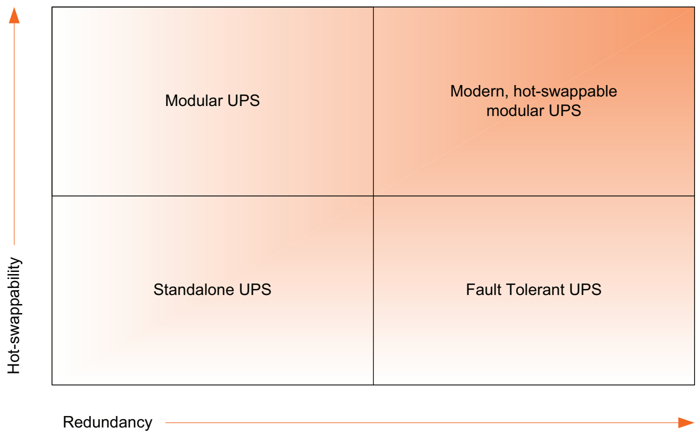


Figure 11.9: Types of UPS mapped onto the PA Chart

Like fault-tolerant UPS, modular UPS offer high power availability. Modular UPS have multiple hot-swappable components and are typically used for multiple servers and critical applications equipment. Many modular UPS also have redundant batteries. Their main advantage over fault-tolerant UPS is that all of the main components which can potentially fail can be hot-swapped, eliminating planned downtime due to a service call.

The modern, modular UPS offers the highest level of power protection currently available where the power electronics, batteries, and processor electronics are both redundant and hot-swappable. This system provides very high power availability and the highest level of protection for IT managers' critical loads.

Power Availability (PA) Index

The different types of power protection systems in the PA Chart can be measured linearly with the PA Index, according to the power availability they provide. The PA Index is a tool to explain the difference between power protection systems. Figure 11.10 shows each of the quadrants from the PA Chart mapped into a level of the PA Index.

Power Availability Index	Definition	Power Availability
PA-1	Not hot-swappable and not redundant	Normal
PA-2	Redundant but not hot-swappable	High
PA-3	Hot-swappable but not redundant	High
PA-4	All main components are redundant and hot-swappable	Very high

Figure 11.10: Quadrants of the PA Chart mapped into a level of PA Index

Figure 11.11 shows the relative power availability provided by each type of system. The PA Index maps directly into the PA Chart and makes the different characteristics of high availability power protection systems clear.

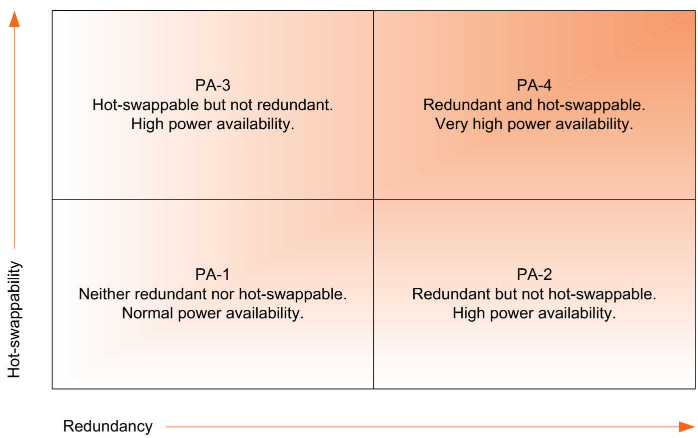


Figure 11.11: The PA Index mapped into the PA Chart

Summary

The PA Chart and the PA Index help to choose the right power protection system for high availability applications.

The standalone UPS, the modular UPS, and the modern, hot-swappable, modular UPS all offer real benefits in terms of power availability versus cost.

Although fault-tolerant UPS offer high power availability – and are marketed as such – they introduce serious drawbacks including a high MTTR and potentially significant inconveniences for IT managers.

The latest UPS designs are cost effective because they are:

- very efficient - kinder to the environment
- electrically very clean (low input current THD)
- quiet
- physically smaller
- have no requirement for 6/12 pulse rectification.

Conclusion

Think about the future - installing a modular, upgradeable, UPS system may cost slightly more initially but will save significant costs in the future so before deciding on a particular UPS configuration, consider:

- possible future load growth – plan for upgrading at the start, consider installing several smaller paralleled UPS instead of one large single unit
- flexibility of smaller lighter units which can easily be moved when the company moves or expands
- a quality UPS should have a useful working life at least 10 years if it is well maintained (*See "System Maintenance" on page 239*)
- paralleling for ultimate reliability and high availability may prove to be a very good investment.

Environmental Considerations

Heat

All UPS manufacturers will quote a maximum operating temperature for their equipment (typically +40°C). The air conditioning plant must have sufficient capacity to maintain the conditions stated. Obviously the overall efficiency of the UPS will have a significant effect on both the size and the operating cost of the air conditioning plant. -

If the UPS batteries are installed in the same room as the UPS, check the air cooling system is able to keep the ambient temperature at a level suitable for the batteries.
(*See "Energy Storage Devices" on page 115*)

Humidity

Again the UPS manufacturer will state maximum permissible relative humidity levels (typically 95%). Whilst most UPS equipment is well designed, high relative humidity levels may promote corrosion of cabinets and internal parts. Simple dehumidification equipment is available for sites where this may be a problem.

Audible Noise

The unit of sound intensity is the decibel (dB) and it represents the ratio between the sound level measured with a microphone and a reference sound level, 0db, which is defined to be approximately equal to the threshold of human hearing. However as the human ear is less sensitive to very low and very high frequencies, an additional ‘A’ filter is applied when measuring background or other intrusive noises, hence the dBA unit used by all UPS manufacturers.

Typical audible noise figures for fully loaded UPS equipment range from 50dBA for 5 kVA to 75dBA at 300 kVA.

Figure 11.12 shows some examples of relative sound intensity.

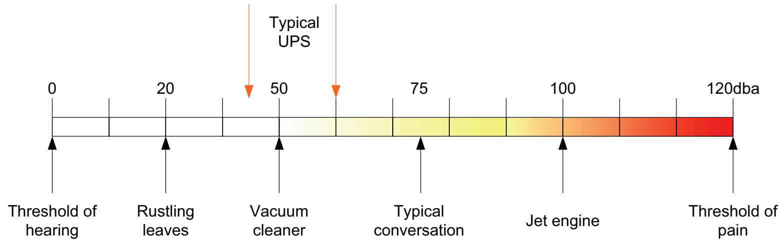


Figure 11.12: Relative Sound Intensity

The acceptable audible noise for any UPS depends on the application and installation location. Check the manufacturer's quoted level to ensure the installation will create the minimum disturbance.

Energy Use and Efficiency

Recent studies of the impact of energy use on the world climate and the anticipated arrival of legislation to improve the efficiency of such usage has led to increased public and corporate awareness of terms such as: Carbon Emissions, Greenhouse Gas and Global Warming.

Companies and Corporations, increasingly keen to emphasize their "green credentials", are including sound environmental practices in their operational policies and often include environmental achievements in Annual Reports.

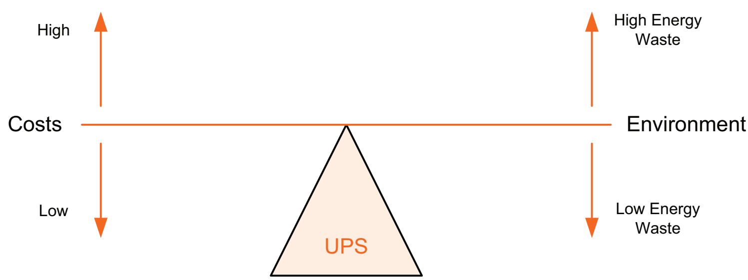


Figure 11.13: Balancing costs and environment

Carbon Emissions

The majority of the electricity generated in the UK is fueled by the fossil fuels, coal or natural gas.

Figures obtained for Q3 2012 show:

- 35.4% Coal
- 28.2% Gas
- 22.3% Nuclear
- 11.7% Renewables
- 0.9% Oil
- 1.6% Other

Saving Energy

Choosing the correct UPS system to support a connected critical load is not simply a matter of matching the output power to that load. The solution must also take into account, reliability, availability and expandability among others. Changes in the way UPS systems are designed and made have also highlighted the benefits to be gained by installing modular, transformerless units. These modern UPS provide new ways to save energy and thus cost over the lifetime of the system including. Rightsizing the UPS system over time, higher UPS efficiency for partial loads, lower cooling requirements and improved input power factor and input current total harmonic distortion.

Rightsizing

Rightsizing refers to selecting an appropriate UPS to support the load at any point in time. Until recently it was common practice to size a UPS to cope with the current load and any anticipated growth.

Example 1 - Traditional Approach

The graph in Figure 11.14 shows an initial expected system load of 35% of the data centre capacity and it is expected that the load will grow over 10 years to approach 90%. In the case shown a UPS system capable of supplying the projected 90% load is installed.

Although the UPS has supported the load, the shaded area on the graph shows it has been utilized very poorly and has been seriously oversized from the start.

In this example, the UPS system is never more than about 35% loaded and this has a serious impact on the efficiency.

A legacy UPS has a maximum efficiency of about 93% when fully loaded, dropping to about 90% at 50% loading and even less at the levels shown in the graph.

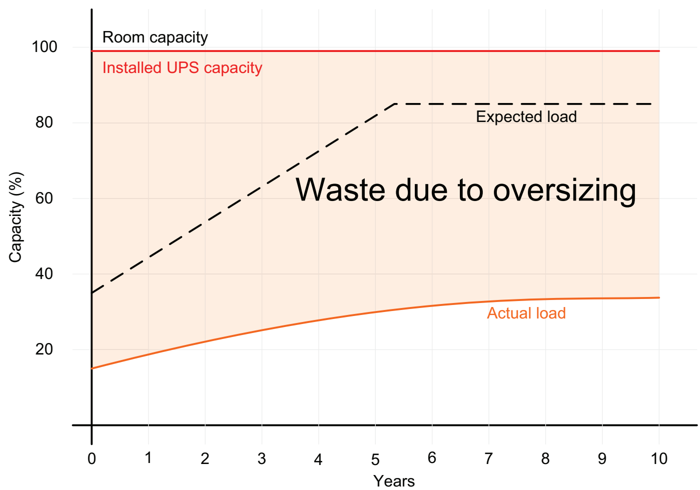


Figure 11.14: Traditional sizing method

Example 2 - Modular Approach

The graph in Figure 11.15 shows the same initial expected load and growth rate. This time the initial load is used as the UPS sizing start point and a modern, modular UPS is chosen. As the load grows, the UPS can be upgraded by adding modules (without increasing the UPS footprint) and the system utilization is greatly improved.

A modern, modular, transformerless design UPS has a maximum efficiency of about 96% when fully loaded and this drops to about 95% for loads between 25% and 75%.

Correct UPS sizing from the outset is vital to achieve minimum capital outlay and maximum power savings throughout the useful life of the system.

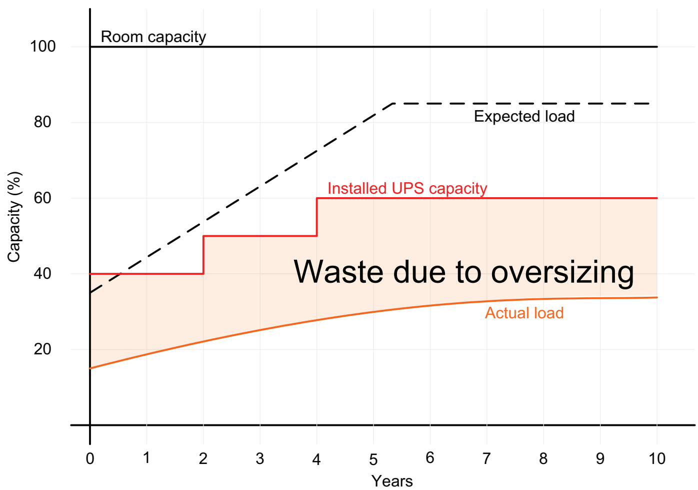


Figure 11.15: Modern sizing method

Manufacturers have acknowledged that in resilient, and hence redundant, UPS configurations the UPS units will never be operating at 100% of their capacity. For example in a single n+1 system with two UPS units operating in parallel and equally sharing the load their maximum operating percentage will be 50% of their individual capacity. Hence manufacturers have shifted the maximum efficiency performance to the actual point of use. Therefore each UPS now will be most efficient generating at 50% rather than at the usually stated 100%.

The concept of right sizing also brings into consideration the idea of granularity. With modern transformerless design UPS units, with their associated 'flat' efficiency curves, the question is “what load steps do I require for my critical IT system?”. For a small to medium-sized data centre, an IT room of say 200 to 500kVA, then the UPS system which increments in 50 kVA modules may be ideally suited. However if the data centre is a large facility of several megawatts then large incremental steps of say 500 kVA would be more appropriate.

Hence the concept of modularity takes into distinct meanings:

1. Slot in/pull out UPS modules contained a in a ‘mother’ frame.
   or
2. Large capacity stand-alone UPS units configured in a modular topology.

Whichever system is most suitable is a combination of facility size, granularity, coupled with high efficiency UPS units. The increased growth of transformerless designed UPS units is testament to the drivers of high efficiency and CSR to be environmentally responsible.

Partial Load Efficiency

There are, of course, many legacy systems in current operation which do not take advantage of the higher efficiencies afforded by the modern transformerless design. Although initial CAPEX may be a little lower, the OPEX's associated with an inefficient system design and transformer based UPS units will soon far outweigh any initial cost savings

The following table shows the comparative running costs for a parallel redundant UPS installation to support a load of 96kW (120kVA @ 0.8 pf) using both methods.

UPS Details	Legacy (2 x 120kVA) 120kVA N+1	Modular Transformerless (4 x 40kVA) 120kVA N+1
Load (%)	50	75
Efficiency (%)	91	94.5
Critical Load (kW)	96	96
Total UPS Input Power (kW)	106	102
Total UPS Heat Loss (kW)	10	6.0
UPS Losses - Cost per Year*	£7,884	£4,730
Cooling Cost per Year*	£5,380	£907
Total Losses + Cooling Cost per Year*	**£13,264**	**£5,637**
Cost of ownership SAVING over FiveYears		**£38,135**

** Costs based on 9.0 p/kWh*

Total Cost of Ownership

It is important to measure the total cost of ownership (TCO) in order to predict how the investment will be paid back. In the case of a data centre, the individual cost factors involved in protecting the investment include the necessary infrastructure for providing power, cooling and IT equipment protection.

Total cost of a UPS system depends not only on the purchase price but also on:

- capital cost including the purchase price and transportation costs
- building/footprint costs including installation cost, power density (kVA/sq m), and security concept (redundancy, availability)
- operating costs, including energy costs, cooling system energy losses, maintenance, training for maintenance, and spare parts stock
- upgrade costs.

The major contribution to the total cost of a data centre is usually an oversized or inefficient UPS system (*See "Rightsizing" on page 204*). Taking the case of a UPS system with a load of 80kVA, total costs and performance of a traditional UPS system are compared with those of an advanced modular UPS system. For optimum availability, a parallel redundant solution (n+1) is selected. A traditional parallel configuration of two 80kVA UPS is compared with an advanced modular parallel configuration of three 40kVA UPS (Figure 11.16).

Load: 80kVA	UPS Design	Configuration	Battery
Traditional		Parallel 2 x 80kVA (1+1) redundant	Mounted within UPS cabinet
Modular		Parallel 3 x 40kVA (2+1) redundant	Mounted within UPS cabinet

Figure 11.16: Comparison of configurations of traditional and modular

Capital Cost

Purchase Price

The purchase price of a traditional UPS system would typically be less than that of an advanced modular UPS system. However, the purchase price is not the only decisive factor when considering overall costs. The lower purchase price of traditional UPS technology must be offset against significantly higher operating costs in comparison with a modular system based on technology which reduces energy loss costs. The higher cost of the modular system is recovered within the first year of operation. A comparison of additional long-term costs also favours modular technology (*See page 208*).

Transportation Cost

A traditional UPS is usually built with an output transformer, which implies a total weight up to two or three times higher than that of a transformerless UPS system. This weight difference can increase transport cost by 100 percent or more (Figure 11.17).

System (80kVA, n+1)	Tot. Weight (inc Batts)	Gross Volume	Transport Cost
Traditional (1 +1)	~ 2 x 1150kg	2x (97x182x75)cm = 2.6m^3	226%
Modular (2 + 1)	~ 379kg	1x (73x197x80)cm = 1.15m^3	100%

Figure 11.17: Transport costs dependent upon weight and volume

Building/Footprint Costs

The traditional UPS system based on two UPS units typically needs two to three times the amount of floorspace in m^2 required for an advanced modular UPS.

System (80kVA, n+1)	Footprint	KVA/m^2	Installation Cost
Traditional (1 +1)	2x(97x75)cm=1.44 m^2	160kVA/1.44m^2 = 111	186%
Modular (2 +1)	1x (73x80cm=0.58 m^2	120kVA/0.58m^2 = 206	100%

Figure 11.18: Installation and footprint costs

Security Concept (Redundancy, Availability)

System availability is dependent on the mean time between failures (MTBF) and, even more, on time to repair in the event of a failure, mean time to repair (MTTR). In modular UPS systems, MTTR can be up to 12 times less in comparison with traditional UPS systems because a module can be quickly exchanged without load interruption, increasing the total availability of the UPS system to 0.999999 (6 nines).

Figure 11.19 illustrates how system MTBF and MTTR affect the availability of two seemingly equivalent systems and shows the MTBF of the non-modular system as being higher than the modular system simply because it comprises two rather than three UPS. If the MTTR of the non-modular and modular systems were the same (for example, six hours) then the non-modular system would have the higher availability (because of the higher MTBF). However the MTTR of the modular system is much lower at 0.5h and has a positive effect on the system availability.

	Traditional (1+1) redundant system	Modular (2+1) redundant system
MTBF	1250,000h	833333h
MTTR	6h	0.5h
Availability = $\frac{MTBF}{MTBF + MTTR}$	0.999995 (5 nines)	0.999999 (6 nines)

Figure 11.19: Comparison of system availability

Operating Costs

Spare Part Stock, Logistics and Exchange

Traditional UPS systems are not built as system-modules and therefore it is very difficult to propose a cost-efficient spare part package. For security reasons, often the most extensive and expensive spare parts kit will be selected. Even then, there is no guarantee that the spares kit will be effective or contain the part required for any or all failures which could arise, and there is a time overhead for stock management and logistics.

The hot-swappable technology of a modular system eliminates the complication of choosing the right spare parts kit. All that is required is a single replacement module, and even when there are different power ranges in operation, holding the highest kVA-rated module as a spare covers all eventualities. Trained personnel can swap modules within 15 minutes.

Through the use of spare modules, it is possible to save up to 50 percent on logistics and stock management costs.

Training Costs

If there are many different types of UPS systems within a company, training for each individual system is time consuming and costly. In contrast, modular systems over a wide range of output powers will have the same architecture and mode of operation.

The know-how gained by training on one UPS module system can be applied to other UPS module systems without additional training.

Upgrade Cost

Upgrading a traditional UPS demands extra space, costly cabling and involves taking the UPS off line during the upgrade.

With a modular UPS, the upgrade is performed by simply inserting the additional power modules into the rack. For example, three 20kVA modules may be replaced by three 30kVA modules, provided the system's distribution and frame has been specified for the maximum foreseeable requirement. Such upgrades can be performed without any interruption to the load, without increasing the footprint, and with no additional work on site. This flexibility makes upgrading a system very easy, and with very little additional cost.

Installing the UPS

Delivery and Positioning

The importance of planning the installation and delivery of the UPS system cannot be overstated. Having chosen a particular system and topology it is important to decide:

- will the system fit into the space reserved for it?
- is the proposed location suitable?
- how will the system be transported to the location?

Size & Weight

Improvements in UPS technology and design have provided much higher power densities which, when combined with the flexible installation options for modern parallel systems, make it much easier to find space for UPS systems. Also, because the most modern designs no longer need bulky and heavy input transformers, installation of very powerful UPS systems is no longer limited to the ground floor or basement plant room.

The manufacturer or supplier will provide details of space requirements and details of module weights in the UPS system specification (*See "Introduction" on page 283*).

> Be sure to consider possible future expansion when choosing a UPS location and if you can allow extra space over and above the manufacturer's recommended minimum, maintenance and service will be easier.

A UPS system is not just a big battery box. It contains electronic components similar to those found in computers and therefore requires careful handling when being transported. Additionally, large UPS equipment will be heavy and unwieldy and will require specialist contractors using 'air-ride' suspension vehicles and specialised lifting equipment to unload and position it. The UPS supplier should be able to recommend handling procedures and suitable contractors with experience in this field.

Choosing a Suitable Location

The choice of a particular installation location for the UPS depends on many things:

- how much space is available?
- can the floor safely support the weight of the equipment?
- will the installation cause continued inconvenience to the existing personnel and business?
- are the environmental conditions at the chosen location suitable?
- can access to the UPS equipment be made secure yet convenient?
- does the UPS comprise one module or several in parallel?
- what is the effect of the installation on existing air flow and air conditioning equipment?
- will the switchgear controlling the UPS be in the same area?
- can the chosen area safely accommodate the battery installation?

In general the location chosen for modern UPS can be summarised as follows:

Small UPS – less than about 20kVA, can be installed in a normal office environment although care should be taken to ensure that the additional noise and heat does not adversely affect the office environment.

Medium UPS – between 20 and 100kVA are designed to be installed in computer rooms.

Free-Standing UPS – greater than 100kVA, will often be located either in a separate UPS room or in an existing plant room.

Modular Rack Format UPS – between 20 and 250kVA are designed to be installed in computer rooms or a suitable plant room.

Floors and Cable Entry

Most medium to large UPS require bottom cable entry and consideration needs to be given when the UPS is located on a solid floor, such as a typical plant room environment or a raised floor, such as a computer room.

Solid Floors

When locating the UPS on a solid floor, provision needs to be made to permit the input and output AC cables, and the battery DC cables, to run beneath the UPS for connection to the UPS terminals. This can be facilitated by either making a cable trench available within the floor or locating the UPS cabinet on a steel plinth. The height of the plinth needs to be sufficient to enable satisfactory cable bend radius through 90°. This is particularly important for large UPS using large cross sectional area cables.

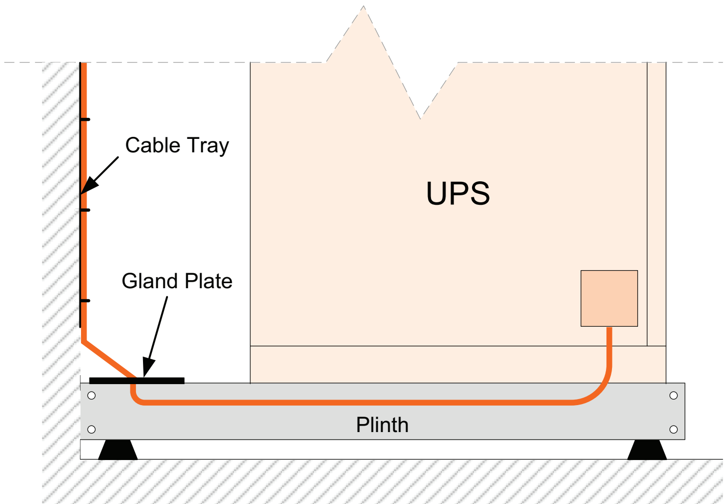


Figure 11.20: Top Cable Entry Using a Plinth

A steel plinth also serves as a convenient means of glanding steel wire armoured (SWA) cables and to facilitate top cable entry as shown in Figure 11.20. Some UPS manufacturers offer a side extension cable-way or busbar chamber to enable top cable entry but this tends to be costly and increases the UPS floor area.

