The UPS Handbook

UPS Topologies

KOHLERPOWER
uninterruptible

4 UPS Topologies

Introduction

There are several categories of static UPS systems available. Broadly speaking, UPS units and 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 stored energy, typically batteries which are charged when the mains supply is available; and a means of converting the stored energy into an alternating current (ac) supply in times of mains failure. All systems must therefore include a *charger* and an *inverter* circuit, as shown in Figure 4.1.

Batteries are currently the most commonly used means of storing energy and will be referred to throughout this book.

As mentioned 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 from the batteries 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.

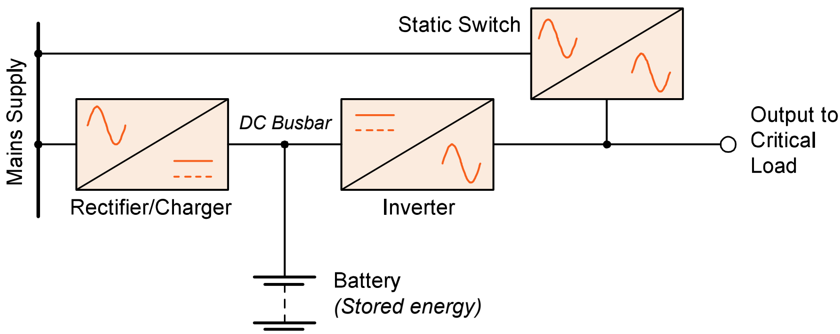

Figure 4.1: Typical Basic UPS Functional Diagram

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 batteries 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 bypass switching circuit is implemented using solid-state switching devices, hence the 'static switch' annotation in 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.

Note: In practice there are numerous static bypass and UPS output switching circuit designs. So, for simplicity, the inverter/static bypass transfer mechanism is represented by a simple changeover switch in the following block diagrams.

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 or frequency goes outside preset limits, or some other supply anomaly. Of course, low voltage is the most common cause of load transfer. During normal operation the load is subjected to any mains disturbances that fall within the acceptable bypass voltage range although most off-line models will include a degree of spike suppression and radio frequency interference (rfi) 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 it is not already running) and the load is 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, but brief, load power break during the transition. Most loads should, however, ride through this period satisfactorily without adverse affects.

