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# Recent breakthroughs in UPS technologies

The ultimate goal of hospitals is to care for patients' health and life. All the relevant architectural and engineering criteria should be aligned with this goal, and any technical decision should take into account how critical any sub-system in the hospital is in the achieving of this goal. Will the decision lead to improving the hospital? Will it contribute to saving more lives and to improving patient care?

UPS systems are critical components in the electrical infrastructure of the hospital yet they are often neglected. Almost every device requires a continuous electrical supply and some equipment cannot function in the event of even a 15 millisecond break in power supply. Sometimes the running of a facility is threatened if there is a blackout time of two hours.

Examined in this article are UPS design concepts and technological breakthroughs, plus benefits derived from these.

## UPS systems and architecture

### UPS systems

A static UPS system is a power electronics device composed of sophisticated control and power sub-systems that manage the grid power and deliver it to connected loads. Quality and continuity of supply is ensured by smartly administering the release of energy that has been stored in batteries.

There are several topologies that create different behaviour and capabilities of the UPS system when supply disturbances occur. For the purpose of this article, the main building blocks of a UPS system (see Fig.1) are the:

- Rectifier.
- Inverter.
- Batteries.
- Bypasses (automatic and maintenance).

The rectifier is the building block responsible for delivering a DC level to the inverter to feed the inverter and allow the generation of the sinusoidal waveform to be delivered to the load. It allows recharging and maintains the batteries which are charged through mains power.

The inverter takes DC power and generates a sinusoidal waveform that "replaces" the commercial grid.

The batteries store energy and can deliver DC current for a certain amount of time depending basically on their capacity and the consumption of the load, which in turn depends on its active power (W).

The bypass can be:

- **Automatic:** in the case of a UPS failure, the UPS will back off the power path and allow the load to be directly fed from the reserve line. It is normally built in.
- **Manual or maintenance orientated:** the same concept as above, but used during maintenance operations on the UPS. It is normally external.

UPS input and output can be single phase or three phase depending on the application and the loads. Although in some applications related to specific electrical architectures (such as railway systems) single phase UPS are used, they are normally not recommended for higher ratings due to the required distribution cables (costly, labour intensive and difficult to install).

### Power architecture

UPS systems can be inserted into the electrical installation according to two main architectures: distributed and centralised.

Distributed power protection assumes the connection of the UPS system very close to the critical load, whereas centralised power protection utilises the

## ABSTRACT

The reliability of electrical power supply to critical areas and essential functions in a hospital is an important objective for design consultants and maintenance service departments.

Uninterruptible Power Supplies (UPS) are the elements that, appropriately selected, configured and included in the electrical installation, will provide quality and continuity to critical loads across the hospital.

The newest UPS systems incorporate advanced technology and high quality components that optimise the intrinsic reliability of the equipment. Real-time remote monitoring and diagnostics capabilities maximise the uptime of the systems and therefore the availability of supply to the loads.

The design of advanced UPS systems does also take into account energy efficiency as a primary goal.

All these aspects represent technological breakthroughs that are not always valued during hospital installation projects. Attributing proper value to advanced UPS systems is essential because of the role they play.

electrical distribution of the building to protect the loads with a remote, concentrated power UPS. Both have advantages and disadvantages, and normally there is a mix of architectures due to reliability, critical aspect and associated costs issues.

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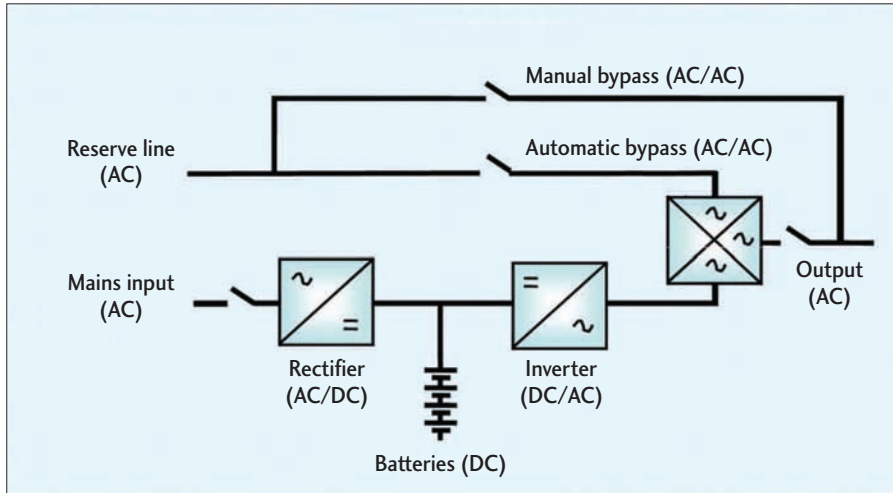
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In his career he has been involved in different pre-sales, consultancy and sales management roles in the IT industry. For the past 10 years he held different positions in the power electronics industry with Chloride, a world leading provider of critical power protection solutions and services.

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Figure 1: UPS block diagram.



‘UPS systems are critical components in the electrical infrastructure of the hospital yet they are often neglected.’

Figure 3: Stand mounted batteries for a UPS system protecting a central IT room.