Raised Floors

If the UPS is to be located in the computer room then more often than not the floor is raised off the sub-floor to permit containment and access for computer equipment network and power cabling, and also sometimes as a means to provide under floor cooling. The raised floor therefore provides a convenient method for gaining bottom access to the UPS for the input and output AC cables, and the battery DC cables. However, UPS equipment can be very heavy, particularly if the batteries are also to be located in the computer room either in the UPS cabinet or in separate matching battery cabinets.

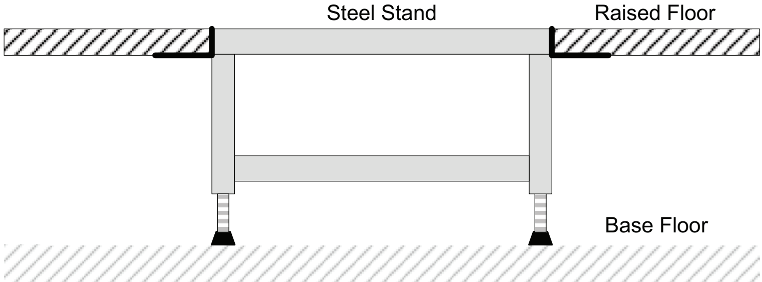


Figure 11.21: Raised Floor

To remove the potential stresses and single point loadings on the raised floor it is normal practice to locate the UPS cabinet, and if applicable the battery cabinet(s) on a steel stand that sits on the sub-floor within the floor void as shown in Figure 11.21. The height of the stand is adjustable so that it can accommodate any unevenness in the sub-floor and to ensure the top of the stand is accurately in line with the top of the raised floor. The stand would normally be provided with a rebate around the top periphery to support adjacent floor tiles which may need to be cut back into position.

Transporting the System

Having chosen a suitable location for the UPS system it is vital to survey the proposed site. If a specialist delivery contractor has been employed for the task they will usually undertake a site access survey before attempting to deliver any equipment.

Even if the location chosen for the installation could in fact accommodate an additional three or four UPS, access to the area may prove problematic.

Check the access route:

- is the site easily accessible by road? Bear in mind the size of the delivery vehicle and the equipment required to off-load the UPS.
- are all doorways large enough for the UPS equipment and any transportation equipment to pass through?
- ensure the equipment can be moved along the entire route especially around corners
- will the UPS need to be carried across soft or uneven surfaces?
- are there stairs between the off-loading point and the final location?
- if the equipment must be transported using a goods lift, check that the lift has the required capacity
- ensure that site staff are aware the equipment is being delivered and have made every effort to ensure that access along the route is unhindered on the day of delivery.

Electrical Installation

Installation Contractors

Electrically installing a UPS or protected power system is a specialised task and should only be performed by a qualified and experienced electrical contractor.

The supplier of the UPS equipment should be able to undertake the installation work or supply a list of suitable contractors who can provide references of previous installations.

Take the time to:

- check the credentials of the staff who will be installing the equipment
- contact and investigate previous installations and discuss their work with the staff on the other sites.

It is important to ensure that the installation is carried out in strict accordance with the supplier's instructions and that it complies with local and national electrical installation regulations.

Installation Design

Small and medium sized UPS equipment will probably require very little installation work and minimal changes to the existing electrical wiring. However, if larger, high-power UPS equipment is being installed then careful consideration of the switchgear and cabling arrangements must be made.

Considerable time and therefore cost savings can be made by carefully planning the electrical installation to allow for possible business growth and the addition of extra UPS modules.

Using an integrated switchgear and busbar solution, such as that shown in Figure 7.21 on page 109, makes the installation process for a modern parallel free-standing UPS system much simpler by:

- providing a single point of entry for the incoming mains supply
- a single point of entry for the bypass mains supply
- a fully interlocked maintenance (or wrap-around) bypass circuit
- correctly sized busbars and circuit breakers
- co-ordinated protection for the load and UPS equipment
- straightforward connection of load distribution panels.

Connecting the Critical Loads

In order to make best use of the UPS equipment and to ensure maximum protection of the critical load it is important to consider carefully how best to connect the load components.

Large ring circuits feeding many critical load devices are unsuitable as a fault on one device may cause the circuit feeding it to trip and consequently disconnect power to other pieces of important equipment.

Radial wiring with individual devices protected by their own circuit breakers is a far better approach – in this way a fault in one device will cause that device only to be disconnected and the remaining critical load elements will remain undisturbed.

To ensure satisfactory downstream discrimination for static UPS systems, it is generally recommended that sub-circuit protective devices are sized according to local regulations, as advised by an electrical contractor.

To avoid confusion, particular attention must be paid to the labelling of circuit breakers and fuses in the load distribution panels.

A selection of sample installation schematics is included in *"Installation Drawings" on page 229*.

External Maintenance Bypass Switch

Whether it is a single free-standing UPS or a multiple parallel UPS system it is good practice to allow for a separate external maintenance bypass switch (sometimes referred to as a “wrap-around” bypass switch). Most modern UPS incorporate an internal maintenance bypass switch which permits the electrical isolation of the UPS components for maintenance or repair (see page page 32 which illustrates the arrangement). However, it is desirable to allow the UPS to not only be electrically isolated but also physically isolated for the swap-out or move without disrupting the load. A suitably designed external maintenance bypass switch, as shown in the following figures, will facilitate this requirement.

Figure 11.22 and Figure 11.23 show examples of typical “single input” and “dual input” 3 phase external maintenance bypass switches

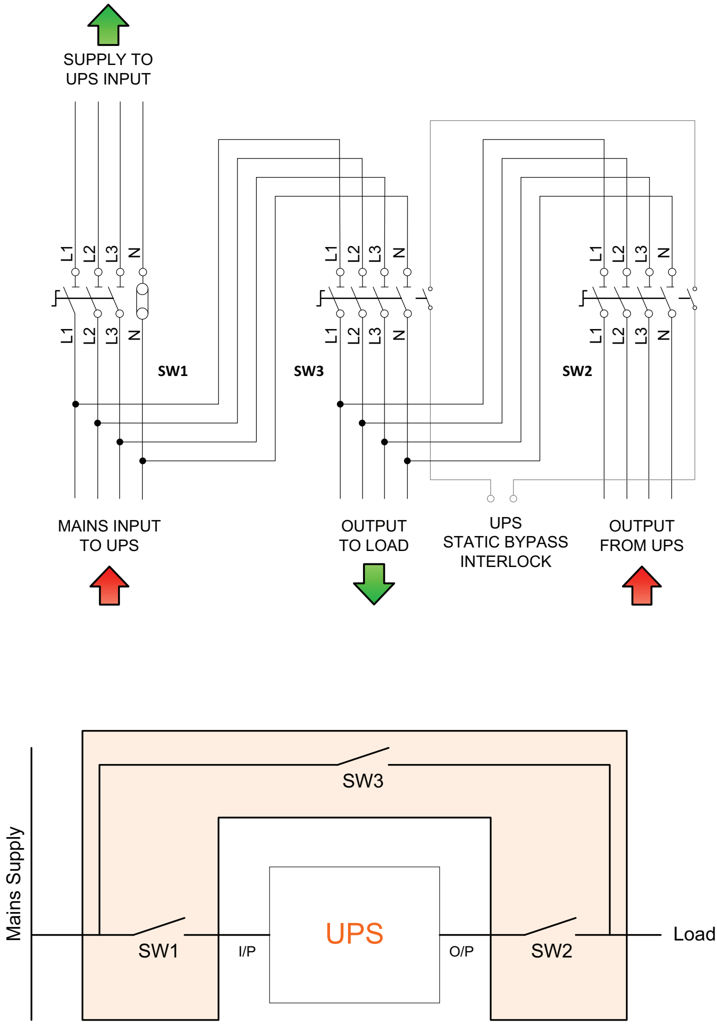


Figure 11.22: Single Input 3 Phase In/Out External Maintenance Bypass Switch

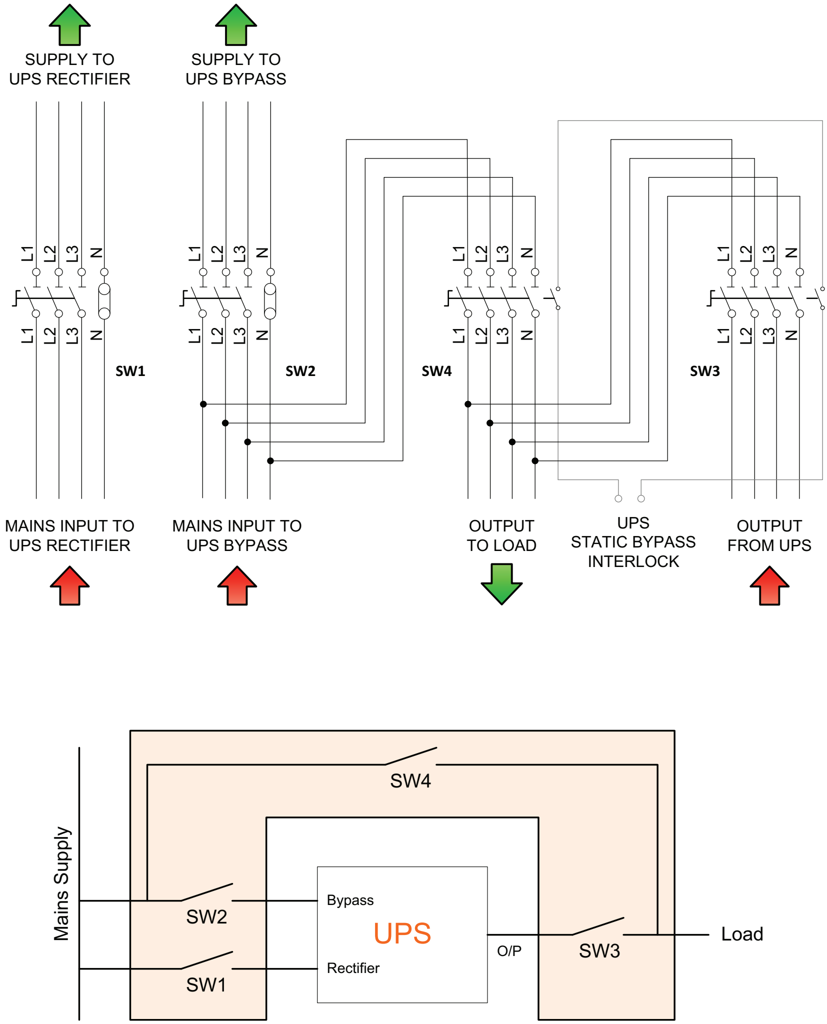


Figure 11.23: Dual Input 3 Phase In/Out External Maintenance Bypass Switch

Earthing

In any electrical installation correct earthing is essential for personnel safety and equipment protection. A protected power installation is no exception, it is essential to ensure that **all** earthing points within the system are connected to a properly planned and secure earthing system.

As a minimum a properly planned and secure earthing system for a computer and UPS installation must provide:

- protection against electrical shock
- a short, low impedance return path for fault currents
- a path for induced currents caused by high voltages such as lightning
- straightforward connection facilities for future expansion.

Most earthing installations are based on star or grid configurations.

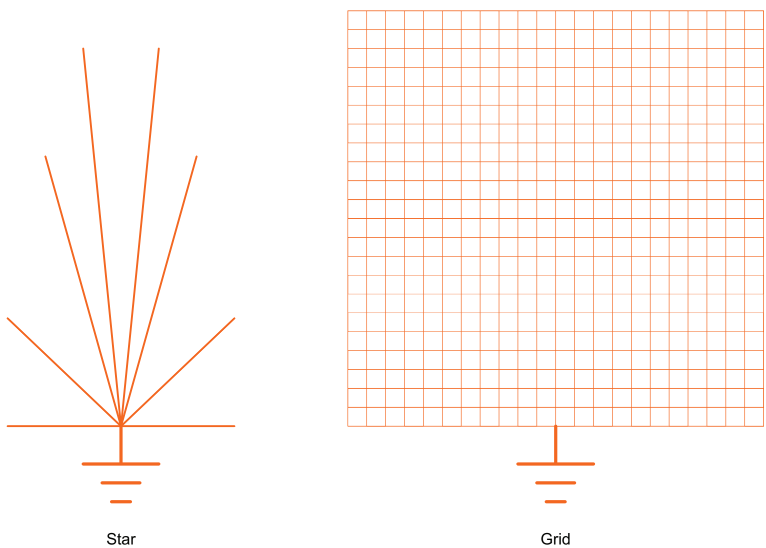


Figure 11.24: Basic Earthing Configurations

In the star system the earth conductor from the incoming mains supply is brought to a central point and radial earth conductors are distributed to each item of equipment whereas in the grid arrangement, the earth from the incoming mains supply is connected to a grid or 'mat' of earth conductors which is installed to cover the entire installation area.

Individual items of equipment may then be connected to the grid with very short conductors. The grid system is more difficult to install, although computer rooms with raised floors have made it easier, but it does offer advantages:

- the whole grid is at near earth potential
- the grid offers very low impedance to all frequencies
- equipment connection to the grid is simple.

However, the star system is much easier to install and is therefore the most common system in use.

Commissioning

Proper commissioning of UPS equipment by the supplier's trained and experienced personnel is essential. The small additional cost incurred is outweighed by the benefits of:

- complete check of system facilities and options
- complete warranty cover on all UPS equipment
- registration of equipment serial numbers with the supplier
- acceptance of environmental conditions
- the user being trained in the operation of the UPS.

A sample of a typical commissioning method statement is given on the following pages.

Sample Commissioning Method Statement

General Instructions

If any corrective measures are required to commission the UPS they shall be carried out under warranty and costs will be borne by the supplier and/or the manufacturer of the UPS. If any corrective measures are needed as a result of shipping or installation damage they shall be made only after liability for the damage is clearly established.

Customer Information

Record customer name and other customer details on the Field Service Report.

Unit Information

Take unit type and serial number details from type plate located inside the door or at the rear of unit and record on FSR.

Equipment Inspection

Check unit and options for damage both externally and internally. If any damage is found record the nature of the damage on the FSR and advise the customer.

Installed Options

Identify what options the customer has also purchased with the system and note on FSR.

Installation Checks

Common items

Check and tighten all external connections to UPS, battery and load.
Check phase rotation of ac and polarity of dc connections.
Check all protective earth connections for proper installation and cable area.
Check installation of service switch if fitted.

Rectifier/Converter, Bypass Line, Load

Check that cable area and fuses are correct according to installation manual.
Check that distribution fuses and cable area for distribution cables are correct according to connected loads.
Note cable areas and fuse ratings in commissioning report.

Computer Interface/Options

Check that installation and connections of all options are made according to the installation manual and customer requirements.

UPS Power Up

The following activities will be performed with live voltage at the UPS input and output terminals. Ensure all company Health & Safety procedures and guidelines are fully complied with at all times.

Line Voltage Rect/Conv

Connect line voltage to UPS Rect/Conv line and measure voltage.

Line Voltage Bypass

Connect line voltage UPS Bypass line and measure voltage.

Unit Started

Perform normal unit start up and check that unit is operating normally.

Output Voltage/Frequency

Measure output voltage and check output voltage waveform and frequency.

SYSTEM TEST

The following activities will be performed with live voltage at the UPS input and output terminals. Ensure all company Health & Safety procedures and guidelines are fully complied with at all times.

Front panel display and switches

Check that all LED's illuminate:
Check the MECHANICAL BYPASS switch. Transfer the load from the inverter via the static switch to the mechanical bypass switch. Check with an oscilloscope the UPS output voltage and check that the transfer is break-free.

Computer Interface

Test for the correct operation of the following alarms (if fitted):
- BATTERY LOW
- LINE FAILURE
- UPS BYPASSED
- UPS ALARM

Line Failure/Synchronisation Test

Look at the inverter output voltage and line voltage with an oscilloscope. Switch the bypass line input off and then back on. Check that the inverter synchronises with the bypass line after 10 sec. and that the phase angle is nominally zero degrees.

Starting Up and Shutting Down

Start up and shut down the UPS by following the start up and shut down procedures as described in the User's manual.

Function of Installed Options

Test the function of each of the options installed.

UPS Failure Test

Check that UPS transfers the load to the bypass line, when simulating trip of internal UPS fault. This test is only to be performed if there is no live customer load and the test can safely be performed on the UPS.

UPS Overload

Check (if possible) that UPS transfers the load to the bypass line, when the load is >100%.

Operator Training

During the Operator Training sessions make sure that the operators are acquainted with the user's manual and use it as the training material.

Operating Principles

Explain the operating principles of the UPS in general terms and in the UPS model specific terms. Explain also the function of all installed options.

- Normal operation
- Mains failure
- Overload
- Bypass switch (Static and Internal).

Safety Information

Review safety information as given in the user's manual and ensure that it is clearly understood.

Indications and Alarms

Review function and meaning of all indications and alarms.
Review function of computer interface and actions that shall be taken in the event of a mains failure.

Start and Stop Procedure

Review and let operators perform UPS start up and shut down procedures for the UPS by following the instructions in the User's manual.

Fault Diagnosis

Review the fault diagnosis activities based on the fault indications from the front panel as described in the User's manual.

Responsible for Operation and Maintenance

Check the name, title and telephone number of a person(s) responsible for the operation and/or maintenance of UPS and note in report.

Notes Record all relevant site/ unit comments in the notes section of the report and discuss each note with the customer.
Signatures Sign and ensure that the customer signs the FSR and the commissioning report. Give the customer a copy of both reports.

Micro and Mini UPS (250VA - 2kVA)

In general the Micro and Mini sized UPS are supplied fitted with standard mains plugs and will not require specialist commissioning. In most cases these UPS are portable and are supplied ‘ready-to-go’ and simply require unpacking and connecting to the mains supply and the load. However, some suppliers will offer to deliver and install the equipment and spend some time explaining the operation of the system.

The output connectors on these small UPS are usually standard IEC sockets, so it is important to ensure that suitable cables for connection of the load equipment are available. *See "Desktop Systems" on page 15.*

Medium UPS (3-20kVA)

Medium sized UPS are designed to support complete office networks or communications centres. They are not usually portable and are connected to the mains supply by fixed wiring.

Some medium sized UPS (small single-phase units up to typically 6kVA) are connected to the mains supply using standard plug and socket arrangements and are put into service in the same way as the Micro and Mini systems.

Larger power ratings will require connection with fixed wiring and should only be commissioned by the supplier’s trained and experienced personnel.

Large UPS (30-400kVA and above)

Large UPS equipment will be electrically installed with fixed cabling and dedicated input and output switchgear and must be commissioned by the supplier’s trained and experienced personnel.

Load Bank Testing

To validate the correct operational performance, and the battery autonomy of the UPS system on-site and under full load conditions, a dummy load bank is sometimes utilised. This facility is normally only required on large UPS since the cost of the provision of a load bank and the engineer's costs become disproportional to the equipment cost for small and medium size UPS.

The load bank is normally resistive (unity power factor) and comprises heating elements and fans for cooling. Reactive load banks are also available (typically 0.8 lagging power factor) but tend to be much larger and heavier due to the wound inductive components. The load bank should be supplied with suitably rated cables, which allow it to be placed approximately 20 metres from the UPS terminals or output PDU. Allowance should be made to ensure the heat from the load bank can be safely dissipated and it should not be located in the vicinity of sensitive fire alarm and sprinkler systems.

If the load bank is being used to verify the specified battery autonomy it is good practice to only undertake the tests at least one week after the UPS has been commissioned to permit the voltage across the battery blocks to equalise and for the battery to be fully charged. For this reason UPS manufacturers do not normally include load bank testing as part of the standard commissioning procedures.

Three Phase UPS Supporting Single Phase Loads

On some occasions it is advantageous to support various single phase loads across the output phases of a 3-phase UPS. Whilst not essential, it is desirable to arrange the single phase loads so that the loading on each of the UPS output phases is equal, or at least close to being equal. This is particularly important to avoid an unbalanced 3-phase load being presented to a closely rated standby generator if, or when, the UPS switches to its bypass mode.

It is permissible to have single phase loads, when being supplied by different phases, in the same vicinity providing Regulation 514-10-01 of BS7671 is enforced. This regulation generally states that:

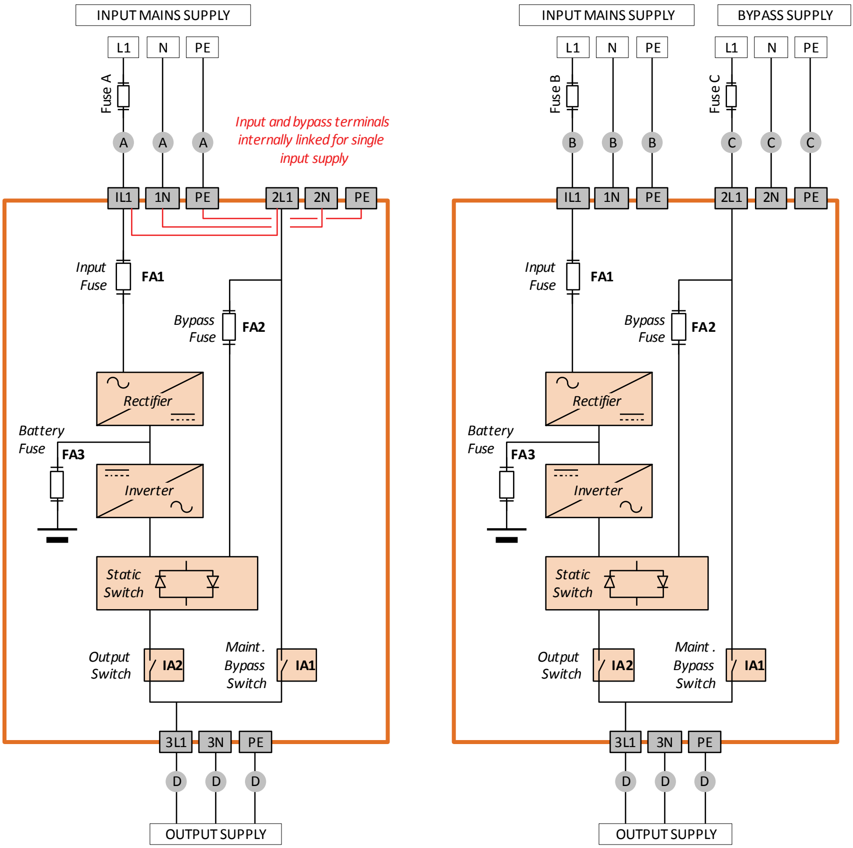
"Every item of equipment or enclosure within which a nominal voltage exceeding 230 volts to earth exists and where the presence of such a voltage would not normally be expected, shall be so arranged that before access is gained to a live part, a warning of the maximum voltage present is visible."

Installation Drawings

The following pages show some typical UPS installation drawings similar to those which your UPS supplier should be able to provide pre-installation.