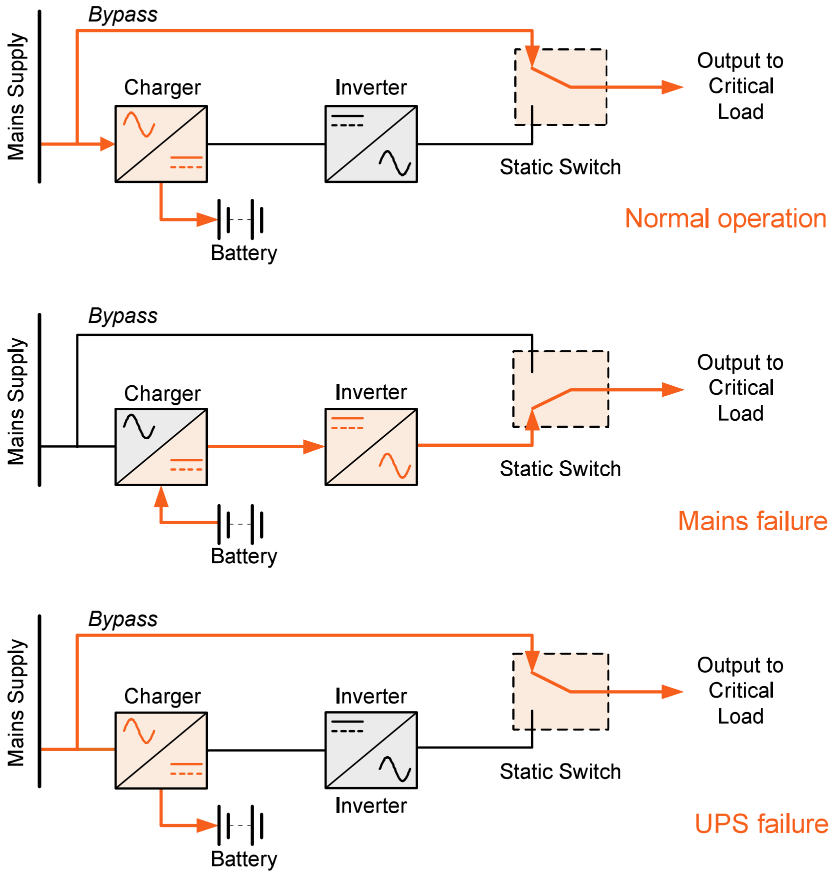

Figure 4.2: Off-line Illustration

When the load is transferred to inverter in this type of UPS 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 inverter will shut down and UPS output supply will fail if the bypass supply is not restored.

If the bypass supply is restored while the load is supplied by the inverter it is re-transferred to the bypass line.

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

Summary

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

- output waveform not closely regulated under normal operation
- 2 to 10 ms. load break during load transferring between inverter and bypass (in either direction)
- 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 some form of voltage regulation feature 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, on page 24).

Like off-line models, a line-interactive UPS normally supplies the critical load through the bypass line and transfers 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 a basic 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 the load between bypass and inverter quite frequently if it is set up to power a critical load that has a tight voltage tolerance. Apart from the power break that occurs each time the load is transferred, this type of operation incurs frequent battery usage which 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 to maintain the UPS output voltage within the required output voltage limits. This means of controlling the output voltage therefore permits a wider variation of bypass input voltage to exist before the output voltage reaches its limits and initiates a load transfer to inverter. Note that, as with the basic off-line design, there will be a brief (2 to 10ms) load supply break while the transfer takes place.

A typical UPS in this category will sustain the output voltage over a bypass input voltage range of +20% to -30%. However, although the output voltage is maintained within a preferred window using this method, buck/boost switching unavoidably leads to a degree of step voltage changes as tap changes take place.

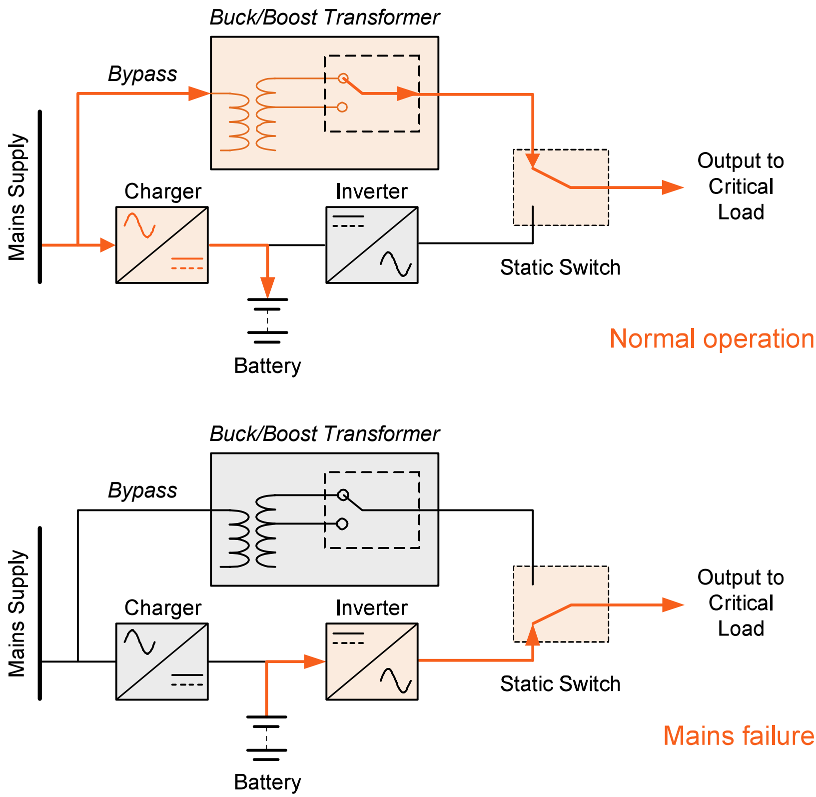

Figure 4.3: Line-Interactive UPS with Buck/Boost Transformer

Ferroresonant Transformer Design

This design is similar to the buck/boost system, but in this case the buck/boost transformer is replaced by a ferroresonant transformer (Figure 4.4).