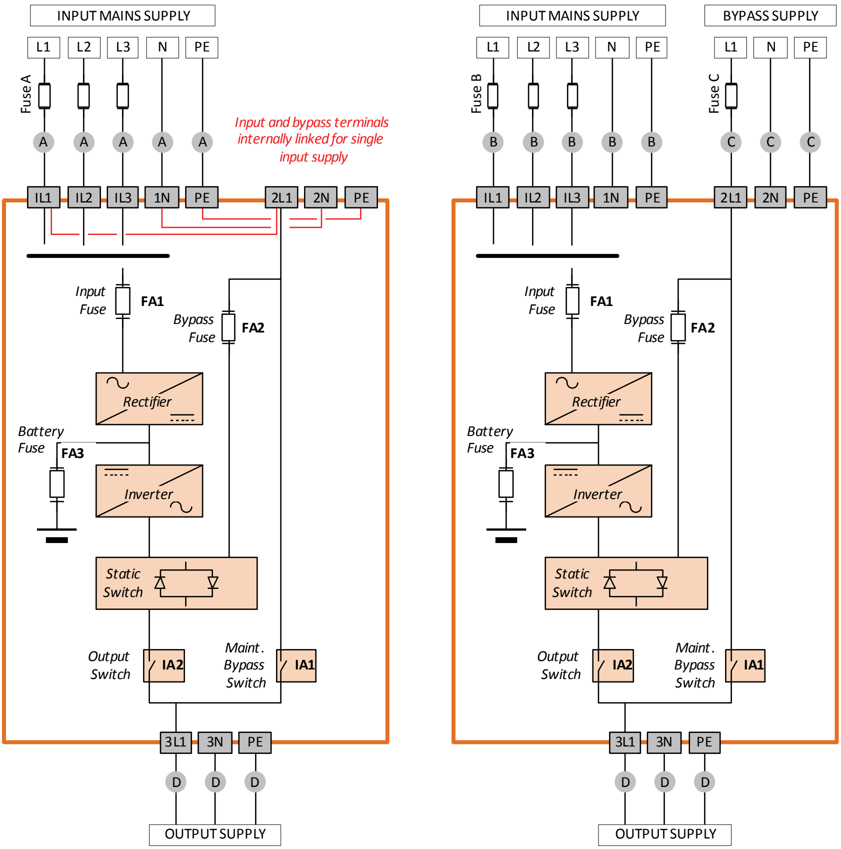
The drawings are shown as examples only and should not be used as references for a particular installation and any cable sizes shown are the minimum recommended.

Unless the UPS supplier is contracted to electrically install the UPS, its correct installation will be the sole responsibility of the electrical contractor.



SINGLE INPUT FEED				DUAL INPUT FEED				
Power (kVA)	Fuse A (A)	Cable A (mm^2)	Cable D (mm^2)	Fuse B (A)	Cable B (mm^2)	Fuse C (A)	Cable C (mm^2)	Cable D (A)
7.5	1 x 40	3 x 6	3 x 6	1 x 40	3 x 6	1 x 40	3 x 6	3 x 6
10	1 x 63	3 x 10	3 x 10	1 x 63	3 x 10	1 x 63	3 x 10	3 x 10
12	1 x 63	3 x 10	3 x 10	1 x 63	3 x 10	1 x 80	3 x 16	3 x 16

Figure 11.25: Typical 7.5-20kVA Single Phase In/Out UPS



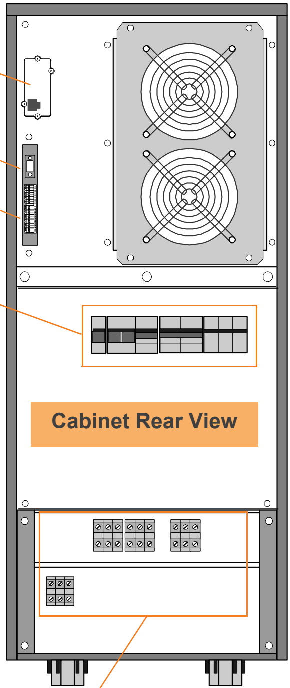
SINGLE INPUT FEED					DUAL INPUT FEED				
Power (kVA)	Fuse A (A)	Cable A (mm^2)	Cable D (mm^2)		Fuse B (A)	Cable B (mm^2)	Fuse C (A)	Cable C (mm^2)	Cable D (A)
7.5	3 x 40	5 x 6	3 x 6		3 x 25	5 x 2.5	1 x 40	3 x 6	3 x 6
10	3 x 63	5 x 10	3 x 10		3 x 25	5 x 2.5	1 x 63	3 x 10	3 x 10
15	3 x 80	5 x 16	3 x 16		3 x 40	5 x 6.0	1 x 80	3 x 16	3 x 16
20	3 x 100	5 x 25	3 x 25		3 x 40	5 x 6.0	1 x 100	3 x 25	3 x 25

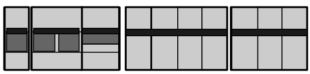
Figure 11.26: Typical 7.5-20kVA Three Phase In / Single Phase Out UPS

Customer Interface Connections

JD1 – Smart Port RS232 (Sub-D9P/F).

X1-X21 – Dry Port volt-free contacts on terminal block.





IA1 – Maintenance Bypass Switch
IA2 – Output Switch
FA2 – Bypass Supply Line Fuse
FA1 – Input Supply line Fuse
FA3 – Battery Fuse

	FA1 (A)	FA2 (A)	FA3 (A)
7.5	50A (14x51) Ultrafast	50A (14x51) GL/GC	32A (10x38) Ultrafast
10	50A (14x51) Ultrafast	50A (14x51) GL/GC	32A (10x38) Ultrafast
15	50A (14x51) Ultrafast	80A (22x58) GL/GC	32A (14x51) Ultrafast

Input/Output Power Connections

* In a 'single feed' (standard) installation terminals 2L1 and 1L1 are linked by cables fitted to the UPS side of the terminal blocks.
Terminals 2N and 1N are similarly linked.
When using a 'dual feed' supply these links should be removed and the bypass supply cable connected as shown in this diagram.

** The UPS internal battery is normally connected to the battery isolator switch (FA3). If an external battery cabinet option is used, the internal batteries are disconnected and the external battery cabinet is connected to the terminals shown in this diagram.

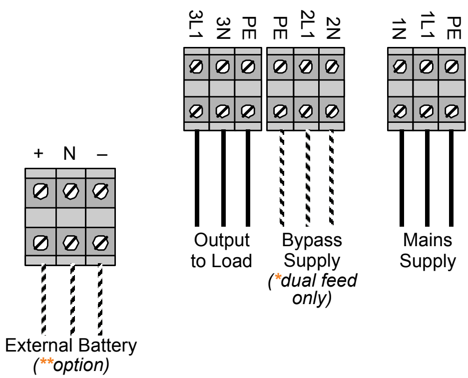
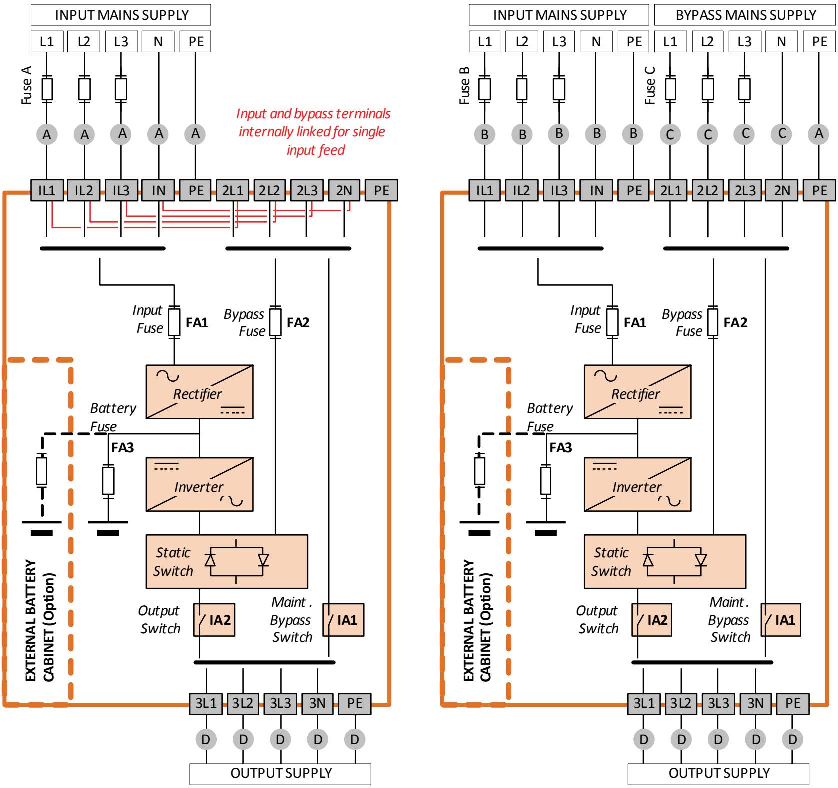


Figure 11.27: Typical 7.5-12kVA Single Phase Input Terminal Block



Power (kVA)	Fuse A,B,C (A)	Cable A,B,C,D (mm^2)
10	3x 20	5 x 2.5
15	3x 25	5 x 4
20	3x 40	5 x 6
30	3x 63	5 x 10
40	3x 80	5 x 25
60	3x 100	5 x 35
80	3x 125	5 x 50
100	3x 160	5 x 50

UPS Power (kVA)	Fuse A,B,C (A)	Cable A,B,C,D (mm^2)
120	3 x 200	5x 70
160	3 x 250	5x 120
200	3 x 350	5x 185
250	3 x 400	5x 240
300	3 x 500	5x (2x120)
400	3 x 630	5x(3x95)
400	3 x 630	5x (2x185)
500	3 x 800	5x (3x 150)

Note: External battery cables and fuses are bespoke to the installation

Figure 11.28: Typical Three-Phase Input/Output UPS

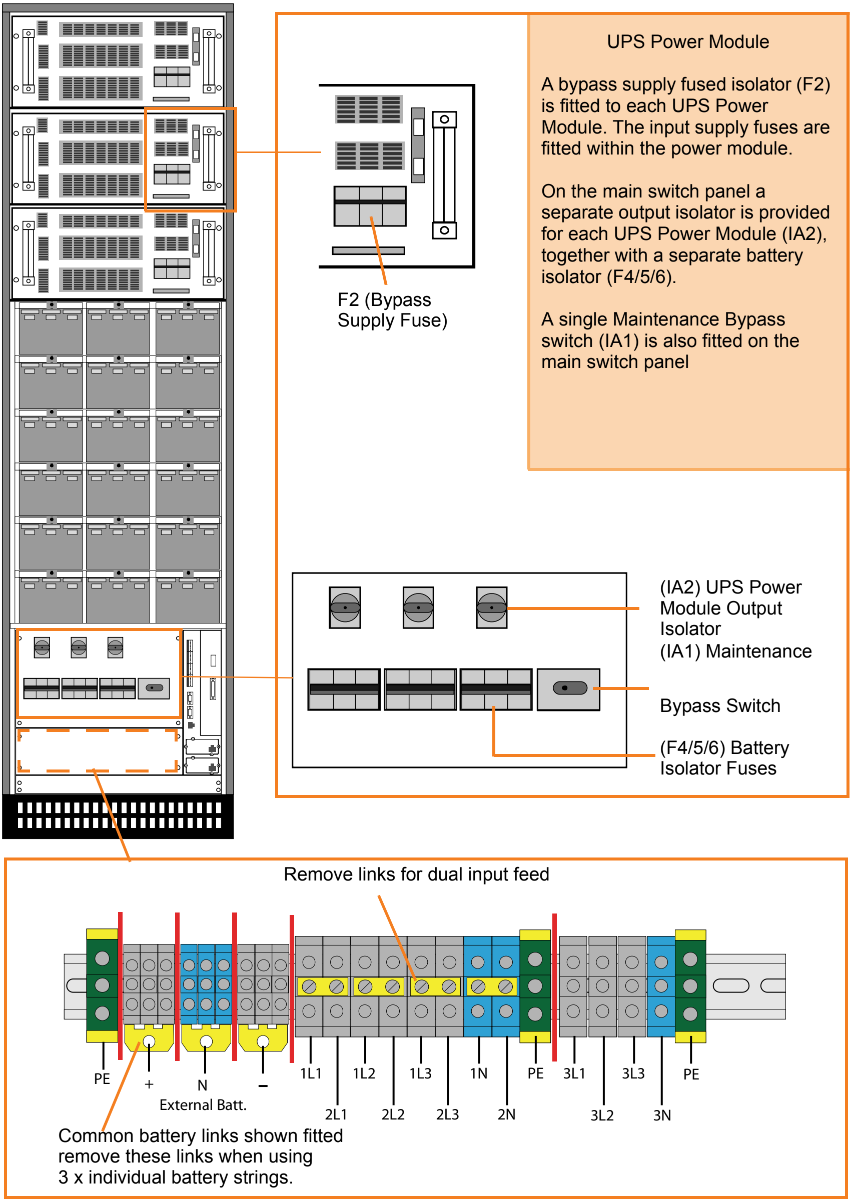


Figure 11.29: Typical 3 phase Input/Output UPS Terminal Block

Parallel Systems

Free-standing, parallel, three-phase input/output UPS modules are installed in much the same way as a single free-standing module shown in Figure 11.25 - Figure 11.29 except that they also require some inter-module control cabling and, of course, paralleling switchgear.

In an N+1 parallel UPS system the cabling and protection for each module is the same as that used for single modules. However, the size of 'wrap-around' bypass cabling and the main output isolator will be dictated by the total capacity of the UPS system. When installing a parallel system consider the future and ensure that these items are sized accordingly.

Figure 11.30 shows a sample parallel system schematic.

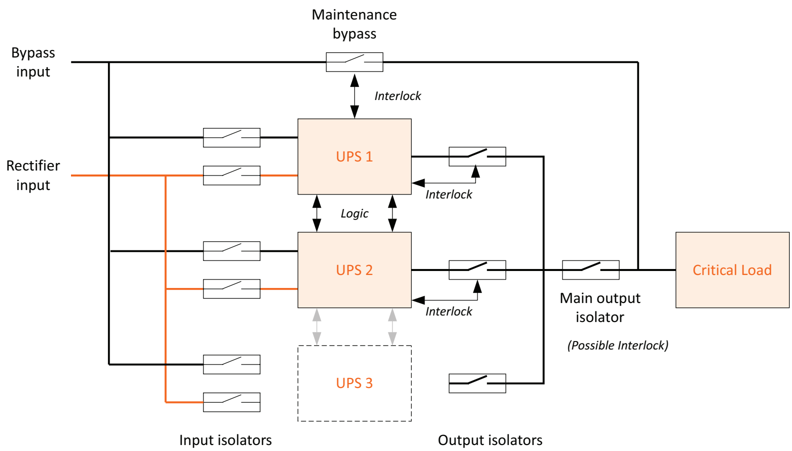


Figure 11.30: Sample Parallel UPS System Schematic with Spare Way Provided for Future Expansion (UPS 3)

Rack format modular UPS modules lend themselves to paralleling much more readily since the inter-module control cabling and the paralleling switchgear is contained within the rack cabinet and requires only the insertion of the UPS module to facilitate communication and parallel connections.

Using and Maintaining the UPS

Responsibilities

Once the UPS is installed (and commissioned, if appropriate) it is important to ensure that someone is made responsible for the UPS and its associated equipment. This need not be an electrical technician, but should be someone who is invariably on-site and easily contactable and is typically the IT manager or facilities manager.

Establishing a central contact responsible for protected power provision is essential to ensure that:

- the UPS is kept in optimum condition
- the UPS or plant room is kept clean, dry, tidy and well lit
- alarms and indications are recorded, logged and reported correctly
- the UPS is correctly maintained
- someone on site knows where the UPS is located.

For small UPS systems, access to the UPS user manual and the phone number of the UPS supplier is all that is typically required. However, for medium and large UPS systems that require routine maintenance, a higher degree of user system awareness is required.

Service and Maintenance

Typically medium sized UPS systems are covered by a service and maintenance contract and this should be considered essential for large systems.

Information regarding the correct care of UPS systems and detail regarding service and maintenance contracts is given in Chapter 12.

UPS equipment should only be operated by trained and experienced personnel as high voltages are present within the UPS cabinets. Also the company maintaining the UPS equipment should be able to confirm that their service personnel are fully trained by the manufacturer and that they have full and unrestricted access to spare parts.

Summary

This section has discussed, in some detail, the steps required to achieve a successful UPS installation.

The correct selection, delivery and positioning, electrical installation, commissioning and maintenance of a UPS system may not be straightforward. There are a large number of diverse skills required to complete all aspects of the installation successfully and within the available budget. The UPS end user may choose to handle all aspects of the installation or they may appoint a consultant or experienced electrical contractor to act for them. Alternatively, there are some UPS suppliers who can offer ‘turnkey’ solutions and the end user may want the security of knowing that the original specifier, supplier and installer will be responsible for the continued operation of the UPS system.

12 System Maintenance

Introduction

All UPS and associated system components need periodic maintenance and occasional replacement of parts in order to ensure optimum reliability.

Most UPS equipment suppliers will offer service contracts to ensure the equipment is kept in optimum condition throughout its useful life.

While the contract details will differ between suppliers, certain items must be included in order to ensure the continued power protection of the critical load and applications:

- emergency call-out facilities with defined response times
- maintenance and testing regimes
- end-of-life component replacement.

Critical loads and applications require power protection equipment which in turn requires regular maintenance.

Emergency Call-out Facilities

A failure is the inability of an item of equipment to perform its designed function and is caused by internal or environmental faults.

Note: Faults usually cause a degradation of the system but do not always cause a system failure.

Unfortunately, no matter how reliable equipment is, at some point it will probably experience failure or malfunction.

The Sample Service Agreement (*on page 251)* shows a typical contract. However, it is not complete as it does not address specific items such as which equipment is covered, engineer's response time, spares availability etc. These would normally be included in a 'schedule' which forms part of the contract. The content of the schedule is site or equipment specific.

The Schedule

When arranging a service agreement careful consideration should be given to the needs of the critical application and site, to ensure that the combined Agreement and Schedule closely match those requirements.

The following items should be specified in the Schedule:

- details of the emergency call-out procedure
  - contact details - phone, fax, email etc.
  - is an engineer available 24 hours per day, 7 days per week?
  - what is the response time? and how is it defined?
  - can I speak to an engineer at any time?
- details of any automatic facilities
  - can the UPS equipment automatically call for emergency response?
- information regarding spares availability
  - does the engineer carry full spares?
  - are spares required to be held on-site?
- details of emergency call escalation procedures
- details of end-of-life replacement policy.

Maintenance and Testing

Each UPS, battery and generator supplier will have its own Planned Maintenance (PM) programmes which will typically include the following:

UPS

- inspect site log for incidents since previous PM visit
- check and record equipment meter readings and verify accuracy
- check that meters and instrumentation operate correctly
- verify the correct status indications for the local and remote monitoring panels and communication facilities
- check that all indication lamps are operational
- check that all switchgear operates correctly
- check the air flow in and around the equipment
- replace the air filters if fitted
- remove any material and obstructions from around the equipment
- check the environment for abnormal conditions
- check for excessive heat, noise and vibration
- visually inspect all components for signs of damage
- visually inspect power and control wiring
- check for loose connections
- inspect the ac and dc capacitors for swelling and leakage
- check the power supply voltages and the power waveforms
- check the operation of the circuit breakers and associated trips and/or undervoltage releases
- check the overall operation of the UPS
- maintain the site log with written service reports.

Additional checks and testing will be required if a parallel UPS system is installed.

Battery Testing and Maintenance

Traditional battery testing and maintenance consists of:

- checking and recording the open-circuit battery voltage
- verifying that the UPS float voltage is correct
- inspecting all battery terminals and connections for corrosion
- inspecting all batteries for cracks, leaks or swelling
- tightening the intercell connections to manufacturer's specifications
- removing any materials and cleaning around the equipment.

However, in recent years the technology of standby batteries has changed dramatically and despite the designer's desire to reduce maintenance it is now more essential and more sophisticated than ever.

In the 1970s the vast majority of standby systems used flooded lead-acid batteries. This type of battery had been in use for many decades and the methods of monitoring and maintenance were well understood. Measurements of the voltage and the specific gravity of the electrolyte were used to determine the state of charge. Visual inspection of the plates and internal parts was made through the glass jar containers. Both the maintenance and the design were fairly low level technology in comparison with the equipment supported.

The 1980s saw dramatic changes with the introduction of the so called 'maintenance free' batteries which, by the end of the 1980s, had captured probably 90% of the market. However, it soon became apparent that the batteries were neither sealed nor maintenance free and the current description of Valve Regulated Lead Acid (VRLA) was introduced.

Most battery maintenance companies continued to treat the batteries in the traditional manner. However, it was no longer possible to measure the specific gravity or to visually inspect, as the battery cases were no longer transparent. Unfortunately the voltage available at the terminals is no indication of true battery condition. Many battery systems failed both prematurely and without warning, leading to a serious loss of confidence in the VRLA product generally.

The 1990s saw these problems answered by new test methods that provide substitute parameters for those which can no longer be measured. The most significant of these parameters is battery impedance testing.

Battery Impedance Testing

Batteries start life with a fairly low internal impedance (measured in milli-ohms). The actual impedance varies between types of battery - for example: A 12 volt battery will have a far higher impedance than a two volt block as the 12 volt block comprises six cells in series, with generally a much smaller plate area. Generally, differences between high quality batteries of the same type and from the same manufacturer are small.

As a battery ages its impedance increases marginally due to normal internal corrosion. This occurs at a similar rate amongst batteries in a string, which is the most common configuration for standby applications (a parallel battery is simply a combination of strings – *See "Energy Storage Devices" on page 115*). Any battery that shows a deviation from the others in the string would be suspect. Similarly, should the impedance of a number, or all, of the batteries in the string rise at a faster rate than would normally be anticipated, the condition of the batteries must be assumed to be abnormal.

Almost any battery problem leads to a rise in internal impedance. A common problem is loss of electrolyte due to venting through overcharging, leakage through seals, or in some designs migration of electrolyte between cells. Another is excessive corrosion of the ‘gridbars’ to which the plates are connected which reduces the area of metal and in extreme cases causes the plates to disconnect from the bar. To find the actual cause of the high impedance, faulty batteries may be dissected and analysed in a laboratory.

Battery impedance is relatively easy to measure. An ac current of a suitable level relative to the Ah rating is passed through the battery. The resulting ac millivolt reading generated between the battery terminals is recorded and used to calculate the internal impedance.

The advantage of this method is that, unlike load testing, they do not leave the battery discharged, and if regularly conducted, they track the battery condition, allowing an accurate prediction regarding the end of reliable operating life. Results can be computer generated to provide clear reports of the battery condition (*See Figure 12.1 and Figure 12.2*).

Figure 12.1 shows a new battery where the float voltages are very similar and the impedance levels for the individual batteries are also very consistent.

Figure 12.2 shows the same battery at the end of its useful life. Most of the float voltages appear satisfactory but the impedance readings for blocks 8 and 9 are particularly high - if load was applied to the battery their voltages would almost certainly collapse. Block 19 has both higher impedance and a low voltage, suggesting that one cell in the block is short circuit.

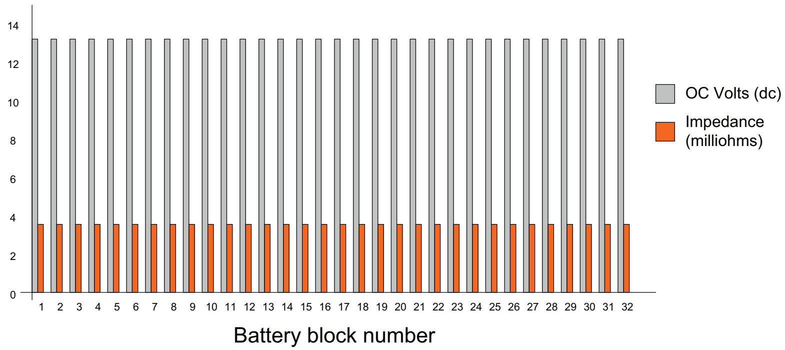


Figure 12.1: Impedance Graph for a New Battery

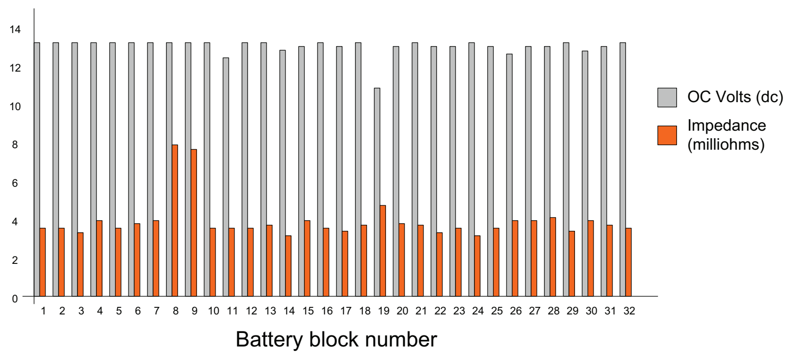


Figure 12.2: Impedance Graph for a Battery at the End of its Useful Life

The test results clearly show that simply measuring battery block float voltages is not an accurate monitor of battery condition as the impedance test has clearly identified three faulty blocks.

Impedance readings and computer generated reports, in conjunction with other tried and tested methods such as load testing, can provide information which gives a clear picture of battery condition. Clear and concise reports on battery condition and life expectancy can be provided with maintenance costs very little higher than traditional, less effective, procedures.

Fixed Battery Monitoring

Fixed battery monitoring systems can be permanently fitted to a battery installation. This is normally done at the time of new battery installation but can be fitted at any time. This type of battery monitoring system allows the continuous monitoring of battery voltages, current, temperature and impedance; and can detect differences between individual battery blocks during any discharge/charge cycles.

The relatively high cost of fixed battery monitoring systems makes them only suitable for use in large battery installations or installations that are highly critical where other forms of battery testing and monitoring are considered insufficient.

Advanced products such as the patented BACS 'Battery Analysis & Care System' provides an Ethernet-network integrated battery monitoring and management system. Using web-management technology, it checks the internal resistance, the temperature and the voltage of every single accumulator sequentially: a patented equalisation process then corrects the charging voltage of each accumulator individually to keep each one in its optimal voltage operating range.

The constant monitoring and controlling of the individual charging voltages for each accumulator guarantees the availability of the battery at all times.

In addition, BACS can manage environmental measurements (temperature, humidity, acid fill level, hydrogen gas concentration, etc.) and appliances (UPS, inverters and other devices).

Load Bank Testing

A load test involves putting the critical load at risk so careful arrangements and agreements must be made.

Load bank tests are an important part of any battery maintenance programme and should be used to determine the battery capacity. Load testing should be used sparingly and in conjunction with impedance testing to assess a battery’s condition.

Load banks, in a range of sizes and configurations are available for hire or rent allowing a variety of tests to be conducted. For example, in addition to a full load test, the UPS performance with step load changes or reactive loads may be monitored. Most load banks are fitted with remote switching facilities allowing them to be controlled while they are temporarily sited at some distance from the UPS under test (*See "Load Bank Testing" on page 228*).

Conducting a Test

In order to perform a **full** load test, it is usual to connect a system of load banks to the output of the UPS system. This means you must either disconnect the critical load or feed it from an alternative source. Choosing the latter option puts an additional load on the incoming mains supply and you must check the supply capacity and the fuse and protection settings of that source before proceeding.

During load testing, you may wish to include:

- thermographic testing, see *"Thermographic Connection Testing" on page 247*
- full system testing, see *"Complete System Testing" on page 250*.

The Advantages of Load Bank Testing

Load testing proves the capacity of the battery **at the time of the test** and the integrity of all of the interconnections. For this reason it is useful at specific times, for instance one week after commissioning, to prove the battery will support the specified load for the specified time.

A load test is also worthwhile at two-thirds of the expected useful life to confirm predicted capacity. However, provided the condition of the battery is correctly monitored and shows it to be healthy, there is no reason to expect that the battery will not perform as required in an emergency and further load tests are therefore unnecessary.

The Disadvantages of Load Bank Testing

Limited discharge/charge regimes were good for flooded cells and countered stratification (*electrolyte settling into layers of varying acidity and density)*, but this does not apply to VRLA batteries.

Completely discharging the battery actually reduces its life and following a discharge test the battery is unable to protect the load fully until it is recharged. Under some circumstances the battery can recharge unevenly leading to serious problems - such as the undercharging and overcharging of battery blocks within the same string (*See "Energy Storage Devices" on page 115*).

Load banks can be large and expensive to purchase or hire, and to transport. A suitable location has to be found for the load bank, whereas impedance testing requires the use of handheld equipment and does not affect the ability of the battery to perform when necessary.

Thermographic Connection Testing

Infrared thermometers measure the surface temperature of an object quickly and without touching or disturbing that object. This feature is particularly useful when examining battery installations as there are many connections to check.

Thermographic imaging takes temperature measurement to the next level for battery installations. In addition to non-contact temperature measurement, an imager takes a thermal picture of any item and can display or prints it for immediate use or store it digitally for future reference and comparative purposes.

Infrared thermometers and imagers can be expensive to buy or rent but the maintenance cost savings may be considerable.

Over time and during normal use, battery connections can become loose as on/off current loading and environmental temperature changes cause heating (expansion) and cooling (contraction) of connections. Loose connectors have higher resistance to current flow and, as a result, generate heat. Connection corrosion has a similar effect.

Knowing the ambient temperature is important when making measurements and this can also be obtained with an infrared device. Increases of 10°C from ambient temperature indicate a poor connection, or abnormally high current flow. Temperatures of 30°C or more above ambient indicate a serious problem that should be investigated further.

Battery Replacement

All batteries will need to be replaced periodically. There are many factors that affect how frequently this needs to happen, but eventually, even under ideal service conditions, they will need to be replaced.

In a typical UPS environment, and depending on the number of discharges experienced, the ambient temperature, etc.:

- a 5 year ‘design-life’ VRLA battery is expected to last 3 to 4 years
- a 10 year ‘design-life’ VRLA battery is expected to last 7 to 8 years.

> Battery cells are consumable items and will require replacement from time to time.

Generators

A regular generator service program should include tests and checks of the following:

- Cooling System
  radiator/heat exchanger, coolant, hoses and connections, fan drive pulley and fan, fan belts, jacket water heater, water pump, thermostats
- Fuel system
  fuel tank, water trap/separator, fuel lines and connections, governor and controls, fuel filters - primary/secondary, fuel pressure, air induction and exhaust system, air filter, air filter service indicator, air inlet system, turbocharger, exhaust manifold, valves and valve rotators
- Lubrication oil system
  oil, oil filters, oil pressure, crankcase breather
- Starting system
  batteries, battery specific gravity, battery charger, starting motor, alternator, engine monitor and safety controls, gauges, remote annunciators/alarms
- Generator
  bearings, slip rings and brushes, space heaters, vibration isolators
- Control panel
  start controls - manual/auto, voltmeter, ammeter, frequency meter, circuit breaker, auto transfer switch
- Gas engine
  gas lines and connections, carburettor and linkage, magneto/ distributor, ignition system, spark plugs
- Insulation test
  main stator, main rotor, exciter stator, exciter rotor
- Load testing
  with full load, perform a two to four hour load test.

Complete System Testing

In addition to Planned Maintenance of each part of the system, consideration should be given to occasionally testing the entire system (every 2 to 5 years).

A complete system test involves putting the critical load at risk so careful arrangements and agreements must be made.

Mains Failure Checks (quarterly)

Disconnect the mains supply to the UPS equipment and check that:	
System with Generator	• Automatic Mains Fail (AMF) equipment operates correctly • generator auto-starts after the expected time • generator output is correct and within acceptable UPS input limits and the UPS accepts the generator supply • battery recharging is normal.
System with No Generator	• UPS battery supports the load for the expected autonomy time • alarms and control signals are correct • load responds correctly to signals from the UPS, e.g. system alarms, orderly shutdown sequence etc.
Reconnect the mains supply to the UPS equipment and check that:	
System with Generator	• Automatic Mains Fail (AMF) equipment operates correctly • UPS signals a mains failure during the changeover • generator shuts down after the expected time • UPS accepts the restored mains and recharges the batteries • alarms can be reset.
System with No Generator	• System returns to normal operation automatically if the UPS is fitted with auto-restart facilities, otherwise • UPS modules can be re-started manually and the system restored to normal operation • alarms can be reset.

Generator Checks (1-3 months)

If it is not possible to carry out a full mains failure check, for example due to critical load requirements, run the generator and check its correct operation.

Sample Service Agreement

In addition to the standard warranty offered by the UPS supplier the user may wish to consider a comprehensive service/maintenance contract, also often referred to as an 'Extended Warranty Agreement' or 'Service Plan'.

The following is a typical service agreement plan.

Service Plan

Definitions

'Agreement'	this Service Plan.
'Company'	the UPS service company.
'Customer'	the person obtaining Equipment and/or Remedial Work and/or Maintenance Service from the Company under this Agreement.
'Employee'	any employee of the Company including any agents or subcontractors.
'Equipment'	the equipment, or any part of it, specified in the schedule.
'Maintenance Service'	the surveillance, preventative upkeep and repair of the equipment.
'Remedial Work'	the service of any equipment in response to an emergency call out.
'Schedule'	the schedule annexed to this agreement.

Maintenance and Support Visits

The Company will provide the following services in respect of the Equipment:

Emergency Visits

The Company will respond to an emergency call-out by the Customer by sending an Employee to start Remedial Work within the emergency service response time stated in the Schedule.

Maintenance Service Visits

The Company will maintain the Equipment in good working order by carrying out Maintenance Service of each piece of Equipment at regular intervals as stated in the Schedule.

Maintenance Service visits will be on an appointment basis and the Customer must give no less than 48 hours notice to the Company to alter the appointment.

Additional Maintenance Service Visits

This agreement does not cover additional Maintenance Service or Remedial Work to remedy abnormal wear and tear resulting from

1. incorrect use or operation
2. neglect
3. mishandling
4. inappropriate positioning of the Equipment
5. operation of the equipment in an unsuitable environment.

The Company reserves the right to charge for any work required to be done to remedy faults caused by any of the above at its prevailing list prices.

Aborted Visits

If a visit is aborted because the Company is unable to carry out Remedial Work or Maintenance Service as a result of

1. inaccessibility of the Customer's premises or Equipment
2. inexact information provided by the Customer
3. unnecessary or undue calls, or
4. insufficient notice, then:
   the Customer will immediately make a new appointment with the Company and the Company reserves the right to charge the Customer at its prevailing rate for the aborted visit and for any other visit in response to an emergency call-out after the aborted visit but before the new appointment with the Company.

Equipment

New Equipment

The addition of any new Equipment to this Agreement will be subject to an additional charge, to be notified to the Customer before the first appointment.

The Company reserves the right to charge the Customer at its prevailing rate for the costs of any investigations and any repairs or adjustments the Company regards as appropriate to carry out before the new Equipment is introduced into this Agreement.

Replacement Equipment

The faulty parts of any Equipment replaced during Remedial Work or Maintenance Service will become the property of the Company.

Unless the Schedule specifically states to the contrary, all replacement parts are covered by the annual premium. If certain replacement parts are not covered, the Company reserves the right to charge the Customer at its prevailing list rate.

Batteries and Capacitors

The replacement of batteries or capacitors is not covered by the annual premium and the Company will charge for any replacement and installation of batteries/ capacitors at its prevailing list price and rate respectively.

Customer Responsibilities

Throughout the term of this Agreement the Customer will:

1. ensure any Employee of the Company has free and sole access to the Equipment and the Customer's premises
2. ensure that all Equipment complies with any applicable installation, health and safety and environmental standards
3. ensure that the Equipment is placed on a site with the following characteristics:
   dust-free, dry, well-ventilated, free from vibration;
   cooling air temperature maximum 25°C is recommended to optimise the durability of the Equipment and batteries, calculated at the air intake point of the Equipment, and
4. comply with the Company's terms and conditions of sale, copies of which are available on request, when paying any charges specified in this Agreement.

Charges

Annual Premium

The Customer will pay the annual premium in advance on signature of this Agreement, or in the case of new Equipment added thereafter, on the date of the commissioning of that new Equipment, and on each anniversary of such date.

Late Payment

If the Customer does not make payment in accordance with the Company's terms and conditions of sale the Company reserves the right to suspend all services under this Agreement until payment is received in full by the Company.

Annual Premium Increases

The annual premium due on signature of this agreement will be increased each year by a percentage equal to the annual aggregate percentage increase of the BEAMA Index relating to electrical labour for the month and year in which the annual premium becomes due.

Value Added Tax

If applicable, the company will charge Value Added Tax, at the prevailing rate, in each invoice.

Original Manufacturer

If the Company is not the original manufacturer, the Company reserves the right to contact the original manufacturer of the Equipment for assistance when appropriate.

Duration and Termination

This Agreement will come into effect from and including the date of the signature by a duly authorised representative of the Company and will continue for a term of ten years unless either party gives the other 90 days advance written notice of termination, such notice to be given at any time after this Agreement has been in effect for a period of nine months.

Liability and Indemnity

The Company will repair damage to property or compensate personal injury only in the following circumstances:

1. The damage or injury is caused by the negligence of the Company or its Employee in the course of operating at the Customer's premises
2. The Company's liability for loss or damage to property resulting from the Company's negligence shall not exceed the annual premium of this Agreement for each event or series of events arising from the same cause
3. Except for injury or death to persons resulting from the Company's negligence, the remedies provided herein shall be the Customer's sole and exclusive remedies. The Company shall not be liable for any direct or indirect damages, however based.

Force Majeure

The Company will not be liable for any default under this agreement resulting from circumstances outside its reasonable control.

For the purposes of this clause, non-exhaustive illustrations of force majeure include industrial conflicts and the nature or absence of directions from the Customer.

Entire Agreement

This Agreement, including any amendments, constitutes the entire understanding of the parties and there are no promises, terms, conditions or obligations, whether written or oral, express or implied, relating to the Equipment other than those contained or referred to in this Agreement.

Waiver and Variation

No amendment to, or waiver of, any clause will be valid unless accepted in writing and signed by the duly authorised representative of both parties.

Jurisdiction

This Agreement will be interpreted in accordance with the law of England and any dispute arising under it will be submitted to the exclusive jurisdiction of the English courts.

13

Applicable Standards

EN 62040

The UPS Standard EN62040 comprises three parts:

EN62040 - Part 1 (General and Safety Requirements)
EN62040 - Part 2 (EMC-Electromagnetic Compatibility)
EN62040 - Part 3 (Performance)

Part 1 - General and Safety Requirements

This standard applies to electronic indirect AC converter systems with an electrical energy storage device in the DC link. The primary function of the UPS covered by this standard is to ensure continuity of an alternating power source. The UPS systems may also serve to improve the power quality of the power source by keeping it within specified characteristics.

This standard is applicable to movable, stationary, fixed and built-in UPS for distribution systems up to 1000Vac.

The standard applies to UPS intended to be installed in any operator accessible area and specifies requirements to ensure safety for the operator and layman who may come into contact with the equipment and, where specially stated, for service personnel.

The standard is intended to ensure the safety of installed equipment, both as a single or as a system of interconnected units, subject to installing, operating and maintaining the equipment in the manner prescribed by the manufacturer.

This standard does not cover UPS based on rotating machines.

Normative References to EN 62040-Part 1:

This standard EN 62040-Part 1 is to be used in conjunction with EN 60950:2006 *"Safety of information technology equipment including electrical business equipments."*

The standard EN 62040-Part 1 incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text of the standard.

Part 2 - Electromagnetic Compatibility

This EMC standard applies to single UPS intended to be installed in any operator accessible area or in separated electrical locations, connected to either industrial or public low voltage supply networks.

This EMC standard will take precedence over all aspects of the Generic standards and no additional testing is necessary.

The requirements have been selected so as to ensure an adequate level of electromagnetic compatibility (EMC) for UPS at public and industrial locations. These levels cannot however cover extreme cases which may occur in any location, but with extremely low probability of occurrence.

It takes account of the differing test conditions necessary to encompass the range of physical sizes and power ratings of UPS.

A UPS unit or system shall meet the relevant requirements of this standard as a stand-alone product. EMC phenomena produced by any customer's load connected to the output of the UPS equipment shall not be taken into account.

Special installation environments are not covered nor are fault conditions of UPS taken into account.

This standard does not cover UPS based on rotating machines.

Normative References to EN 62040-Part 2:

The standard EN 62040-Part 2 incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text of the standard.

Part 3 - Performance

The standard applies to electronic indirect AC converter systems with an electrical energy storage device in the DC link. The primary function of the UPS covered by this standard is to ensure continuity of an alternating power source. The UPS systems may also serve to improve the power quality of the power source by keeping it within specified characteristics.

The performance requirements of this standard are for UPS within the scope of EN 62040-1.

The standard applies to UPS with:

- Single or three phase, fixed frequency, 50/60Hz AC output voltage
- Single or three phase input voltage
- Electrical energy storage device in the DC link, if not otherwise specified
- With rated voltage not exceeding 1000V AC
- Movable, stationary or fixed equipment.

This standard's specifics:

- Characteristics of the equipment
- Test methods
- Minimum performance levels.

Normative References to EN 62040-Part 3:

The standard EN 62040-Part 3 incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text of the standard.

UPS Topologies

The International Electrotechnical Commission (IEC) established the standard, IEC 62040-3, to define different UPS topologies and the measurements of performance. Cenelec, the European standards committee, adopted the IEC standard as EN 62040-3, which is now recognised as the authoritative definition of the following three standardised UPS topologies:

- Off-Line - VFD or Class 3 Category
- Line Interactive - VI or Class 2 Category
- On-Line - VFI or Class 1 Category.

UPS Classification - EN 62040-3

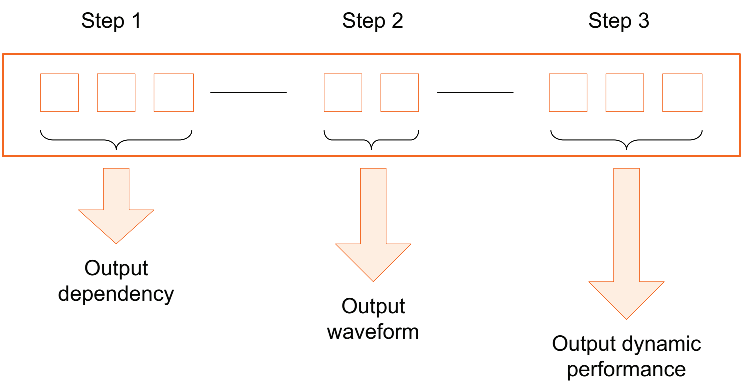


Figure 13.1: Classification of UPS - EN 62040-3

Classification Code Step 1 - UPS Output Dependency

V	F	D	UPS output is Dependant on mains Voltage and Frequency variations – *Off-Line*
V	I		UPS output is Dependant on mains Frequency variations, mains Voltage variations are regulated (Independent) – *Line Interactive*
V	F	I	UPS output is Independent of mains Voltage and Frequency variations – *On-Line*

Mains Problem	Time	E.G.	EN 50091-3	UPS Solution
Mains failure	> 10ms		VFD	**Class 3** Off-Line
Power sag	< 16 ms			
Power surge	< 16 ms			
Undervoltage	Continuous		VI	**Class 2** Line Interactive Delta Conversion
Overvoltage	Continuous			
Switching transient	Intermittent		VFI	**Class 1** On-Line Double Conversion
Power surge	< 4ms			
Frequency variation	Intermittent			
Voltage spikes	Periodic			
Harmonic distortion	Continuous			

Classification Code Step 2 - UPS Output Waveform

Y Y — Non-Sinusoidal: where the total harmonic factor D> 0.08 and harmonics within IEC 61000-2-2 under linear/non-linear reference load conditions

X X — Non-Sinusoidal: where the total harmonic factor D> 0.08 and harmonics within IEC 61000-2-2 under non-linear reference load conditions

S S — Sinusoidal: where the total harmonic factor D< 0.08 and harmonics within IEC 61000-2-2 under linear/non-linear reference load conditions

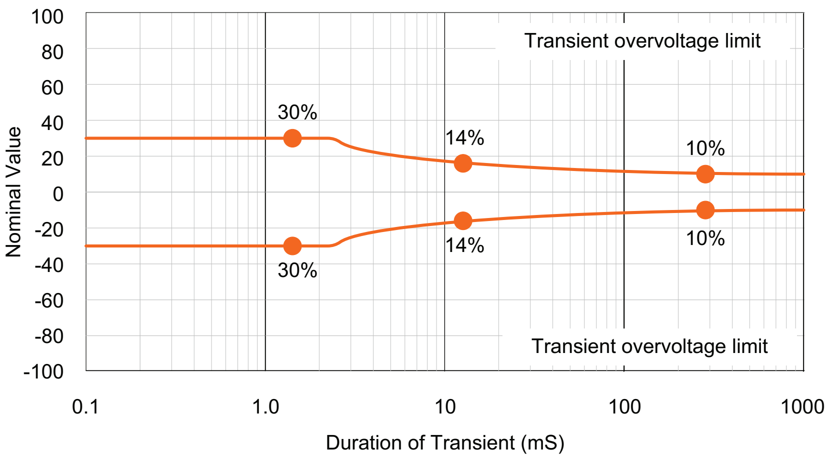
► ***On battery operation***

► ***On mains operation***

Classification Code Step 3 - UPS Output Dynamic Performance

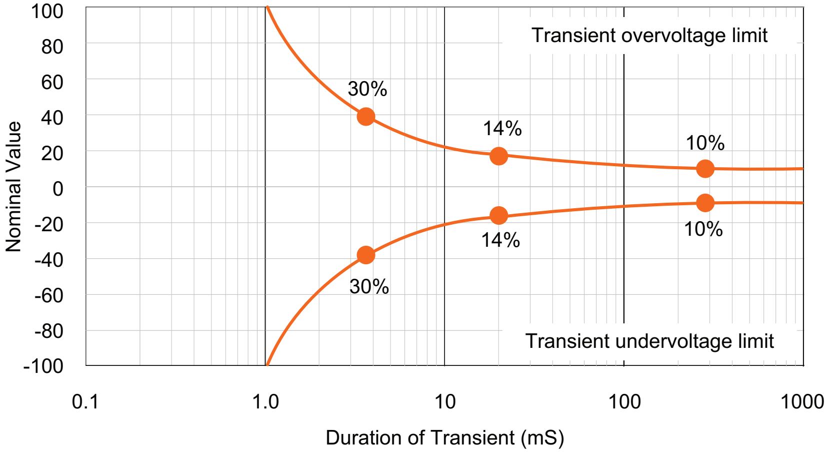
1 2 3 — Classification 1

► ***Change of operation mode performance***



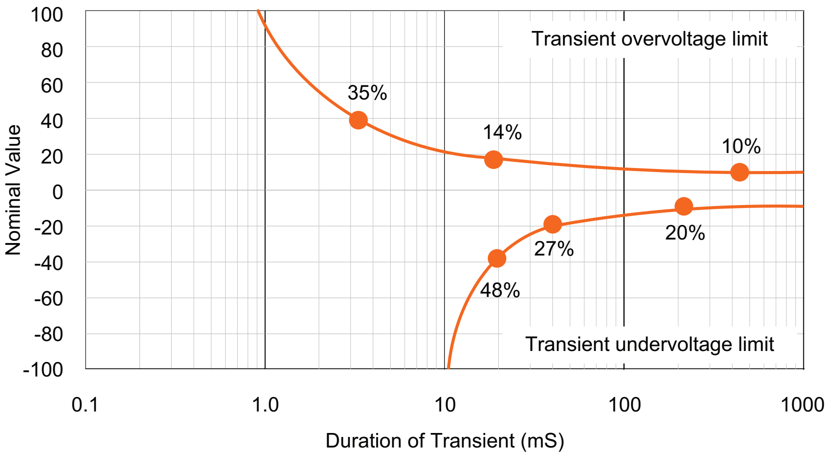
1 2 3 Classification 2

Step linear load performance in mains/battery mode



1 2 3 Classification 3

Step reference non-linear load performance in mains/battery mode



European standard EN 62040-3 is recognised as the correct way to specify the required UPS topology and performance criteria.
The highest classification of UPS is **VFI-SS-111**, which is only met by modern, true on-line, double conversion UPS.