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%. The stored energy in the ferroresonant transformer is usually sufficient to ride through a bypass supply break of one or two cycles and will sustain the UPS output during load transfers between the bypass and inverter, which effectively turns the system into a true on-line system in that the load is effectively transferred without a power break.

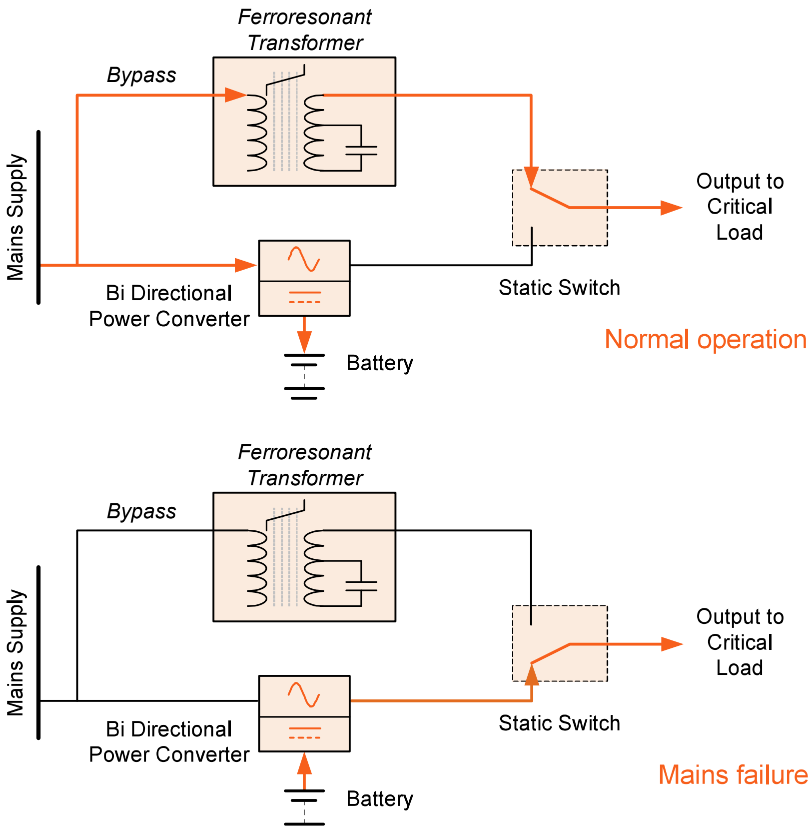

Figure 4.4: Line-Interactive UPS with Ferroresonant Transformer

Bi-directional Power Converter

In Figure 4.4 a single bi-directional power converter block has been used to replace the rectifier/charger and inverter power blocks shown in earlier diagrams. 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

When comparing line-interactive with on-line UPS systems the advantages/disadvantages are generally similar to those summarised on page 22 concerning off-line systems, with the exception that a line-interactive system provides a degree of automatic voltage regulation that is not present in an off-line UPS.

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

- a ferroresonant line-interactive UPS is generally larger, heavier and more expensive than a comparable buck/boost UPS
- a ferroresonant line-interactive UPS is less efficient than a comparable buck/boost system, especially on light loads, and therefore has higher running costs and generates more heat
- the output voltage of a ferroresonant UPS is more closely regulated than that of a buck/boost system and it does not present step voltage changes that occur normally in a buck/boost system
- due to the acceptance of a wider input voltage range, a ferroresonant UPS switches to inverter operation less frequently than its buck/boost counterpart and therefore causes less degradation to battery life
- the ferroresonant UPS transformer is tuned to operate at the line frequency (e.g. 50Hz or 60 Hz) and it is not suitable for use with a possibly (frequency) unstable bypass supply, such as a generator
- the stored energy in a ferroresonant UPS is sufficient to ride through minor outages and bypass/inverter load transfer operation.
- the output form a buck/boost UPS will exhibit a brief load-break during load transfer, however as this is typically less than half a cycle (10ms) most computer loads will be unaffected

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, and is described in more detail later – *See "Rectifier Power Block," on page 39*. When the mains supply is present this block float charges the battery and supplies the inverter with a regulated 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 dc power 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. As the load is powered from the inverter under normal circumstances it is supplied with a well regulated voltage and protected from input supply aberrations because the rectifier and inverter act as a barrier to mains-borne noise and transient voltage excursions.

If the input supply goes outside a preset voltage range (typically +10% to -20%) or frequency, 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 resulting in a total loss of load power.

One means of overcoming this potential problem is to include a standby generator in the system design which provides an alternative UPS input supply source during a prolonged utility mains failure – see below.

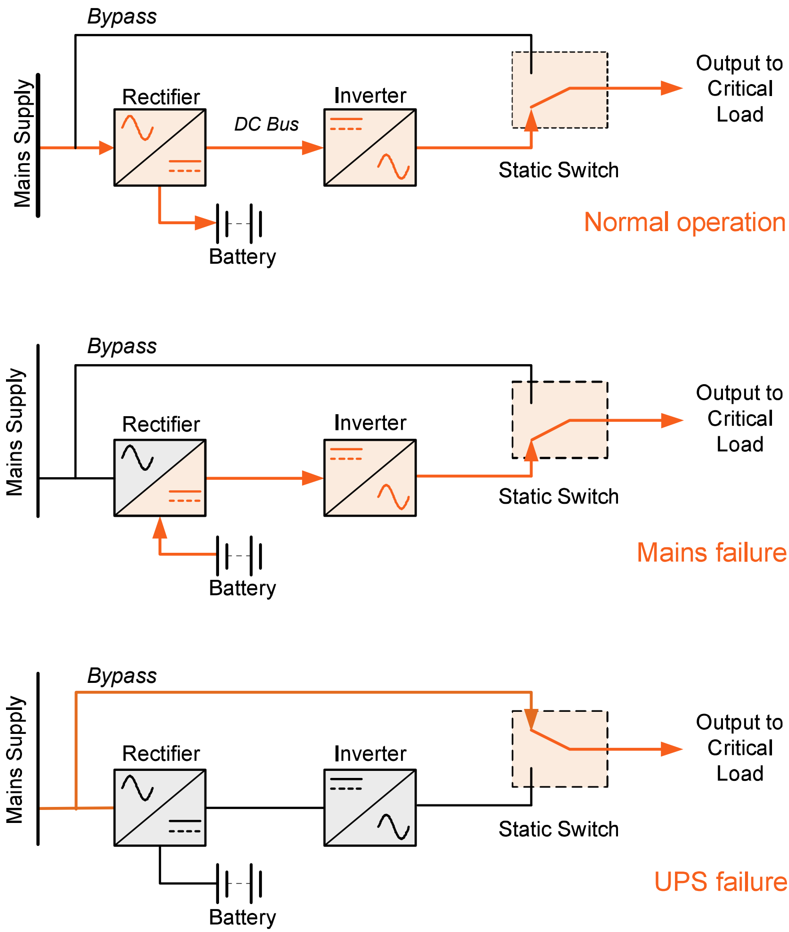

Figure 4.5: On-line UPS Operation

Standby Generator

A standby generator 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 (Figure 4.6).

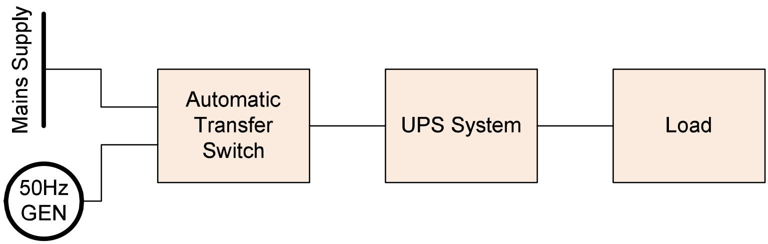

Figure 4.6: Standby Generator

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 low voltage (LV) supply.