Energy Networks Association ER G5/4-1

The Electrical Association Engineering Recommendation (ER) G5/4, which was published in February 2001, has been revised and replaced with the Energy Networks Association Engineering Recommendation (ER) G5/4-1 This revision was published in August 2005 after consultation between the Energy Networks Association members, interested manufacturers and trade associations such as Gambica.

The Energy Networks Association states that the satisfactory operation of the electricity supply system and user's equipment is only obtained where electromagnetic compatibility (EMC) between them exists. By limiting the harmonic emissions of customers' non-linear loads and generating plant, the Engineering Recommendation G5/4-1 helps to fulfil the technical objective of the UK EMC Regulations. These Regulations seek to limit the voltage distortion present in distribution networks to levels below the immunity levels at which equipment function and performance are likely to be impaired. Equipment immunity levels are based on a total voltage harmonic distortion (THDv) of 5% in 400V systems. Engineering Recommendation G5/4-1 sets the planning levels for harmonic voltage distortion to be used in the process for the connection to the supply system of non-linear equipment.

Whilst harmonic distortion limits are not governed by statute, it is incumbent upon the electrical design consultants and manufacturers to ensure equipment emissions when connected to the supply system do not exceed the planning levels set by G5/4-1 and that such harmonic distortions are agreeable to the Network Operating Company (NOC).

Stage 1 of the Engineering Recommendation G5/4-1 sets out the maximum aggregate value of three-phase convertors or AC regulator equipment, which may be connected to low voltage (230/240V) networks without further assessment *(See Table 13.1)*. 'Aggregate' is defined as the rating equal to the sum of the individual non-linear equipment ratings.

Supply system voltage at the Point of Common Coupling (PCC)	Three phase convertors	
	6 pulse (kVA)	12 pulse (kVA)
400V	12	50

Table 13.1: Aggregates

For all installations where there are concentrations of non-linear equipment >16A per phase, the aggregate emissions per phase should not exceed the values given in Table 13.2. The limits shown are based on a typical supply system fault level of 10MVA and where the network is not known to have excessive background levels of harmonic voltage distortion.

Special consideration should therefore be given to transformer based UPS utilising 6 pulse rectifiers since this equipment produces high emission currents typically >30% THDi.

Harmonic order 'h'	Emission current I_h	Harmonic order 'h'	Emission current I_h	Harmonic order 'h'	Emission current I_h	Harmonic order 'h'	Emission current I_h
2	28.9	15	1.4	28	1.0	41	1.8
3	48.1	15	1.8	29	3.1	42	0.3
4	9.0	17	13.6	30	0.5	43	1.6
5	28.9	18	0.8	31	2.8	44	0.7
6	3.0	19	9.1	32	0.9	45	0.3
7	41.2	20	1.4	33	0.4	46	0.6
8	7.2	21	0.7	34	0.8	47	1.4
9	9.6	22	1.3	35	2.3	48	0.3
10	5.8	23	7.5	36	0.4	49	1.3
11	39.4	24	0.6	37	2.1	50	0.6
12	1.2	25	4.0	38	0.8		
13	27.8	26	1.1	39	0.4		
14	2.1	27	0.5	40	0.7		

Table 13.2: Emission Currents

It is strongly recommended that the reader consults the full requirement of Engineering Recommendation G5/4-1 at the earliest stage of planning the installation of non linear equipment.

RoHS and WEEE Directives

RoHS (2002/95/EC "Restriction of the use of certain Hazardous Substances in Electronic Equipment") and **WEEE (2002/96/EEC "Waste of Electrical and Electronic Equipment").**

RoHS and WEEE directives do not directly apply to UPS systems since Annexes 1A and 1B of the Directives do not mention UPS anywhere, nor do they mention any other type of energy conversion equipment. This view has been confirmed both by the European Commission (FAQ document published May 2005) and subsequently ORGALIME (guide published February 2006).

Standards Relevant to UPS Installations

Standard	Details
CE	Marking in compliance with the following European directives: • Low Voltage Directive 2006/95/EC • EMC Directive 2004/108/EC
ISO/IEC 27001:2005	Information Security Standards
BS 25999-1:2006	Business continuity management. Part 1: Code of practice
BS 7698-1:1993, ISO 8528-1:1993	Reciprocating internal combustion engine driven alternating current generating sets. Specification for application, ratings and performance
ER G59/1	Recommendations for the connection of embedded generating plant to the Public Electricity Suppliers distribution systems. Energy Networks Association
BS EN 60529:1992	Specification for degrees of protection provided by enclosures (IP code) BS EN 60439-4:2004: Low-voltage switchgear and control gear assemblies
BS 7671:2001	Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition
BS EN 50310:2006	Application of equipotential bonding and earthing in buildings with information technology equipment
BS EN 60439-4:2004	Low-voltage switchgear and control gear assemblies

Standards Relevant to Lead Acid Batteries

Standard	Details
BS 6133:1995	Code of practice for safe operation of lead-acid stationary batteries
BS 6290-4: 1997	Lead-acid stationary cells and batteries. Specification for classifying valve regulated types
BS EN 60896-1:1992, IEC	Stationary lead-acid batteries. General requirements and methods of test. Vented type
BS EN 60896-2:1996, IEC	Stationary lead-acid batteries. General requirements and methods of test. Valve regulated type
BS EN 50272-2:2001	Safety requirements for secondary batteries and battery installations. Stationary batteries
ANSI/IEEE 450-2002	IEEE recommended practice for maintenance, testing and replacement of vented lead-acid batteries for stationary applications
ANSI/IEEE 1184-1994	IEEE recommended guide for selection and sizing batteries for Uninterruptible Power Supplies (UPS)
ANSI/IEEE 1188-1996:	IEEE recommended practice for maintenance, testing and replacement of valve-regulated lead-acid (VRLA) batteries for stationary applications

14 Glossary of UPS Terminology

AC - Alternating Current

Electrical current that continually reverses direction, the frequency of change in direction being expressed in Hertz (Hz), or cycles per second.

Amp or Ampere

Unit of measurement of electrical current. Abbreviated as A.

Autonomy

This is the time that the battery must support the load and is also often called back-up or discharge time.

Blackout

A total loss of electrical power.

BMS

UPS systems are often required to interface with the client's building management system (BMS) to provide remote indications of the operating status of the UPS. This is accomplished using the volt-free changeover contact signals available from the UPS, or where more comprehensive data is required, via the UPS RS232 communications port.

Brownout

A low voltage condition over an extended period of time.

Bunding

The oil storage regulations (DEFRA - Control of Pollution (Oil Storage) (England) Regulations 2001) require oil storage tanks to have a secondary containment facility.

Bypass

An ac power path around a UPS.
An *automatic bypass* is controlled by a UPS and operates under fault or overload conditions to maintain power to the protected load.
A *manual bypass* is a user switch on a UPS allowing a complete electrical bypass of the unit, used when there is a total UPS failure or when carrying out maintenance or repair without shutting down the load. Some parts of the UPS - the input and output terminations for example – may remain live.
A *service or maintenance bypass* is a manual bypass allowing complete isolation, maintenance, or removal of the UPS without load shutdown.

Capacitance

The ability of a system or component to store an electric charge. Capacitance is measured in Farads although, as this a very large unit, the most usual reference will be the micro Farad (μF).

Circuit Breaker

A protective device that interrupts the flow of current when it exceeds a specified value.

Clamping Level

The voltage level above which a surge suppression device diverts energy away from the load.

Clamping Time

The time taken by a surge suppression device to clamp or divert away from the load a voltage above the clamping level.

Common Mode Noise

Disturbances between the neutral and earth or grounding conductors. Noise may result from injection into the neutral or grounding wires, wiring faults, or overloaded power circuits.

Crest Factor

The ratio between the crest (peak or maximum) value of a current to the root-mean-square (rms) value. A square wave of current has a crest factor of one. A sine wave has a crest factor of 1.412. Some computer power supplies draw current with a crest factor of between two and three.

Current
The flow of electricity expressed in Amperes.

Current Limit
The function of a circuit or system that maintains a current within its prescribed limits. UPS systems have an electrical current limit that regulates the output current to a value within the UPS limits. Current limiting may occur when a load demanding high inrush current is switched on.

DC - Direct Current
Electrical current which flows only in one direction.

Differential Mode Noise
Describes noise which occurs between the live and the neutral conductors. Caused by load switching locally.

Dip
A transient voltage decrease. See also ‘Sag’.

Distortion
The difference between the actual ac voltage waveform delivered and an ideal sinewave.

EMI - Electro-Magnetic Interference
Electrically induced noise or transients.

Ferroresonance
Occurs when an iron-core inductor is part of an LC circuit and it is driven into saturation, causing its inductive reactance to increase to equal the capacitive reactance of the circuit.

Ferroresonant Transformer
A transformer that regulates the output voltage by the principle of ferroresonance.

Filter
An electronic device that allows only certain frequencies to pass.

Float Charging

A battery charging scheme suitable for UPS batteries. A float charger maintains a voltage on the battery, known as the float voltage, which is the ideal voltage for the battery and maximizes battery life. At float voltage, a current flows into the battery which exactly cancels the battery's internal self discharge current.

Fuel Cell

A fuel cell produces electricity from external supplies of fuel and oxidant. The fuel and the oxidant react in an electrolyte to produce an electrical output. Fuel cells can operate virtually continuously as long as the flows of fuel and oxidant are maintained. Unlike batteries, which store energy, fuel cells must be continually replenished.

Ground Fault

An undesirable connection that allows current to flow from a conductor to ground.

Harmonic

Voltage or current signals that are not at the desired 50Hz fundamental frequency, but are at some multiple frequency, such as the third harmonic, 150Hz and the fifth harmonic, 250Hz. Excessive harmonic voltages can have serious effects on modern equipment power supplies and may cause overheating.

Harmonic Distortion

Excessive harmonic (a frequency that is a multiple of the fundamental frequency) content that distorts the normal sinewave.

Hertz or Hz

The unit of measure of the frequency of alternating current (ac), the same as cycles per second.

Hot-Scalable

A UPS system is hot-scalable if its power capacity can be increased:

- Vertically - by adding hot-swappable UPS modules in a rack without removing power from the critical load or transferring the critical load onto the raw AC mains supply.
- Horizontally - by adding free-standing UPS cabinets/racks without removing power from the critical load or transferring the critical load onto the raw AC mains supply.

Hot-Swappable

A UPS power module is hot-swappable if:

- it can be inserted or removed from the host UPS system without removing power from the critical load or transferring the critical load onto the raw AC mains supply.
- it can be safely electrically disconnected from its host system by means of electrically safe connectors.
- it can be isolated from the rest of the host system without the risk of human error that may cause damage to the module, the host system or the critical load.

IGBT - Insulated Gate Bipolar Transistor

A high power switching transistor used in modern UPS inverters.

Inductance

The property of an electric circuit, or component, that causes an electromotive force to be generated by a change in the current flowing. Inductance is measured in Henry (H) although, as this a very large unit, the most usual references will be the milli Henry (mH) or micro Henry (µH).

Inrush Current

The current drawn by a device when it is first switched on. Computer equipment often draws inrush currents of three to ten times the nominal operating value.

Inverter

Part of a UPS that converts the dc into ac power.

Isolation

The degree to which a device like a UPS can electrically separate its input from its output.

Joules

A measure of the amount of energy delivered by one watt of power in one second. The Joule rating of a surge protection device is the amount of energy that it can absorb before it is damaged.

kVA

Thousand VA (*See "Volt-Ampere"*).

Load

Any electrical device connected to a power source is a ‘load’. For a UPS, the load is the amount of current/power required by the attached electronic equipment.

MOV - Metal Oxide Varistor

A voltage clamping device capable of absorbing very large currents without damage.

Noise (Electrical)

Any undesirable electrical signal.

Overvoltage

An abnormally high voltage sustained for an extended period.

Phase

Load current is drawn from a voltage source. In ac systems, the voltage is a sinewave and for a purely resistive load, the current drawn is also a sinewave aligned perfectly (in phase) with the voltage sinewave. Most loads, however, are not purely resistive and the current drawn is delayed and lags behind the voltage sinewave (out of phase). The lag is measured in degrees. Power factor is equal to the cosine of this phase difference.

Power Factor

The relationship between actual power (W) and apparent power (VA). Calculated by dividing Watts by Volt-Amperes (W/VA).

PWM - Pulse-Width Modulation

Process of varying the width of a train of pulses to adjust the rms voltage and frequency and modify the waveshape, typically to sinusoidal.

Rectifier/Charger

Part of a UPS that converts the incoming ac utility power to dc power for the inverter and to charge the batteries.

Regulation

Describes the amount that the voltage of an ac power source changes. A UPS has poor regulation when its average voltage varies or drifts, or if the voltage varies when a load is applied.

RFI - Radio-Frequency Interference

Electrical noise resulting from some parts of the equipment or wiring acting as a radio antenna. This noise may be large enough to disrupt communications or cause computing errors.

RMS - Root Mean Square

The square root of the average value of the squares of all the instantaneous values of current or voltage during one half cycle of an alternating current. The rms value of a sinewave is approximately 0.707 times the peak value.

RS-232

A serial communications protocol. It may be used between a UPS and computer to communicate alarm, status or control signals and instructions.

Sealed Lead-Acid Battery

A battery containing a liquid electrolyte that has no opening for level top-up (sometimes mistakenly referred to as *maintenance free*).

Sinewave

A fundamental waveform produced by periodic, regular oscillation that expresses the sine or cosine of a linear function of time or space or both.

Slew Rate

In order that a UPS can transfer to bypass circuit without load interruption, the UPS must remain synchronised to the mains supply. However, as sudden changes in UPS output frequency may cause problems in the load, circuits in the UPS control the permitted rate of change (slew rate).

SNMP

Simple Network Management Protocol is a set of protocols for managing complex networks. SNMP works by sending messages, called protocol data units (PDUs), to different parts of a network. SNMP-compliant devices store data about themselves in Management Information Bases (MIBs) and return this data to the SNMP requesters.

Static Switch

A static switch is an 'intelligent switch' used to select either the UPS inverter output voltage or the raw mains to supply the load. The selection is made by control logic which continually monitors the bypass (raw mains) and inverter voltages.

Stratification

An undesirable condition which may exist in a battery cell or block where, over time, the electrolyte settles into layers. Each layer is of a different density and acidity. Under normal conditions the electrolyte should have a consistent acidity and density.

Surge

An abnormally high voltage lasting for a short period of time.

Switching Time

The amount of time (usually in milliseconds) taken by a standby or off-line UPS to switch from utility output to inverter output when the UPS senses a power interruption.

THDi

THDi is the abbreviation used for the input Total Harmonic Distortion of the input current waveform. It is generally accepted that the THDi should be kept low to avoid excessive current distortion at the point of common coupling within a building due to the cumulative effect of other connected equipment.

Three Phase
An electrical system with three different voltage lines with sinewave waveforms that are 120 degrees out of phase from one another.

Total Harmonic Distortion
The ratio of the rms sum of all the harmonic components and the fundamental signal. *See THDi.*

Transfer Time
The amount of time (usually in milliseconds) taken by a standby or off-line UPS to sense a power interruption and switch from utility output to inverter output.

Transformer
A device used to change the voltage of ac power or to isolate a circuit from its power source.

Transient
Any abnormal or irregular electrical event, such as a surge or sag.

Transverse Mode Noise
Noise resulting from the conversion of common-mode noise to normal-mode noise after passing through a transformer.

Undervoltage
An abnormal low voltage lasting for a longer period of time than a sag.

UPS - Uninterruptible Power Supply
A general term used to describe any of the various types of standby power systems.

VA
See Volt-Ampere.

Volt
The unit of electrical force or potential.

Volt-Ampere

The unit of apparent power that is the traditional unit of measure for rating UPS. Compare to watts, which is the unit of measure of actual power.

Voltage Regulator

A device providing constant or near-constant output voltage even when the input voltage fluctuates.

VRLA - Valve Regulated Lead Acid Batteries

Valve regulated batteries emit virtually no gas, require no topping up and need no special ventilation other than that required by the local building codes.

Watts

The unit of actual power. Compare with Volt-Amperes (VA), which is the unit of measure of apparent power.

Waveform

The graphical representation of an electrical signal.

15 Further Reading

This final section of the Handbook contains links and details of web sites for organisations you may find useful.

General Information	
Uninterruptible Power Supplies Ltd	www.upspower.co.uk/resources/document-downloads.aspx
Power Management Design Line	www.powermanagementdesignline.com/
The Uptime Institute	www.uptimeinstitute.com/
Modern Building Services	modbs.co.uk/
Electrical Times	www.electricaltimes.co.uk/
The Institution of Engineering and Technology	www.theiet.org/
Electrical Review	www.electricalreview.co.uk/
Electrical Construction and Maintenance	ecmweb.com/
Institute of Electrical and Electronics Engineers	www.ieee.org/portal/site/
Yuasa Industrial Batteries	www.yuasa-battery.co.uk/
Energy Bulletin	www.energybulletin.net/
British Standards Institute	www.bsi-global.com/
Building Design	www.buildingdesign.co.uk/

UK Government	
ECA - Enhanced Capital Allowance scheme	https://etl.decc.gov.uk/etl/site.html
DEFRA - Sustainable Energy	www.defra.gov.uk/environment/energy/
Ofgem	www.ofgem.gov.uk/

European Union	
EU Energy Legislation	europa.eu/
European Commission - Energy	ec.europa.eu/energy/index_en.htm/

Renewable and Green Energy	
CADDET	www.caddet.org/
World Renewable Energy Congress / Network	www.wrenuk.co.uk/
Renewable Energy Foundation	www.ref.org.uk/
NaREC	www.narec.co.uk/

Professional Organisations	
Institute of Electrical and Electronics Engineers	www.ieee.org/
IEEE Computer Society	www.computer.org/
Association of Building Engineers	www.abe.org.uk/

Professional Organisations	
Chartered Institution of Building Services Engineers	www.cibse.org/
Energy Networks Association	www.ena-eng.org/

16 Sample UPS Specifications

Introduction

The following pages contain sample manufacturers' specifications for modern UPS systems, and are provided for guidance only.

When comparing manufacturers' specifications it is important to consider:

- reliability/availability
- efficiency/running costs
- input current THD
- input power factor
- load power factor derating factor
- UPS topology – be sure to only compare 'like with like'
- system upgradeability
- size/weight
- flexibility of battery configuration
- serviceability
- reputation of supplier
- installation references
- cost.

The UPS Guide Specification which follows is a comprehensive generic specification for a contemporary, free-standing, three phase UPS system such as might be produced by a specialist electrical consultant on behalf of a client. The specification ensures compliance with relevant international safety, performance and quality standards in addition to incorporating the latest technological advances. The specification may be used for stand alone or paralleled, free-standing UPS systems.

The specifications which appear from page 301 onwards contain technical and physical data guidelines for UPS systems in particular power ranges which may be incorporated into specification layouts similar to the full written example.

UPS Guide Specifications

Three-Phase Uninterruptible Power Supply System (Static, Free-Standing)

SECTION 1 - GENERAL

1.1 SUMMARY

This specification describes a free standing, continuously rated, solid state Uninterruptible Power Supply (UPS). The UPS utilises true on-line, double conversion topology, whereby the output power supplied is derived directly from the UPS inverter without the need for an internal step-up output transformer. The UPS will be used to operate in conjunction with the existing building supplies and shall provide high quality power distribution for critical loads.

1.2 STANDARDS

The product shall have CE marking in compliance with the following European directives:

- Low Voltage Directive - 2006/95/EC
- EMC Directive - 2004/108/EC

The manufacturer shall demonstrate conformity with the UPS harmonised standards and directives EN 62040-1-1 (Safety) and EN 62040-2 (EMC).

The UPS shall be designed in accordance with the applicable sections of the current revision of the following standards. Where a conflict arises between these documents and statements made herein, the statements in this specification shall govern.

Safety Standard:	EN 62040-1-1:2003 EN 60950-1:2001/A11:2004
Electromagnetic Compatibility Standard (EMC):	EN 62040-2:2005 EN 61000-3-2:2000 EN 61000-3-3:2008 EN 61000-6-2:2001 EN 61000-6-4:2007+A1:2011
Performance Standard:	EN 62040-3:2001

1.3 SYSTEM DESCRIPTION

1.3.1 General

The UPS system shall consist of a single UPS unit or the appropriate number of UPS units connected in parallel for operation in capacity or N+n redundancy mode. For a parallel installation all UPS units must operate simultaneously and equally share the load without the need for either a centralised static bypass switch or system control cabinet.

1.3.2 Parallel Installation

Capacity (non-redundant) system.

All the UPS units connected in parallel are required to supply the full rated load. If a UPS unit power or control module should malfunction, the load is to be transferred automatically to the bypass line via each of the UPS units with their static bypass switches being triggered simultaneously. The battery set should consist of at least two strings so that in the event of a battery malfunction the affected string is automatically isolated from the system thereby ensuring battery autonomy is retained, albeit of a shorter duration.

Redundant operation

The UPS system will operate in an N+n configuration where N is the number of UPS units connected in parallel to support the load and n is the number of UPS units connected in parallel to provide the coefficiency of redundancy.

The parallel UPS units shall be capable of operation from a common d.c. bus or with a separate d.c. supply for each UPS unit. In either case the batteries should be configured so that the failure of one battery string (common d.c. bus) or the failure of one battery set (separate d.c. supply for each UPS) provides battery redundancy whereby the specified autonomy at full load is maintained.

The malfunction of one of the UPS units power or control modules shall cause that particular UPS unit to be automatically isolated from the system and the remaining UPS units shall continue to support the load. Replacement or repair of a UPS unit shall be achieved without disturbance to the connected load.

1.3.3 Modes of Operation

The UPS shall be designed to operate as a true on-line, double conversion, Voltage and Frequency Independent (VFI) system where the UPS output is independent of supply (utility/generator) voltage variations, and frequency variations are controlled within EN 61000-2-2 limits. The following modes of operation shall apply

A *Normal - The critical a.c. load is continuously supplied directly by the UPS inverter. The UPS input free running rectifier derives power from the utility or generator a.c. source and supplies d.c. power to the inverter. A separate but integral battery charger shall maintain a ripple free float-charge voltage to the battery.*

B *Battery - Upon failure of the input a.c. power supply the critical a.c. load is supplied by the inverter, which obtains power from the battery. There shall be no interruption in power to the critical load upon failure or restoration of the utility or generator a.c. source.*

C *Recharge - Upon restoration of utility or generator a.c. power after a power outage, the input rectifier shall automatically restart and resume supplying power to the inverter and the battery charger shall recommence recharging the battery. The UPS input rectifier shall provide a soft start on the return of the utility or generator a.c. power. For parallel configurations, each UPS unit shall switch on sequentially, with a switch on delay of between approximately 5 to 10 seconds.*

D *Automatic Restart - Upon restoration of utility or generator a.c. power, after an a.c. power outage and after a complete battery discharge, the UPS unit(s) shall automatically restart and resume supplying power to the connected load via the inverter.*

E *Static Bypass - The static bypass shall provide an alternate path for power to the connected a.c. load and shall be capable of operating in the following manner:*

Single UPS installation

1 *Automatic - In the event of a UPS failure or should the inverter overload capacity be exceeded the UPS unit shall perform an automatic transfer of the connected a.c. load from the inverter to the bypass source.*

2 *Eco-Mode - The UPS unit shall be able to operate in Eco-Mode when the power quality parameters of the by-pass source are within permissible tolerances. The UPS system shall automatically transfer the load to normal mode if the by-pass source goes out of permissible tolerances. Transfer in both directions shall be less than 5mS.*

3 *Manual - Should the UPS unit need to be taken out of service for limited maintenance or repair, manual activation of the bypass shall cause an immediate transfer of the connected a.c. load from the inverter to the bypass source. Full electrical isolation of the UPS system shall therefore be obtained, without disruption to the critical load, by operation of a separate wrap-around maintenance bypass.*

Parallel UPS installation

1 *Automatic - In the event of a UPS failure the faulty UPS unit shall automatically disconnect itself from the critical bus without affecting the critical load. If the remaining UPS unit(s) are unable to support the load, e.g. an overload condition, all the UPS units (including the faulty module) shall perform an automatic transfer of the connected a.c. load to the bypass source via each of their internal static bypass switches.*

2 *Manual - Should all the UPS units need to be taken out of service for limited maintenance or repair, manual activation of the static bypass switch on one of the UPS units shall cause an immediate transfer of the connected a.c. load to the bypass source via each of the UPS units' internal static bypass switch. Full electrical isolation of the UPS system shall therefore be obtained, without disruption to the critical load, by operation of the wrap-around maintenance bypass switch located in the UPS parallel switch panel.*

1.4 PERFORMANCE REQUIREMENTS

The UPS shall be a true on-line double conversion, Voltage and Frequency Independent (VFI) technology in accordance with Standards IEC 62040-3. The UPS shall be provided with the facility for paralleling for capacity or redundancy without limitation on the number of UPS units connected in parallel.

1.4.1 AC Input to UPS

Voltage configuration	400/230, 415/240 or 380/220 Vac nominal, three-phase, 4-wire-plus-ground.
Input frequency	35 to 70Hz, without switching to battery supply
Input current distortion	Sinewave <3.5% THDi maximum at 100% rated load, 400/230 Vac
Input power factor	Equal to or greater than 0.99 at 100% rated load, 0.98 at 50% rated load (lagging)
Inrush current	Limited by soft-start

The input voltage window shall be as shown in the table below, based on a nominal input voltage of 230/400V and according to the output load of the UPS. Within the input voltage range shown below the UPS shall not draw power from the batteries to support the load.

Load (% of UPS rating)	**Input voltage (Lower limit)**	**Input voltage (Upper limit)**
100	- 20%	+ 15%
90-99	- 23%	+ 15%
80-89	- 26%	+ 15%
70-79	- 30%	+ 15%
60-69	- 35%	+ 15%
<60	- 40%	+ 15%

1.4.2 AC Output

Output Rating	Single UPS Installation - Continuously rated at XXX kVA /0.8 p.f. Parallel UPS Installation - N+1 parallel redundant, continuously rated at XXX kVA/0.8 p.f.
Voltage configuration	3 x 400/230, 415/240 or 380/220 Vac, three-phase, 4-wire-plus-ground.
Voltage tolerance	static ± 1%, dynamic ± 4% (0-100-0 load steps)
Frequency regulation	50 or 60 Hz, ± 0.1%.
Frequency slew rate	2.0 Hertz per second maximum
Bypass frequency synch. range	± 2% or ± 4% (programmable)
Voltage Distortion	< 3% total harmonic distortion (THD) maximum - 100% linear load. < 4% total harmonic distortion (THD) maximum - 100% non-linear load with crest factor ratio of 3:1.
Load power factor range	0.9 leading to 0.6 lagging without derating kVA
Load peak (crest) factor	3:1 minimum
Load imbalance	100% (all 3 inverter phases shall be regulated independently)
Overload capability	@ p.f. 1.0 – 110% Load - 10 min, 135% Load - 60 sec @ p.f. 0.9– 125% Load - 10 min, 150% Load - 60 sec If the overload limits or times are exceeded the UPS will transfer the load to bypass (if available) via the static transfer switch
Transient recovery time	within 1% of steady state output voltage within 20 milliseconds

1.4.3 UPS Efficiency

The overall efficiency (ac-dc-ac, on-line mode) shall not be less than the figures shown in the table below:

UPS unit rating	**Load**			
	100%	**75%**	**50%**	**25%**
<= 60 kVA	95.2	95.5	95.7	94.5
> 60 kVA	95	95.5	96	95.5
Measurement with linear load (p.f. = 1.0.)				

1.4.4 Batteries

A *The battery system shall be sized to support a connected load of XX (0.8 p.f.) for a minimum of XX minutes at an ambient temperature of 20°C.*

B *The battery system shall consist of gas recombination, valve regulated, lead acid cells, compliant with BS6290 Part 4 and BS EN6089-2. Flame retardant batteries shall be provided, which renders the UPS suitable for installation inside a computer room.*

C *The UPS battery charging circuit shall comprise of a separate battery charger and not depend on a charge voltage being derived from the UPS input rectifier. Consequently the battery charging voltage shall have zero a.c. (ripple) content.*

D *For single UPS systems the battery system shall consist of a minimum of 2 parallel strings of multiple cells. Each individual parallel string shall have its own dedicated means of electrical protection.*
For multiple UPS units connected in parallel the battery system shall be either:

- *A common battery feeding all the UPS units. In this case the battery system shall consist of a minimum of two parallel strings of multiple cells. Each individual string shall have its own dedicated means of electrical circuit protection.*
- *A separate battery system for each individual UPS unit. In this case each separate battery system may consist of one protected string of multiple cells. If two or more parallel strings are used then each individual string shall have its own dedicated means of electrical circuit protection.*

For all the above battery system arrangements the batteries shall be configured so that in the event of a battery malfunction the affected string is automatically isolated from the system thereby ensuring battery autonomy is retained (see System Description 1.3.2).

E *The batteries shall be housed in cabinet/s comprising a floor-standing steel enclosure with dimensions and paint finish to match the UPS system cabinet/s to form a continuous suite when standing immediately adjacent to the UPS system cabinet/s. The battery cabinet/s shall have full width opening doors to permit ease of access for the purposes of maintenance and/or repair of the batteries.*
Alternatively, the batteries shall be housed on open or cladded racks of a steel construction, having an epoxy powder-coated finish, with adjustable feet for levelling and adequately designed to support the weight of the batteries and permit ease of access for the purposes of maintenance and/or repair of the batteries. If the battery system is located on open stands then all individual battery cell terminals shall be fully shrouded to prevent inadvertent contact.

F *A fully discharged battery system shall be capable of being recharged to 80% of the UPS output capacity within a maximum period of 10 times the normal total discharge time period, and to 90% of the UPS output capacity within a maximum period of 4 hours.*

G *The UPS d.c. bus voltage shall be variable whereby the number of battery blocks can be adjusted between 40 to 50 (12 Vdc) or 80 to 100 (6 Vdc) to enable the battery system to be optimised for size and cost.*

1.5 ENVIRONMENTAL CONDITIONS

1.5.1 Temperature and Humidity

The UPS system shall be designed to operate continuously at full load without degradation of its reliability, operating characteristics or service life in the following environmental conditions:

- UPS ambient temperature range: 0°C to 40°C
- Battery ambient temperature: 20°C
- Humidity: 5 to 95% RH non-condensing

1.5.2 Altitude

The UPS system shall be designed for operation in altitudes up to 1000 metres (3300 ft.), without the need for derating or reduction of the above environmental operating temperatures.

1.5.3 Audible Noise

The audible noise generated by the UPS system >60kVA operating on 100% load not exceed 71 dBA measured at 1 metre from the surface of the UPS. For a module <60kVA this shall not exceed 65 dBA

1.5.4 Electrostatic Protection

The UPS system shall be able to withstand a minimum 15kV electrostatic discharge without affecting the critical load.

1.5.5 Floor Loading

The maximum floor load of the UPS system cabinet (excluding batteries) shall not exceed a UDL of 8.0 kN/ m^2

1.5.6 Dimensions

To permit access through a standard single doorway opening, either the width or the depth of the UPS and battery cabinets shall not exceed 750mm.

1.5.7 Cabinets

The UPS system cabinet shall comprise of a floor standing steel enclosure to house the power system, control systems, battery connections and all associated switchgear necessary for the correct operation of the UPS in accordance with the requirement of the specifications. All switchgear and interconnections must be adequately protected to enable an isolated section to be safely maintained or repaired whilst the remaining system supports the load.

1.5.8 Harmonic Currents

The UPS system shall be designed to limit the injection of current harmonics in to the incoming utility supply source to within limits acceptable to the Network Operating Company (NOC) and in accordance with the Electricity Association Recommendation G5/4.

1.6 USER DOCUMENTATION

The specified UPS system shall be supplied with one (1) user's manual. Manuals shall include:

- General arrangement of the UPS showing dimensions and weight
- User operating instructions
- Single line schematic diagram with functional description of the equipment
- Installation drawing along with recommended cable and protective device sizes
- Safety and maintenance guidelines

1.7 AFTER SALES SERVICE

1.7.1 Warranty

The UPS manufacturer shall warrant the UPS system, including the batteries, against defects in materials and workmanship for 12 months from the date of commissioning or 15 months from the date of delivery, whichever is soonest. Subject to the UPS's being commissioned by the manufacturers trained engineer, the warranty shall provide free replacement parts and on-site labour.

1.7.2 Extended Warranty

The UPS manufacturer shall provide the facility for enhancing or extending the warranty by providing an annual maintenance contract. The maintenance contract shall provide:

- Guaranteed response time
- Two preventative maintenance visits per year
- 24 hour telephone support directly from the UPS manufacturer
- Free labour, travelling to site and incurred expenses
- Free replacement parts (excluding batteries outside the warranty period)

1.8 QUALITY ASSURANCE

1.8.1 UPS Manufacturer Qualifications

The UPS manufacturer shall have a minimum of 10 year's experience in the design, manufacture, and testing of solid-state UPS systems.

1.8.2 Factory Testing

Before shipment, the manufacturer shall fully and comprehensively test the system to assure compliance with the specification. These tests shall include full functional tests at the UPS rated load and a minimum 12 hour continuous burn in test at the UPS rated load.

SECTION 2 - PRODUCT

2.1 FABRICATION

2.1.1 Construction

All materials and components making up the UPS shall be new, of current manufacture, and shall not have been in prior service except as required during factory testing. The UPS shall be constructed of replaceable sub-assemblies.

2.1.2 Wiring

Wiring practices, materials, and coding shall be in accordance with the requirements of the IEC 60950-1:2001 and other applicable British and European codes and standards.

2.1.3 UPS Cabinet

The UPS system cabinet shall offer a minimum degree of protection to the EN 60529 standard, IP20 code.

The UPS cabinet shall be cleaned, primed and painted in graphite grey (RAL 7024). Either the width or the depth of the UPS cabinet should not exceed 750mm, to permit access through a standard doorway.

2.1.4 Battery Cabinet

The battery cabinet shall offer a minimum degree of protection to the EN 60529 standard, IP20 code.

The battery cabinet shall be cleaned, primed and painted to RAL 7024 and should match the UPS cabinet(s) in appearance and height. Either the width or the depth of the battery cabinet should not exceed 750mm to permit access through a standard doorway.

2.1.5 Battery Racks

The battery racks shall be of a steel construction, having an epoxy powder-coated finish, with adjustable feet for levelling. Open racks shall not exceed 2 meters in height to the top tier and should not be more than 2 rows deep if it is not possible to gain rear access, e.g. the rack is placed against a wall.

Cladded racks shall offer a minimum degree of protection to the EN 60529 standard, IP20 code and the panels shall be cleaned, primed and painted to RAL 7024.

2.1.6 Cooling

The UPS shall be forced-air cooled by internally mounted fans.

2.2 COMPONENTS

2.2.1 Input Converter

A General

Incoming a.c. power shall be converted to a regulated d.c. output by the input converter for supplying d.c. power to the inverter. The input converter shall provide input power factor and input current harmonic distortion correction. 12 pulse rectifier and/or filter devices will not be accepted if they have a detrimental effect on the overall UPS efficiency.

B AC Input Current Limit

The input converter shall be provided with a.c. input over current protection.

C Input Protection

The UPS shall have built-in protection against undervoltage, overcurrent, and overvoltage conditions, including low-energy surges introduced on the primary a.c. source and the bypass source. The UPS cabinet shall not contain an input circuit breaker. The electrical contractor shall supply an input circuit breaker/fuse sized to supply the rated load and to recharge the battery at the same time.

D Battery Recharge

To prolong battery life, the UPS shall have the facility for automatically adjusting the battery charging voltage according to the environmental temperature of the batteries. Battery charger shall be ripple-free avoiding premature battery ageing.

2.2.2 Inverter

A General

The inverter shall convert d.c. power from the input converter output, or the battery, into precise regulated sinusoidal wave a.c. power for supporting the critical a.c. load.

B Overload

The inverter shall be capable of supplying current and voltage for overloads exceeding 100% and up to 150% of full load current. A visual indicator and audible alarm shall indicate overload operation. The load shall be immediately transferred to bypass when the load current exceeds this level of overload.

In the event the bypass supply is unavailable (e.g. mains failure), the inverter shall have electronic current-limiting protection to prevent damage to internal components. The inverter shall be self-protecting against any magnitude of connected output overload and the inverter control logic shall sense and disconnect the inverter from the critical a.c. load within 200 mS.

C Output Frequency

The output frequency of the inverter shall be controlled by an oscillator. The oscillator shall hold the inverter output frequency to ± 0.1% for steady state and transient conditions. The inverter shall synchronise with the bypass supply assuming the bypass supply stays within the selected range. If the bypass source fails to remain within the selected range, the inverter shall revert to the internal oscillator.

D Battery over Deep Discharge Protection

To prevent battery damage from deep discharging, the UPS control logic shall monitor the discharge voltage and shut the UPS down at a pre-set minimum dc voltage. This level is dependent on the rate of discharge and battery autonomy and shall be adjusted at the time of commissioning the UPS equipment. Under any circumstances it should not be set to less than 1.67V per cell.

2.2.3 Display and Controls

A General

The UPS front panel shall consist of multiple status LEDs, switches, and an alphanumeric LCD display for additional alarm/configuration information. During normal operation (on-line), all mimic display LEDs shall be green in colour and indicate the following:

Line 1	(a.c. Input rectifier)
Line 2	(a.c. Input by-pass)
Battery	(Load supplied from the battery)
On Inverter	(Load supplied from the inverter)
On Bypass	(Load supplied from the by-pass)

A UPS fault shall be identified via additional indicators and audible alarms to notify the user that a UPS fault condition has occurred. During mains failure the colour of the LED's shall be as follows:

Line 1	(a.c. Input rectifier)	red
Line 2	(a.c. Input by-pass)	red
Battery	(Load supplied from the battery)	green
On Inverter	(Load supplied from the inverter)	green
On Bypass	(Load supplied from the by-pass)	off (no colour)

If there is a fault condition, the UPS shall attempt to maintain conditioned power to the load or at minimum transfer to bypass.

In addition to a visual fault signal (alarm), the UPS shall also record fault occurrences in a rolling event log. The event log shall record up to 64 occurrences, with the oldest events discarded first, etc. The user shall have access to the event log through the LCD display. Every alarm and/or event recorded in the event log will contain a time and date stamp.

B Audible Alarms

The volume of all audible alarms shall be at least 65 dBA at a distance of one meter. An audible alarm shall be used in conjunction with the LED/LCD display to indicate a change in UPS status.

The audible alarms shall warn loss of mains or generator supply, low battery (whilst on battery), and all other alarm conditions. For all audible alarm conditions, the display shall identify the cause of error/alarm. All alarm tones shall be a continual tone until the condition rectifies itself or the alarm is silenced. Once silenced, the audible alarm shall not sound until a new alarm condition is present, but the LED indication shall continue to identify the alarm condition.

C Alarm Silence Button

The display panel shall include an audible alarm 'Reset' switch. If the alarm mute (Reset) switch is pressed for one second, all current audible alarms shall be disabled. If a new alarm occurs, or a cancelled alarm condition disappears and then re-appears, the audible alarm is re-enabled.

D LCD Display

The LCD display shall be used to provide the following information to the user and UPS service engineer:

Phase Voltages:	Input to converter Input to by-pass UPS output
Battery	DC Voltage (voltage to/from battery)
Current:	UPS output (line current) Battery charging/discharging
Frequency:	UPS Input UPS output
Autonomy:	Remaining back-up time (minutes) Battery capacity (%)
Others:	UPS output active power (kW) UPS output reactive power (Kvar) UPS output apparent power (kVA) UPS load (% per phase)

2.2.4 Automatic Battery Test

The UPS shall initiate an automatic battery testing sequence periodically (default setting once a month), at a programmed day and time of day, selectable by the end user. It shall be possible for the user to disable the automatic battery test.

Should a fault with the battery be detected, the UPS will immediately return to normal mode and a fault status (visual, audible, and remote) shall be indicated. No audible or remote signal indication of the battery test shall be communicated during the duration of the automatic battery test.

The automatic battery test shall operate if no UPS alarm conditions are present and if the battery is at least 90% of its full capacity.

2.2.5 Remote Emergency Power Off (EPO)

The remote 'emergency power off' function (EPO) shall allow the user to immediately shutdown the UPS output supply in an emergency situation. The EPO shall be able to interface with normally closed, volt-free contacts external to the UPS. The EPO connection to the UPS shall be to a clearly identified terminal block type connector.

The UPS EPO shutdown function shall not operate if the UPS internal manual bypass switch is in the bypass position. When the external EPO function has been re-set, manual intervention is required to restart the UPS. The electrical contractor shall include the facility for interfacing the EPO circuit with the supply feed of the UPS and provide a means of disconnecting all sources of power to the UPS.

2.2.6 Standby Generator On contact

The UPS shall have the facility whereby, on receipt of a volt free contact closure start signal from a standby generator supplying the UPS, the UPS system will automatically inhibit battery recharge (selectable) and Inhibit transfer to bypass (selectable).

2.2.7 Bypass

A. General

A bypass circuit shall be provided as an integral part of the UPS.

The bypass control logic shall contain an automatic transfer control circuit that senses the status of the inverter logic signals and operating and alarm conditions. This control circuit shall provide a transfer of the load to the bypass source, without exceeding the transient limits specified herein, when an overload or malfunction occurs within the UPS.

B. Automatic Transfers

The transfer control logic shall automatically activate the bypass, transferring the critical a.c. load to the bypass source, after the transfer logic senses one of the following conditions:

- Inverter overload capacity exceeded
- Inverter over temperature
- UPS fault condition (non redundant configuration)

For inverter overload conditions, the transfer control logic shall inhibit an automatic transfer of the critical load to the bypass source if one of the following conditions exists:

- Inverter/Bypass voltage difference exceeding preset limits (-20/+15% of nominal load)
- Bypass frequency out of preset limits (± 4% of nominal frequency)

C. Automatic Retransfer

Retransfer of the critical a.c. load from the bypass source to the inverter output shall be automatically initiated unless inhibited by manual control. The transfer control logic shall inhibit an automatic retransfer of the critical load to the inverter if one of the following conditions exists:

- Bypass out-of-synchronization range with inverter output
- Overload condition exists in excess of inverter full load rating
- UPS fault condition present (non redundant configuration)

D. Manual Transfer

In addition to the internal static bypass switch, the UPS shall have an internal manual bypass 'make-before-break' transfer switch. The manual bypass function shall be provided via a switch, which is accessible from the front of the UPS and located behind the UPS cabinet door.

The manual bypass switch shall be electrically interlocked to prevent back-feeding the UPS output in the event of incorrect operation, e.g. transferring the load to bypass via the manual bypass switch when the load is supplied by the inverter.

The UPS shall initiate an audible alarm upon transfer to manual bypass. The alarm shall be capable of being muted by the user. The alarm shall continue to sound (unless muted) while in bypass mode. This shall provide a reminder to the user that the load continues to be powered from utility or generator supply alone.

2.2.8 Battery

The battery system shall consist of gas recombination, valve regulated, lead acid cells, compliant with BS6290 Part 4 and BS EN6089-2. Flame retardant batteries shall be provided, which renders the UPS suitable for installation inside a computer room.

The UPS battery charging circuit shall comprise of a separate battery charger and not depend on a charge voltage being derived from the UPS input rectifier. Consequently the battery charging voltage shall have zero a.c. (ripple) content.

For single UPS systems the battery system shall consist of a minimum of 2 parallel strings of multiple cells. Each individual parallel string shall have its own dedicated means of electrical protection.

For multiple UPS units connected in parallel, the battery system shall be either:

- A common battery feeding all the UPS units. In this case the battery system shall consist of a minimum of 2 parallel strings of multiple cells. Each individual string shall have its own dedicated means of electrical circuit protection.

- A separate battery system for each individual UPS unit. In this case each separate battery system may consist of one protected string of multiple cells. If two or more parallel strings are used then each individual string shall have its own dedicated means of electrical circuit protection.

For all the above battery system arrangements the batteries shall be configured so that in the event of a battery malfunction the affected string is automatically isolated from the system thereby ensuring battery autonomy is retained (see System Description 1.3.2).

2.3 COMMUNICATIONS

2.3.1 Voltage-Free Contacts

The UPS shall incorporate voltage-free relay contacts suitable for direct communication with either a computer system, remote alarm panel or the clients BMS system and an RS-232 communication port for serial communications and to enable communication via modem equipment.

2.3.2 Relay Contacts

The relay contacts shall be available through one DB-25F communication connector. The UPS shall communicate, via volt-free relay changeover contacts, the following status signals:

Pin 1	Mains Failure	(normally open)
Pin 2	Mains Failure	(normally closed)
Pin 4	Load on inverter	(normally closed)
Pin 5	Load on inverter	(normally open)
Pin 7	Battery low	(normally open)
Pin 8	Battery low	(normally closed)
Pin 10	Load on mains	(normally open)
Pin 11	Load on mains	(normally closed)
Pin 13	Common alarm	(normally open)
Pin 14	Common alarm	(normally closed)
Pin 23	+12 Vd.c.	(max. 100mA)
Pin 22	GND	

2.3.3 Serial Communications

The UPS shall have the facility for communication via an RS-232 port. The pin-out configuration for RS 232 port shall be as follows:

Pin 2	Transmit Data
Pin 3	Receive Data
Pin 5	Common

2.3.4 Network Communications

The UPS unit(s) shall include a facility for installing an optional SNMP adapter card to the UPS to permit one or more network management systems (NMS) to monitor the UPS in TCP/IP network environments. 10/100 Mbit Ethernet support shall be included.

2.3.5 Parallel Operation

It shall be possible to configure the status signals from each UPS unit connected in parallel to a common signal programmer device whereby, using Boolean logic, input events or combinations of input events can trigger specified output signal alarms and status events. It shall be possible to communicate the status of the parallel UPS configuration over a LAN/WAN network via NMS and provide modem communication to facilitate remote monitoring via a dedicated telephone line.