What Happens if the on-line 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 will 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 within 5ms, 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 critical load may be transferred back to the inverter automatically once the inverter fault clears.

The response of an on-line system to an output overload, short-circuit or UPS over-temperature is usually similar to that of the UPS failure described above, in that the load is transferred to bypass until the cause of the transfer clears whereupon it automatically re-transfers back to the inverter. If the bypass supply is unavailable when called upon to clear the overload this will lead to a total loss of load supply; 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 item 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
- load break of less than 5ms 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 87.*

Maintenance Bypass

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

Internal Maintenance Bypass

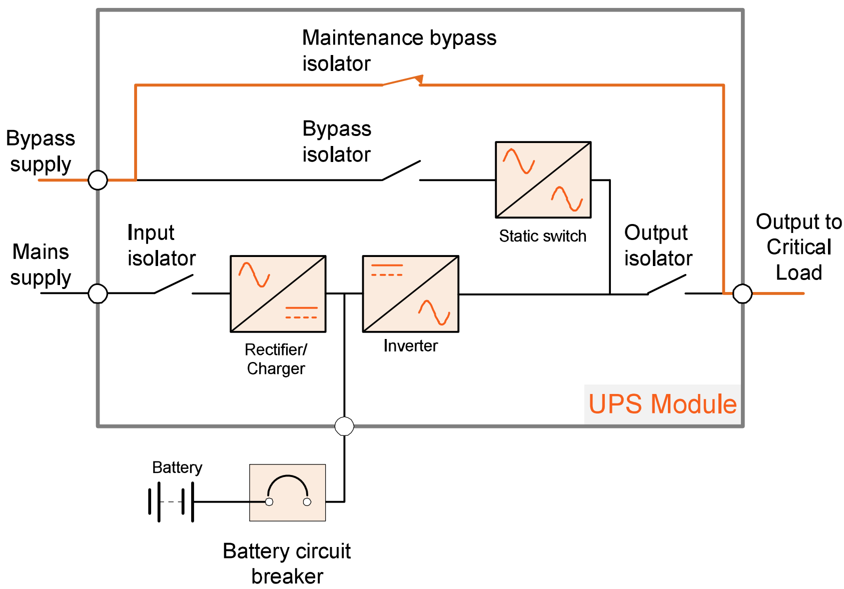

Figure 4.7: Internal Maintenance Bypass Illustration

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

This diagram shows that although the UPS power blocks are isolated while the load is powered through the internal maintenance bypass, live power is still applied to the UPS module input/output terminals and isolator connections, and presents potential shock hazards. This situation is overcome when using an external maintenance bypass facility.

External Maintenance Bypass

An external maintenance bypass system is illustrated in Figure 4.8, and 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.

This diagram illustrates how the UPS system is totally isolated when the external switches 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.

The external maintenance bypass switchgear can be incorporated into a switchgear panel but is often mounted in a bespoke *maintenance bypass cabinet*.

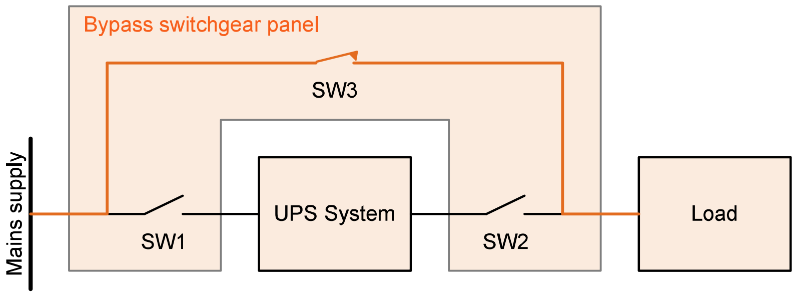

Figure 4.8: External "Wrap-Around" Bypass

Bypass Interlocking

Interlocking between the maintenance bypass and UPS isolators is necessary to ensure that the UPS inverter is not damaged by back-feeding the maintenance bypass supply into the UPS output terminals while the inverter is on line.

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