7.5 - 12 kVA, single-phase input and output
7.5 - 20kVA, 3-phase input, single-phase output

Mechanical data

Cabinet A
7.5kVA, 10kVA, 12kVA
(WxDxH =340 x 800 x 820)

Cabinet B
10kVA, 15kVA, 20kVA
(WxDxH =450 x 860 x 1250)

Cabinet C
10kVA, 15kVA, 20kVA
(WxDxH =550 x 890 x 1650)

Transportation pallet	Provided with UPS
Packaging	Cardboard (standard)
Accessibility	Rear/side access for cabinet A, front/side access for cabinets B & C
Positioning	Min. 200mm rear space (required for ventilation)
Input/output power cabling	From bottom rear (Cabinet A) and bottom front (Cabinets B and C)

General data

Module rating (kVA)		**7.5**	**10**	**12**	**15**	**20**
Output power factor		0.7				
Output rated power @ p.f. 0.7	kW	5.25	7.0	8.4	10.5	14.0
Output current In @ p.f. 0.7 (230V)	A	22.83	30.43	36.52	45.65	60.87

Module rating (kVA)		7.5	10	12	15	20
Topology		On-line, double conversion, VFI, with static and maintenance bypass				
Technology		Second generation, transformerless				
Double conversion AC-AC efficiency						
100% / 75% / 50% / 25% linear load (cosϕ=0.8ind)	%	93.5 / 93.5 / 92 / 89		94 / 94 / 92.5 / 90		94.5 94.5/ 93/91
100% / 75% / 50% / 25% linear load (cosϕ= 1)	%	93 / 93 / 91.5 / 88.5		93.5 / 93.5 / 92 / 89.5		94/94/92/ 90
Eco-mode efficiency 100% load (on by-pass)	%	98				
Remote signalling and alarms						
Dry port (volt-free contacts) standard		For remote signalling and automatic computer shutdown				
Smart Port (RS 232)		For monitoring and integration in network management				

Rectifier data

Module rating (kVA)		7.5	10	12	15	20
Input voltage 1 : 1	V	1x220V+N, 1x230V+N, 1x240V+N			N/A	
Input voltage 3 : 1	V	3x380/220V+N 3x400V/230V+N 3x415/240V+N		N/A	3x380/220V+N 3x400V/230V+N 3x415/240V+N	
Input voltage window (@ 3x400/230V)	V (%)	For loads <100% (-23%, +15%) For loads <80 (-30%, +15%) For loads <60% (-40%, +15%)				
Input frequency window	Hz	35 - 70				
Input power factor		Single-phase in: 0.98 @ 100% load Three-phase in: 0.95 @ 100% load, 0.98 (inc. filter option)				
Input current form		Single-phase in THDi <7 - 9% @ 100% load Three-phase in THDi <25% @ 100% load; Three-phase in THDi <7 - 9% (with optional filter)				
Inrush current		Limited by soft start				
Input power with rated output power and charged battery	kW	5.6	7.4	9.4	11.1	14.8
Maximum input power with rated output power and discharged battery	kW	6.1	8.1	10.3	12.1	16.2

Battery data

Module rating (kVA)	**7.5**	**10**	**12**	**15**	**20**
Battery type	Lead-acid, maintenance-free VRLA or NiCd				
Number of 12V battery blocks	22-50	26-50	30-48	32-50	
Battery ambient temperature	20°C (recommended)				
Battery storage time	Maximum 6 months (at ambient temperature)				
Temperature controlled battery charger	Not available				
Maximum battery charger current	6 A (standard)				
Battery charging curve	Ripple-free; IU (DIN 41773)				
Battery charger ripple	< 1%				
Battery test	Automatic and periodic (adjustable)				

Inverter data

Module rating (kVA)		**7.5**	**10**	**12**	**15**	**20**
Output rated voltage	V	1 x 220V, 1 x 230V, 1 x 240V				
Output power factor		0.7				
Output waveform		Sinewave				
Output frequency	Hz	50 or 60				
Output frequency tolerance		Free-running, quartz oscillator <±0.1% Synchronized with mains <±2% or ±4% (selectable)				
Overload capability	%	125 for 10 min. and 150 for 1 min.				
Crest factor		3 : 1				
Output voltage stability						
Static	%	< ± 1				
Dynamic (with load step 0-100%, 100-0%)	%	< ± 4				
Output voltage distortion						
With linear load	%	< 1				
With non-linear load	%	< 3 (EN 62040-3:2001)				

Environmental data

Module rating (kVA)		**7.5**	**10**	**12**	**15**	**20**
Audible noise at 100%/50% load	dBA	50/47			53/49	
Ambient temperature (UPS)	°C	0 to 40				
Ambient temperature (Batteries)		20 (recommended)				
Relative humidity	%	Maximum 95% (non-condensing)				
Heat Dissipation						
100% non-linear load (EN 62040-3)	W	460	600	650	800	1120
	BTU/h	1638	2048	2218	2730	3822
100% load ($\cos\phi$=0.8ind)	W	380	500	550	700	800
100% load (resistive $\cos\phi$=1)	W	400	550	600	750	960
Cooling		Fan-assisted				
Recommended airflow (25 - 30°C) with 100% non-linear load per range (EN 62040-3)	m^3/h	110			150	200

Bypass data

Module rating (kVA)		**10**	**15**	**20**	**25**	**30**	**40**	**50**
Bypass operation		At nominal input voltage of 3x400 V ±15%, (196 V to 264 V ph-N)						

Standards

Module rating (kVA)	**7.5**	**10**	**12**	**15**	**20**
Safety	EN62040-1-1:2003 EN60950-1:2001/A11/;2004				
Electromagnetic compatibility	IEC/EN 62040-2:2005, IEC/EN61000-3-2:2000, IEC/EN61000-6-2:2001,				
Performance	IEC/EN 62040-3:2001				
Product certification	CE				
Degree of protections	IP20				

10- 50 kVA, 3-phase input and output

Mechanical data

Cabinet A	Cabinet B	Cabinet C
10kVA, 15kVA, 20kVA (WxDxH =345 x 710 x 720)	15kVA, 20kVA, 25kVA (WxDxH =345 x 710 x 1045)	25kVA, 30kVA, 40kVA, 50kVA (WxDxH =440 x 910 x 1420)

Transportation pallet	Provided with UPS
Packaging	Cardboard (standard)
Accessibility (operator)	10kVA – 25kVA in type A or B cabinets require front/rear access 25kVA – 50kVA in type C cabinets require front access only
Positioning	Front: A minimum of 900mm for free passage. Left/Right Side: 600mm required for service access. Rear: A minimum of 200mm is required for cooling air circulation and the unit should be cabled such that it can be pulled forward to allow 600mm rear clearance for service/maintenance.
Input/output power cabling	10kVA – 25kVA in type A or B cabinets cabled at rear 25kVA – 50kVA in type C cabinets are cabled at rear

General data

Module rating (kVA)		10	15	20	25	30	40	50
Output power factor		0.9						
Output rated power @p.f. 0.9	kW	9.0	13.5	18	22.5	27	36	45
Output Current In @ 400V /0.9 p.f.	A	13.0	19.5	26.0	32.5	39.0	52.0	65.0
Output Current In @ 400V /1.0 p.f.	A	14.4	21.7	28.9	36.1	43.3	57.7	72.2
Topology		On-line, double conversion						
Technology		Third generation, transformerless						
Construction		Parallelable (optional)						
Parallel configuration		Load sharing, decentralized control						
Double conversion AC-AC efficiency								
100/75/50/25% linear load p.f =1.0	%	95.5/ 95.5/ 95.5/ 94.5						
Remote signalling and alarms								
Dry port (volt-free contacts)		For remote signalling and automatic computer shutdown						
Smart port (RS 232)		For monitoring and integration in network management						
Input terminals		EMERGENCY OFF (normally closed) GENERATOR-ON (normally open) BATTERY TEMPERATURE SENSOR						

Rectifier data

Module rating (kVA)		10	15	20	25	30	40	50
Input voltage (factory selectable)	V	3x380/220V+N, 3x400/230V+N, 3x415/240V+N						
Input voltage tolerance (ref to 3x400/230V) for loads in %:		(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load						
Other input voltages		On request						
Input frequency window	Hz	35 - 70						
Input power factor		0.99 @100% Load						
Input current form		Sinewave (THD 7 - 9% input voltage dependant)						
Inrush current		Limited by soft start						
Rectifier max. input power/current								
With rated output power and charged battery (output pf = 0.9)	kW	9.6	14.4	19.1	23.9	28.7	38.3	47.9

Module rating (kVA)		10	15	20	25	30	40	50
With rated output power and charged battery (output pf = 0.9)	A	13.9	20.8	27.8	34.7	41.6	55.5	69.4
With rated output power and discharged battery (output pf = 0.9)	kW	10.5	15.7	21	26.2	31.4	41.9	52.4
With rated output power and discharged battery (output pf = 0.9)	A	15.2	22.8	30.4	37.9	45.5	60.7	75.9

Battery data

Module rating (kVA)	10	15	20	25	30	40	50
Battery type	Lead-acid, maintenance free						
Number of 12V battery blocks*	22-50	32-50	32-50	40-50	24-50	32-50	40-50
Battery ambient temperature	20°C						
Battery storage time	Maximum 6 months (at ambient temperature)						
Temperature controlled battery charger	Yes (with optional temperature sensor)						
Maximum battery charger current	4A				6A		
Battery charging curve	Ripple free IU (DIN 41773)						
Battery charger ripple	< 1%						
Battery test	Automatic and periodic; adjustable						
**Depending on the effective load in kW used by the system (numbers shown are for 0.8 - 0.9 pf only)*							

Inverter data

Module rating (kVA)		10	15	20	25	30	40	50
Output rated voltage	V	3x380/220V, 3x400/230V, 3x415/240V						
Output power factor		0.9						
Output waveform		Sinewave						
Output frequency	Hz	50 or 60						
Output frequency tolerance		Free-running, quartz oscillator <±0.1% Synchronized with mains <±2% or ±4% (selectable)						
Permissible unbalanced load	%	100% (all 3 phases regulated independently)						
Overload capability	%	At p.f. 0.9 110% load 10 min. At p.f. 0.9 130% load 1 min. At p.f. 0.8 125% load 10 min. At p.f. 0.8 150% load 1 min						

Module rating (kVA)		10	15	20	25	30	40	50
Output short capability	A	Inverter: up to 3 x In during 40 ms Bypass: 10 x In during 10 ms						
Crest - factor		3 : 1						
Output voltage tolerance								
Static	%	< ±1						
Step load jump (0-100%, 100-0%)	%	< ±4						
Output voltage distortion								
With linear load	%	< ±2						
With non-linear load	%	< ±4						

Bypass data

Module rating (kVA)		10	15	20	25	30	40	50
Bypass operation		At nominal input voltage of 3x400 V ±15%, (196 V to 264 V ph-N)						

Environmental data

Module rating (kVA)		10	15	20	25	30	40	50
Audible noise @ 100/75% load	dBA	55 / 49		57 / 49		58/ 50	59 / 51	
Ambient temperature (UPS)	°C	0 to 40						
Ambient temperature (Batteries)	°C	20 (recommended						
Relative humidity		Maximum 95% at 20°C (non-condensing)						
Heat dissipation (EN 62040-3)								
100% Non-linear load	W	600	900	1100	1400	1700	2300	2900
100% Non-linear load	BTU/h	2048	3072	3754	4778	5802	7850	9898
Heat dissipation without load	W	120	150	150	170	250	300	350
Airflow (25°C - 30°C) with 100% non-linear load	m^3/h	150	150	150	150	570	570	570
Cooling		Fan assisted						

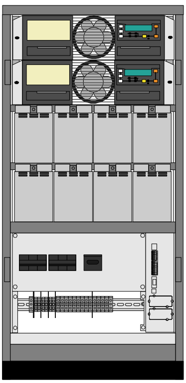
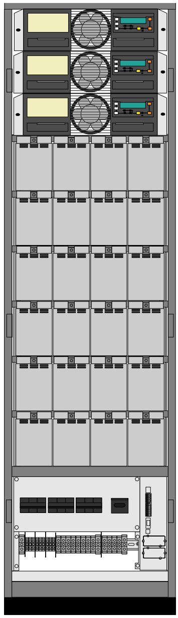
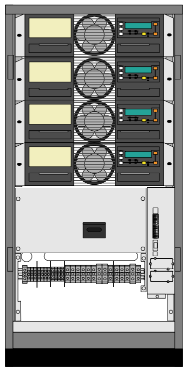
Standards

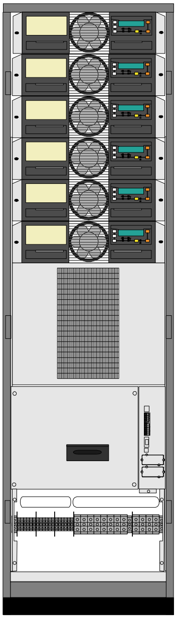
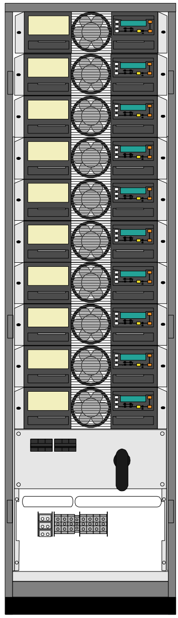
Module rating (kVA)	10	15	20	25	30	40	50
Safety	IEC/EN 62040-1-1:2003, IEC/EN 60950-1:2006+A:2010						
Electromagnetic compatibility	IEC/EN 62040-2:2006, IEC/EN61000-3-2:2006+A2:2009 IEC/EN 61000-6-2						
EMC Classes C2 domestic or industrial In < 16A C3 industrial In >16A	C2	C3					
Performance	IEC/EN62040-3:2001						
Product certification	CE						
Degree of protection	IP 20						

40- 200 kVA 3-phase modular system

This system comprises a range of cabinets that can be populated with a number of 10kVA or 20kVA power modules that operate in parallel within the cabinet to provide the cabinet's rated output. Each power module is a self-contained UPS and incorporates a rectifier, inverter and static bypass.

Mechanical data

		
40KVA (2x20kVA modules) (WxDxH 550 x 1135 x770) Internal battery	60KVA (3x20kVA modules) (WxDxH 550 x 1975 x770) Internal battery	80KVA (4x20kVA modules) (WxDxH 550 x 1135 x770) External battery
Transportation pallet	Provided with UPS	
Packaging	Polythene	
Accessibility (operator)	Totally front accessibility for service and maintenance (no need for side, top or rear access)	
Positioning	Min. 200mm rear space (required for ventilation)	
Input/output power cabling	From the bottom on the front	

	
120KVA (6x20kVA modules) (WxDxH 550 x 1975 x770) External battery	200KVA (10x20kVA modules) (WxDxH 550 x 1975 x770) External battery

General data

Power module rating (kVA)		**10**	**20**
Output power factor		1.0	
Output rated power @ 0.8 p.f.	kVA	10	20
Output rated power @ 1.0 p.f.	kW	10	20
Output current In @ 1.0 p.f.	A	14.5 (@400 V)	29 (@400 V)
Double conversion AC-AC efficiency			
Efficiency AC-AC up to (at Cosφ 1.0) (depending on Module power)		*Load*: *100%* *75.0%* *50.0%* *25.0%* 20kVA: 95.5% 95.5% 95.0% 94.5% 10kVA: 95.5% 95.5% 95.0% 94.5%	
With linear load at 0.8 p.f. ind. With non-linear load (EN 62040-1-1:2003)		Typically up to 1% higher of above values Typically up to 1% lower of above values	

Power module rating (kVA)	**10**	**20**
Eco-mode efficiency at 100% load	98%	
Remote signalling and alarms		
Dry port (volt-free contacts)	For remote signalling and automatic computer shutdown	
Smart port (RS 232)	For monitoring and integration in network management	
Input terminals	EMERGENCY OFF (normally closed) GENERATOR-ON (normally open) BATTERY TEMPERATURE SENSOR	

Rectifier data

Power module rating (kVA)		**10**	**20**
Nominal input voltage	V	3x380/220V+N, 3x400V/230V+N, 3x415/240V+N	
Input voltage tolerance (ref to 3x400/230V) for loads in %:	V	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load	
Input frequency	Hz	35 – 70	
Input power factor		PF=0.99 @ 100% load	
Inrush current	A	limited by soft start	
Output rated power @ p.f.= 0.8	kVA	10	20
Output rated power @ p.f. = 1.0	kW	10	20
Input distortion THDI		Sine-wave THDi = 3% @ 100% load	
Max. input power with rated output power and charged battery (output p.f. = 1.0)	kW	10.5	21
Max. input current with rated output power and charged battery (output p.f. = 1.0)	A	15.2	30.4
Max. input power with rated output power and discharged battery (output p.f. = 1.0)	kW	11.5	23
Max. input current with rated output power and discharged battery (output p.f. = 1.0)	A	16.6	33.3

Battery data

Power module rating (kVA)		**10**	**20**
Battery type		Maintenance free VRLA or NiCd	

Power module rating (kVA)		10	20
Number of 12V battery blocks	No.	24-50 *	36-50 *
Battery ambient temp.	°C	20 (recommended)	
Battery storage time		Maximum 6 months (at ambient temperature)	
Temperature controlled battery charger		Yes (with optional temperature sensor)	
Maximum battery charger current	A	4 A	4 A
Battery charging curve		Ripple free: IU (DIN 41773)	
Battery test		Automatic and periodically (adjustable)	
** Depending of the effective load in kW used by the module*			

Battery capacity usage	10kVA UPS Module				20kVA UPS Module			
Number of battery blocks	24	28	30	34-50	36	40	40	48-50
Max. power in KW	8	8	10	10	16	20	16	20
Max. autonomy (min.)	5	999	5	999	5	5	999	999

Inverter data

Power module rating (kVA)		10	20
Output rated voltage	V	3x380/220V or 3x400/230V or 3x415/240V	
Output waveform		Sinewave	
Output frequency	Hz	50 Hz or 60 Hz	
Output frequency tolerance	%	Free running, quartz oscillator < ±0.1% Synchronized with mains < ±2% or < ±4% (selectable)	
Permissible unbalanced load	%	100% (All 3 phases regulated independently)	
Phase angle tolerance	Deg.	+/- 0 deg. (With 100% unbalanced load)	
Inverter overload capability	%	125% load for 10 min. 150% load for 60 secs.	
Output short capability (RMS)	A	3 x In during 40 ms	
Crest factor		3: 1	
Output voltage stability			
Static	%	< ±1%	
Dynamic (with step load 0%-100% or 100%-0%)	%	< ±4%	
Output voltage distortion			

Power module rating (kVA)		10	20
With linear load	%	< 1.5%	
With non linear load	%	< 3% (EN62040-3:2001)	

Bypass data

Power module rating (kVA)		10kVA UPS Module	20kVA UPS Module
Bypass operation		At nominal input voltage of 3x400 V ±15%, (196 V to 264 V ph-N)	
Bypass short capability (RMS)	A	10 x In during 20 ms	

Environmental data

Power module rating (kVA)		10	20
Audible noise at 100% / 50% load	dBA	55 / 49	57 / 49
Ambient temperature (UPS)	°C	0 - 40	
Ambient temperature (Batteries)	°C	20 (recommended)	
Relative air-humidity		Max. 95% (non-condensing)	
Max. altitude (above sea level)	m	1000m (3300ft) without de-rating	

Power module rating (kVA)		10	20
Derating for altitude			
De-rating factor for use at altitudes above 1000m sea level according (IEC 62040-3)		Height above sea level (m / ft)	De-rating factor for power
		1500 / 4850	0.95
		2000 / 6600	0.91
		2500 / 8250	0.86
		3000 / 9900	0.82
Heat dissipation with 100% non-linear load per module (EN 62040-1-1:2003)	W	550	1100
	BTU/h	1887	3745
Airflow (25° - 30°C) with non-linear load per module (EN 62040-1-1:2003)	m^3/h	150	150
Dissipation at no load	W	120	150

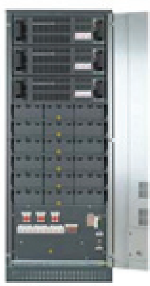
Standards

Power module rating (kVA)	10	20
Safety	EN 62040-1-1:2003, EN 60950-1:2001/A11:2004	
Electromagnetic compatibility	EN 62040-2:2005, EN61000-3-2:2000, EN61000-3-3:1995/A1:2001, EN61000-6-2:2001	
Emission class	C2	
Immunity class	C3	
Performance	EN62040-3:2001	
Product certification	CE	
Degree of protection	IP 20	

25- 250 kVA 3-phase modular system

This system comprises a range of cabinets that can be populated with a number of 25, 30, 40 or 50kVA power modules that operate in parallel within the cabinet to provide the cabinet's rated output. Each power module is a self-contained UPS and incorporates a rectifier/charger, inverter and static bypass.

Mechanical data

		
25-50kVA (1 x 25-50kVA module) Internal Batteries (WxDxH 730x800x1650)	**75-150kVA** (3 x 25-50kVA module) Internal Batteries (WxDxH 730x800x1975)	**125-250kVA** (5 x 25-50kVA module) External Batteries (WxDxH 730x800x1975)
Transportation pallet	Provided with UPS	
Packaging	Polythene	
Accessibility	Front service access requires minimum 1000mm clearance	
Positioning	Minimum 200mm rear clearance required for ventilation	
Input/output power cabling	From bottom front of the cabinet	

General data

Power module rating (kVA)		**25**	**30**	**40**	**50**
Output power factor		0.8			
Output Rated Power p.f.=0.8	kVA	25	30	40	50/45*
Output Rated Power p.f.=1.0	kW	20	24	32	40
Output current In (p.f =1.0 400V)	A	29	35	46.5	58
Double conversion AC-AC efficiency					
Efficiency with linear load (p.f.=1.0)	%	Load 25% Efficiency 93%	50% 94%	75% 94.5%	100% 94.5%

Power module rating (kVA)	25	30	40	50
Remote signalling and alarms				
Dry port (volt-free contacts)	For remote signalling and automatic computer shutdown			
Smart port (RS 232)	For monitoring and integration in network management			
Input terminals	EMERGENCY OFF (normally closed) GENERATOR-ON (normally open) BATTERY TEMPERATURE SENSOR			
**On-Inverter mode 50kVA/40kW, On-Bypass mode 45kVA/40kW*				

Rectifier data

Power module rating (kVA)		25	30	40	50
Nominal input voltage	V	3x380/220V +N, 3x400V/230V +N, 3x415/240V +N			
Input voltage tolerance (ref to 3x400/230V) for loads in %:	V	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load			
Input frequency	Hz	35 - 70			
Input power factor		PF=0.99 @ 100% load			
Input distortion THDi		Sinewave THDi = < 2% @ 100% load			
Max. input power with rated output power and charged battery per module (p.f.=1.0)	kW	21.3	25.4	33.9	42.9
Max. input current with rated output power and charged battery per module (p.f.=1.0)	A	30.8	36.8	49.1	62.1
Max. input power with rated output power and discharged battery per module (p.f.=1.0)	kW	23.3	27.8	37.1	46.9
Max. input current with rated output power and discharged battery per module (p.f.=1.0)	A	33.7	40.3	53.7	68.0

Battery data

Power module rating	25	30	40	50
Battery type	Lead acid maintenance free VRLA or NiCd			
Number of 12V battery blocks	48-50			
Battery ambient temperature	20°C (recommended)			
Battery storage time	Maximum 6 months (at ambient temperature)			

Power module rating	25	30	40	50
Temperature controlled battery charger	Yes (with optional temperature sensor)			
Maximum battery charger current	6A Standard (10A option)	10A Standard (15A option)		
Battery charging curve	Ripple-free; IU (DIN 41773)			
Battery test	Automatic and periodic (adjustable)			

Inverter data

Power module rating		25	30	40	50
Output rated voltage	V	3x380/220V, 3x400V/230V, 3x415/240V			
Output power factor		0.8			
Output waveform		Sinewave			
Output frequency	Hz	50 or 60			
Output frequency tolerance	%	Free running = < ±0.15 Synchronised with mains = < ±2 or < ±4 (selectable)			
Overload capability		125% Load = 10min 150% Load = 60secs			
Output short capability (rms)	A	Inverter: 2 x In for duration of 250 ms			
Permissible unbalanced load		100%, 3 phase regulated independently			
Crest factor		3 : 1			
Output Voltage Stability					
Static		< ±1%			
Dynamic (step load 0%-100% or 100%-0%)		< ±4%			
Output Voltage Distortion					
With linear load		< 2.0%			
With non linear load		< 3% (EN62040-3:2001)			

Bypass data

Power module rating		25	30	40	50
Bypass operation	%	At nominal input voltage of 3x400 V ±15%, (196 V to 264 V ph-N)			
Output short capability (rms)	A	10 x In for duration of 10 ms			

Environmental data

Power module rating (kVA)		25	30	40	50
Audible noise at 100% / 50% load	dBA	57/49	59/51	65/55	65/55
Ambient temperature (UPS)	°C	0 - 40			
Ambient temperature (Batteries)	°C	20 (recommended)			
Relative Air-humidity		Max. 95% (non-condensing)			
Ambient Temperature for Batteries (recommended)	°C	20			
Max. altitude (above sea level)	m	1000m (3300ft) without de-rating			
Derating for altitude					
De-rating factor for use at altitudes above 1000m sea level according (IEC 62040-3)		Height above sea level (m/ft)		De-rating factor for power	
		1500 / 4850		0.95	
		2000 / 6600		0.91	
		2500 / 8250		0.86	
		3000 / 9900		0.82	
Heat dissipation with 100% non-linear load (EN 62040-1-1:2003)	W	1500	1670	2225	2780
	BTU/h	5118	5698	7592	9485
Airflow (25° - 30°C) with non-linear load (EN 62040-1-1:2003)	m^3/h	150	380		

Standards

Power module rating (kVA)	**25**	**30**	**40**	**50**
Safety	EN 62040-1-1:2003, EN 60950-1:2001/A11:2004			
Electromagnetic compatibility	EN 62040-2:2005, EN61000-3-2:2000, EN61000-3-3:1995/A1:2001, EN61000-6-2:2001			
Emission class	C2			
Immunity class	C3			
Performance	EN62040-3:2001			
Product certification	CE			
Degree of protection	IP 20			

60, 80, 100kVA 3-phase input and output

		
60, 80, 100kVA Without internal batteries (WxDxH 550 x 750 x 1820)	60, 80, 100kVA With (80) internal batteries (WxDxH 970 x 750 x 1820)	60, 80, 100kVA With (120) internal batteries (WxDxH 1180 x 750 x 1820)
Transportation pallet	Provided with UPS	
Packaging	Polythene	
Accessibility	Front access for operator and service	
Positioning	Min 200mm rear clearance required for ventilation	
Input/output power cabling	From below UPS, terminations at front	

General data

Module rating (kVA)		**60**	**80**	**100**
Power factor		1.0		
Output rated power	kW	60	80	100
Output current In (PF=1.0)	A	87	116	145
Topology and technology		On-line, double conversion. Third generation, transformerless		
Parallel configuration		For added redundancy and/or capacity a parallel system can be extended to up to 10 modules		
Double conversion AC-AC efficiency with fully charged battery and linear load (pf=1.0)		Load(%) 25 50 75 100 eff. (%) 95.5 96.0 95.5 95.0		
Remote signalling and alarms				
Dry port (volt-free contacts)		Remote signalling and auto. computer shutdown		
Smart Port (RS 232)		Remote control/integration in network management		

External inputs	Emergency Off (normally closed) Generator On (normally open)

Rectifier data

Module rating (kVA)		**60**	**80**	**100**
Input voltage	V	3x380, 3x400, 3x 415 +N		
Input voltage tolerance (ref to 3x400/230V) for loads in %:	%	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load		
Other input voltages		On Request		
Input frequency	Hz	35-70		
Input power factor		0.99		
Inrush current		Limited by soft-start		
Input current form (100% load)		Sinewave <3.5% distortion		
Max. input power with charged battery and rated output power	kW	64	85	107
Max. input current with rated output power and charged battery (pf=1.0)	A	93	123	154
Max. input power with rated output power and discharged battery	kW	70	94	117
Max. input current with rated output power and discharged battery (pf=1.0)	A	102	136	170

Battery data

Module rating (kVA)	**60**	**80**	**100**
Battery type	Lead-acid, maintenance-free		
Variable number of 12V battery blocks	44-50 (only even numbers allowed)		
Battery ambient temperature	20°C (recommended)		
Battery storage time	Maximum 6 months (at ambient temperature)		
Temperature controlled battery charger	Yes (with optional temperature sensor)		
Battery charger current (max) (standard)	Adjustable up to 25A		
Battery charging curve	Ripple free, IU (DIN 41773)		
Battery test	Automatic and periodic, adjustable		

Inverter data

Module rating (kVA)		**60**	**80**	**100**
Output rated voltage	V	3x 380/220 or 3x 400/230 or 3x 415/250		
Power factor		1.0		
Output waveform		Sinewave with 0deg. phase imbalance @100% unbalanced load		
Permissible unbalanced load	%	100% (all 3 phases independently regulated)		
Output frequency	Hz	50 or 60		
Output frequency tolerance	%	Free running = < ±0.15 Synchronised with mains = < ±2 or < ±4 (selectable)		
Frequency slew rate	Hz/s	1.0		
Overload capability on inverter	%	At PF=1.0 110% load for 10 minutes At PF=1.0 135% load for 1 minute At PF=0.9 125% load for 10 minutes At PF=0.9 150% load for 1 minute		
Inverter short circuit capability (x rated output for 40ms)	A	2.7x	2.0x	2.3x
Crest-factor		3:1		
Output voltage stability				
Static	%	< ± 1.0		
Dynamic	%	< ±4 (with load step 0-100%, 100-0%)		
Output voltage distortion				
With linear load	%	< 2 with linear load		
With non-linear load	%	< 4 (EN 62040-3:2001)		

Bypass data

Module rating (kVA)		**60**	**80**	**100**
Bypass short capability (RMS)	A	10 x In during 10 ms		
Load transfer time – inverter to bypass Load transfer time – bypass to inverter	ms	0.0 ms < 1.0 ms		
Minimum mains voltage before bypass inhibited	V	At nominal input voltage of 3x400 V ±15%, (196 V to 264 V ph-N)		
Integrated maintenance bypass		Yes		

Environmental data

Module rating (kVA)		**60**	**80**	**100**
Audible noise with 100%/75% load	dBA	<65		
Ambient temperature (UPS)	ºC	0 - 40		
Ambient temperature (Batteries)	ºC	20 (recommended)		
Cooling				
Cooling airflow (25 - 30°C) with 100% non-linear load	m^3/h	1300	1500	1700
Heat dissipation				
Heat dissipation without load	W	850		
Heat dissipation with 100% non-linear load	W	3830	5106	6368
Heat dissipation with 100% non-linear load	BTU/h	13071	17428	21785

Standards

Module rating (kVA)	**60**	**80**	**100**
Safety	EN62040-1-1:2003 EN60950-1:2001/A11/;2004		
Electromagnetic compatibility	IEC/EN 62040-2:2005, IEC/EN61000-3-2:2000, IEC/EN61000-6-2:2001,		
Performance	IEC/EN 62040-3:2001		
Product certification	CE		
Degree of protections	IP20		

120, 160, 200, 250, 300kVA, 3-phase input and output

	
120, 160, 200kVA Without internal batteries (WxDxH 850 x 750 x 1820)	250, 300kVA Without internal batteries (WxDxH 1100 x 750 x 1920)
Transportation pallet	Provided with UPS
Packaging	Polythene
Accessibility	Front access for operator and service
Positioning	Min 200mm rear clearance required for ventilation
Input/output power cabling	From below UPS, terminations at front

General data

Module rating (kVA)		**120**	**160**	**200**	**250**	**300**
Power factor		1.0				
Output rated power	kW	120	160	*200	250	300
Output current In (PF=1.0)	A	174	232	*290	361	433
Topology and technology		On-line, double conversion. Third generation, transformerless				
Parallel configuration		For added redundancy and/or capacity a parallel system can be extended to up to 10 modules				
Double conversion AC-AC efficiency with fully charged battery and linear load (pf=1.0)		Load(%) 25 50 75 100 eff. (%) 95.5 96.0 95.5 95.0				
Remote signalling and alarms						
Dry port (volt-free contacts)		Remote signalling and auto. computer shutdown				
Smart Port (RS 232)		Remote control/integration in network management				

External inputs	EMERGENCY OFF (normally closed) GENERATOR ON (normally open)
** with 50 battery blocks only*	

Rectifier data

Module rating (kVA)		**120**	**160**	**200**	**250**	**300**
Input voltage	V	3x380, 3x400, 3x 415 +N				
Input voltage tolerance (ref to 3x400/230V) for loads in %:	%	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load				
Other input voltages		Available on request				
Input frequency	Hz	35-70				
Input power factor		0.99 @100% load				
Inrush current		Limited by soft-start				
Input current form (100% load)		Sinewave <3.5% distortion				
Max. input power with charged battery and rated output power	kW	128	170	213	266	319
Max. input current with rated output power and charged battery	A	185	247	308	386	463
Max. input power with rated output power and discharged battery	kW	141	187	234	293	351
Max. input current with rated output power and discharged battery	A	204	271	339	424	509

Battery data

Module rating (kVA)	**120**	**160**	**200**	**250**	**300**
Battery type	Lead-acid, maintenance-free				
Variable number of 12V battery blocks (only even numbers allowed)	44-50		50	44-50	
Battery ambient temperature	20°C (recommended)				
Battery storage time	Maximum 6 months (at ambient temperature)				
Temperature controlled battery charger	Yes (with optional temperature sensor)				
Battery charger current (adjustable)	Up to 50A			Up to 60A	
Battery charging curve	Ripple free, IU (DIN 41773)				
Battery test	Automatic and periodic, adjustable				

Inverter data

Module rating (kVA)		**120**	**160**	**200**	**250**	**300**
Output rated voltage	V	3x 380/220 or 3x 400/230 or 3x 415/250				
Output power factor		1.0				
Output waveform		Sinewave with 0deg. phase imbalance @100% unbalanced load				
Permissible unbalanced load	%	100% (all 3 phases independently regulated)				
Output frequency	Hz	50 or 60				
Output frequency tolerance	%	Free running = < ±0.15 Synchronised with mains = < ±2 or < ±4 (selectable)				
Frequency slew rate	Hz/s	1.0				
Overload capability on inverter	%	At PF=1.0 110% load for 10 minutes At PF=1.0 135% load for 1 minute At PF=0.9 125% load for 10 minutes At PF=0.9 150% load for 1 minute				
Inverter short circuit capability (x rated output for 40ms)	A	1.8x	1.9x	2.1x	1.8x	2.0x
Crest-factor		3:1				
Output voltage stability						
Static	%	< ± 1.0				
Dynamic	%	< ±4 (for load step 0-100%, 100-0%)				
Recovery time after load step (0-100%, 100-0%)	ms	20				
Output voltage distortion						
With linear load	%	< 2				
With non-linear load	%	< 4 (EN 62040-3:2001)				

Bypass data

Rated output power (kVA)		**120**	**160**	**200**	**250**	**300**
Load transfer time – inverter to bypass Load transfer time – bypass to inverter		0.0 ms < 1.0 ms				
Minimum mains voltage before bypass inhibited		190V				
Integrated maintenance bypass		Yes				
Bypass short capability (RMS)	A	10 x In during 10 ms				

Environmental data

Rated output power (kVA)		120	160	200	250	300
Audible noise with 100%/75% load	dBA	<69			71	
Ambient temperature (UPS)	°C	0 - 40				
Ambient temperature (Batteries)	°C	20 (recommended)				
Cooling						
Cooling airflow (25 - 30°C) with 100% non-linear load	m^3/h	2500			3350	
Heat dissipation						
Heat dissipation with 100% non-linear load	W	7660	10213	12766	15957	19149
Heat dissipation with 100% non-linear load	BTU/h	26142	34856	43570	54462	65355
Heat dissipation without load	W	1500			2300	

Standards

Rated output power (kVA)	120	160	200	250	300
Safety	EN62040-1-1:2003 EN60950-1:2001/A11/;2004				
Electromagnetic compatibility	IEC/EN 62040-2:2005, IEC/EN61000-3-2:2000, IEC/EN61000-6-2:2001,				
Performance	IEC/EN 62040-3:2001				
Product certification	CE				
Degree of protections	IP20				

400, 500kVA 3-phase input and output

400, 500kVA
Without internal batteries
(WxDxH 1650 x 850 x 1940)

Transportation pallet	Provided with UPS
Packaging	Polythene
Accessibility	Front access for operator and service
Positioning	Minimum 100mm from side and 400mm top clearance for fan exhaust. No rear space required.
Input/output power cabling	From below UPS, terminations at front

General data

Rated output power (kVA)		**400**	**500**
Power factor		1.0	
Output rated power	kW	400	500
Output current In (PF=1.0)	A	577	722
Topology and technology		On-line, double conversion. Third generation, transformerless	
Parallel configuration		For added redundancy and/or capacity a parallel system can be extended to up to 10 modules	
Double conversion AC-AC efficiency with fully charged battery and linear load (pf=1.0)		Load(%) 25 50 75 100 eff. (%) 95.5 96.0 95.5 95.0	
Remote signalling and alarms			

Dry port (volt-free contacts)	Remote signalling and auto. computer shutdown
Smart Port (RS 232)	Remote control/integration in network management
External inputs	EMERGENCY OFF (normally closed) GENERATOR ON (normally open) MAINTENANCE BYPASS (normally open) OUTPUT ISOLATOR (normally open)

Rectifier data

Module rating (kVA)		**400**	**500**
Input voltage	V	3x380, 3x400, 3x 415 +N	
Input voltage tolerance (ref to 3x400/230V) for loads in %:	%	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load	
Other input voltages		Available on request	
Input frequency	Hz	35-70	
Input power factor		0.99 @100% load	
Inrush current		Limited by soft-start	
Input current form (100% load)		Sinewave <3.5% distortion	
Output voltage tolerance	%	± 1	
Max. input power with charged battery and rated output power	kW	426	532
Max. input current with rated output power and charged battery	A	617	771
Max. input power with rated output power and discharged battery	kW	468	585
Max. input current with rated output power and discharged battery	A	679	848

Battery data

Rated output power (kVA)	**400**	**500**
Battery type	Lead-acid, maintenance-free	
Variable number of 12V battery blocks (only even numbers allowed)	44-50	
Battery ambient temperature	20°C (recommended)	
Battery storage time	Maximum 6 months (at ambient temperature)	
Temperature controlled battery charger	Yes (with optional temperature sensor)	

Battery charger current (adjustable)	Up to 60A	Up to 100A
Battery charging curve	Ripple free, IU (DIN 41773)	
Battery test	Automatic and periodic, adjustable	

Inverter data

Rated output power (kVA)		**400**	**500**
Output rated voltage	V	3x 380/220 or 3x 400/230 or 3x 415/250	
Output power factor		1.0	
Output waveform		Sinewave with 0deg. phase imbalance @100% unbalanced load	
Permissible unbalanced load	%	100% (all 3 phases independently regulated)	
Output frequency	Hz	50 or 60	
Output frequency tolerance	%	Free running = < ±0.15 Synchronised with mains = < ±2 or < ±4 (selectable)	
Frequency slew rate	Hz/s	1.0	
Overload capability on inverter	%	At PF=1.0 110% load for 10 minutes At PF=1.0 135% load for 1 minute At PF=0.9 125% load for 10 minutes At PF=0.9 150% load for 1 minute	
Inverter short circuit capability (x rated output for 40ms)	A	2.0 x In	
Crest-factor		3:1	
Output voltage stability			
Static	%	< ± 1.0	
Dynamic	%	< ±4 (for load step 0-100%, 100-0%)	
Recovery time after load step (0-100%, 100-0%)	ms	20	
Output voltage distortion			
With linear load	%	< 2	
With non-linear load	%	< 4 (EN 62040-3:2001)	

Bypass data

Rated output power (kVA)		400	500
Load transfer time – inverter to bypass Load transfer time – bypass to inverter		0.0 ms < 1.0 ms	
Minimum mains voltage before bypass inhibited		190V	
Integrated maintenance bypass		Yes (option)	
Bypass short capability (RMS)	A	10 x In during 10 ms	

Environmental data

Rated output power (kVA)		400	500
Audible noise with 100%/75% load	dBA		
Ambient temperature (UPS)	ºC	0 - 40	
Ambient temperature (Batteries)	ºC	20 (recommended)	
Cooling			
Cooling airflow (25 - 30°C) with 100% non-linear load	m^3/h	6550	
Heat dissipation			
Heat dissipation with 100% non-linear load	W	24000	30000
Heat dissipation with 100% non-linear load	BTU/h	81913	102389
Heat dissipation without load	W	4000	

Standards

Rated output power (kVA)	400	500
Safety	EN62040-1-1:2003 EN60950-1:2001/A11/;2004	
Electromagnetic compatibility	IEC/EN 62040-2:2005, IEC/EN61000-3-2:2000, IEC/EN61000-6-2:2001,	
Performance	IEC/EN 62040-3:2001	
Product certification	CE	
Degree of protections	IP20	

100- 500 kVA 3-phase modular system

This system comprises a cabinet that can be populated with up to five 100kVA power modules that operate in parallel within the cabinet to provide the cabinet's rated output. Each power module is a self-contained UPS and incorporates a rectifier, inverter and static bypass. Six of the cabinets shown can be connected together to form a 3 MVA parallel system.

Mechanical data (cabinet frame)

Maximum cabinet rating	500 kVA / 500kW (with 5 power modules fitted)
Dimensions (W x D x H) mm	1580 x 945 x 1975
UPS Type	On-line, transformerless, modular, decentralized parallel architecture
Parallel capability	Up to 6 frames (with up to 5 x 100 kVA modules in each frame)
Battery	Not included
Performance specification	VFI-SS-111
Weight	975 kg (with five power modules fitted)
Colour	Graphite Grey (RAL 7024)
Positioning	Min. 200mm rear space (required for ventilation) Min. 900mm required at front for access
Input/output power cabling	From the top or bottom

Mechanical Data (100 kVA Power Module)

Active Sub-module 	Passive Sub-module 
Dimensions (W x H x D) mm	710 x 178 x 750
Weight (kg)	55 (active module) 54 (passive module)
UPS Type	On-line, transformerless, modular, decentralized parallel architecture

General data		**100 kVA UPS Module**
Output power factor		1.0
Output rated power @ 0.8 p.f.	kVA	100
Output rated power @ 1.0 p.f.	kW	100
Output current In @ 1.0 p.f.	A	145 (@400 V)
Efficiency AC-AC up to (at Cosφ 1.0)		*Load*: *100%* *75.0%* *50.0%* *25.0%* 95.6% 96.0% 96.1% 95.8%
Eco-mode efficiency at 100% load		99% or better
Remote signalling and alarms		
Dry port (volt-free contacts)		For remote signalling and automatic computer shutdown
Smart port (RS 232)		For monitoring and integration in network management
RS485 on RJ45 port		For remote monitoring (optional)
RS485 on RJ45 port		For multidrop purposes
SNMP card slot		For monitoring and integration in network management
Input terminals		EMERGENCY OFF (normally closed) GENERATOR-ON (normally open) BATTERY TEMPERATURE SENSOR

Rectifier data		**100 kVA UPS Module**
Nominal input voltage	V	3x380/220V+N, 3x400V/230V+N, 3x415/240V+N (Three phases and Neutral required)
Input voltage tolerance (ref to 3x400/230V) for loads in %:	V	(-23% to +15%) for <100 % load (-30% to +15%) for < 80 % load (-40% to +15%) for < 60 % load
Input frequency	Hz	35 – 90 (nominal 50)
Input power factor		PF=0.99 @ 100% load
Inrush current	A	<100 of rated current, limited by soft start
Input distortion THDI		<3.5% @ 100% load
Max. input current with rated output power and charged battery (output p.f. = 1.0)	A	152
Max. input current with rated output power and discharged battery (output p.f. = 1.0)	A	167

Battery data (external)		
Technology		VRLA, vented lead acid, NiCd
Number of 12V blocks (even and odd)		
@ 380/220V or 400/230V output		40 to 50
@ 415/240V output		42 to 50
Number of NiCd cells (even and odd)		
@ 380/220V or 400/230V output		400 to 500
@ 415/240V output		420 to 500
Charger capability (each module)	A	60.0
Ripple current (rms)	%	< 2.0
Floating voltage	VDC	2.25 VLRA / 1.4 (NiCd)
End of discharge voltage	VDC	1.65 VLRA / 1.05 (NiCd)
Temperature compensation		Optional
Battery test		Automatic and periodic (selectable)
Max. input current with rated output power and discharged battery (output p.f. = 1.0)	A	167

Inverter data		100 kVA UPS Module
Output voltage (steady state rms)	V	3x380/220V or 3x400/230V or 3x415/240V (Three phase + Neutral)
Output voltage variation	%	± 1.5 (Normal and battery mode)
Output waveform		Sinewave
Output current (rms rated)	A	145
Output frequency	Hz	50 Hz or 60 Hz
Output frequency tolerance	%	Free running, quartz oscillator < ±0.1% Synchronized with mains < ±2% or < ±4% (selectable)
Permissible unbalanced load	%	100% (All 3 phases regulated independently)
Phase angle tolerance	Deg.	+/- 0 deg. (With 100% unbalanced load)
Inverter overload capability	%	110% load for 60 mins. 125% load for 10 mins. 150% load for 30 secs.
Output short capability (rms)	A	2.6 x In during 40 ms
Output voltage transient recovery time with 100% step load		
Linear	%	< ±4%
Non linear	%	< ±4% (EN62040-3)
Output voltage distortion (THD) @100% load (normal and battery mode)		
With linear load	%	< 2.0%
With non linear load	%	< 4% (EN62040-3)

Static Bypass data		100 kVA UPS Module
Transfer break time	ms	1.5
Rated current	A	160
overload current	%	110% load for 85 mins. 125% load for 65 mins. 150% load for 50 mins.
Bypass short capability (RMS)	A	10 x In during 20 ms

Environmental data		100 kVA UPS Module
Audible noise at 100% / 50% load	dBA	
Ambient temperature (UPS)	°C	0 to 40
Storage temperature (UPS)	°C	-25 to +40
Ambient temperature (Batteries)	°C	20 (recommended)
Relative air-humidity		Max. 95% (non-condensing)
Max. altitude (above sea level)	m	1000m (3300ft) without de-rating
Heat dissipation with 100% non-linear load per module (EN 62040-1-1:2003)	W	4500
	BTU/h	15359
Airflow (25° - 30°C) with non-linear load per module (EN 62040-1-1:2003)	m³/h	1200
Dissipation at no load	W	660

Standards	100 kVA UPS Module
Safety	EN 62040-1-1
Electromagnetic compatibility	EN 62040-2
Emission class	C2
Immunity class	C3
Performance	EN62040-3
Product certification	CE
Degree of protection	IP 20

Uninterruptible Power Supplies Ltd
Woodgate
Bartley Wood Business Park
Hook, Hampshire
RG27 9XA

Tel: 01256 386700
Fax: 01256 386701
Email: sales@upspower.co.uk
Web: www.upspower.co.uk

Uninterruptible Power Supplies Ltd
A KOHLER COMPANY

£40 | €58