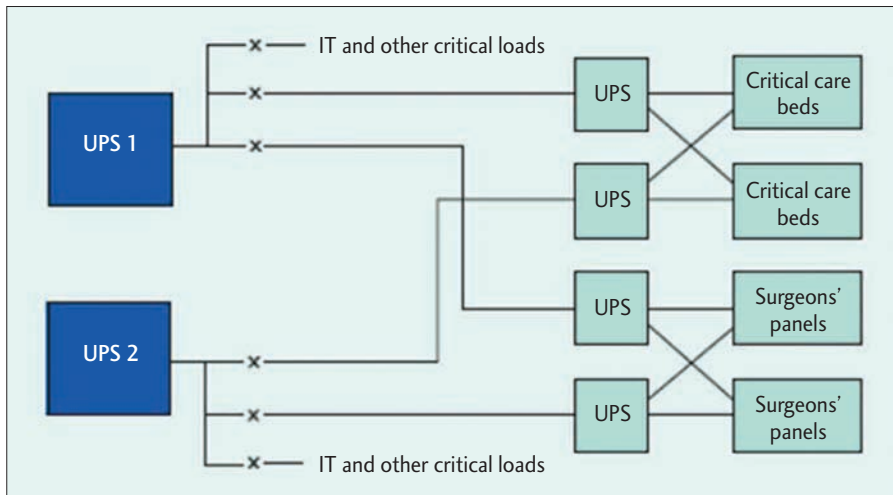


Figure 2: An example of a highly reliable power protection architecture.

In centralised architectures (Fig. 2), it is quite common to complement the UPS systems with diesel generators that will provide extended runtime. The UPS guarantees quality and, in the case of a blackout, its continuous supply allows the diesel generator to start up (in 10-20 seconds ideally) and take over once the permanent regime is achieved. Unfortunately, sometimes diesel generators may have problems in starting to run, or simply do not come into operation (there is a list of historical reasons such as lack of fuel, lack of maintenance, overload, etc). Thus, for some applications in

the hospital such as operating rooms, the UPS system by itself should be able to deliver a long runtime. In any case, the hospital should be prepared for the unexpected and make all efforts to guarantee and maximise back-up time for loads and applications that are considered to be critical and therefore to be protected.

Taking advice from an expert UPS manufacturer at the design stage will help develop a sound power strategy which minimises potential points of failure and allows significant savings in capital, installation, maintenance and operating costs.

**IGBT technology in the rectifier**

There are several ways to rectify the sinusoidal waveform of the commercial electrical network, and the most basic one is a diode bridge. Other classic schemes used in UPS systems are thyristors' bridges (electronic devices similar to transistors) with proven reliability. In general, rectifiers introduce a harmonic distortion of the input current that depends on their design and topology. This is why any improvement in the process that contributes to decrease the level of harmonics will have a beneficial impact in the installation.

Use of Insulated Gate Bipolar Transistors (a special type of transistors that allow a better control of the current flow) in the rectifiers represent a breakthrough. The IGBT based rectifier is able to draw sinusoidal current at unity power factor from the supply. This provides for negligible voltage and current distortion normally below 3% THDi (Total Harmonic Distortion current). This low THDi has several benefits, namely an excellent matching of the diesel generators (they do not have to be oversized and smaller

Figure 4: IGBT – (A) symbol, (B) i-v characteristics, (C) idealised characteristics.

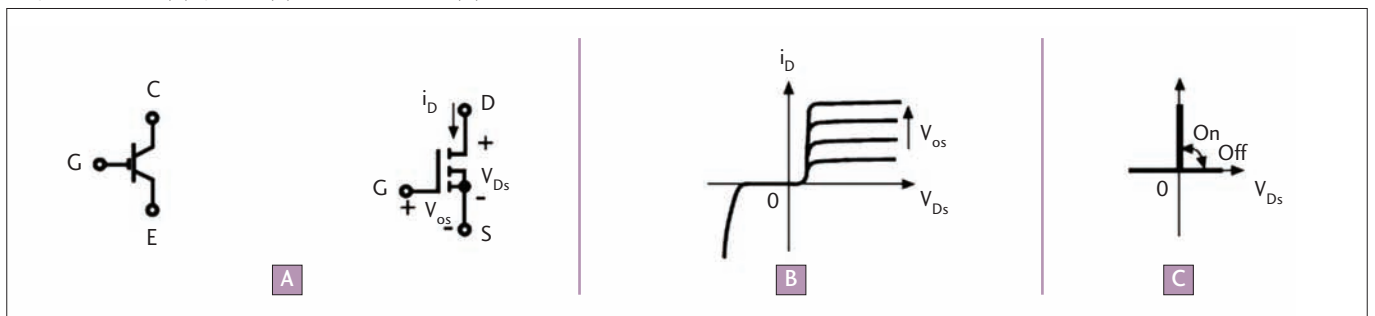
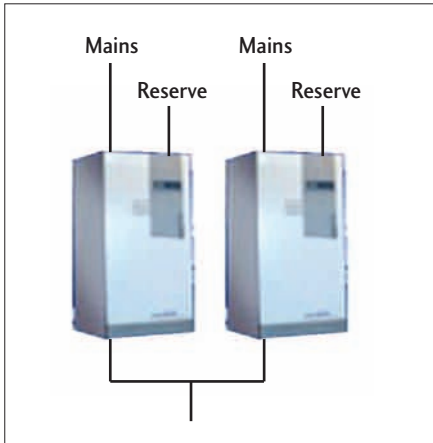


Figure 5: Parallel configuration of two UPS systems.



generators can be selected). The subsequent reduction in input current (up to 25% compared to harmonic rich currents present with other rectifiers) also provides savings in supply cabling and switchgear costs.

The clear benefit for the hospital will be the savings of these two aspects (diesel generator, cabling) which will allow the better distribution of sometimes scarce economic resources into other sub-systems to improve overall performance.

#### Advanced battery care

The life of batteries depends, from a design point of view, on their composition and quality. Batteries to be used in UPS systems protecting hospital applications should meet high standards.

Once the batteries are selected, their life in service will depend on the:

- Number of times they deliver energy.
- Temperature of the environment.
- Quality of the UPS charger.
- Preventive maintenance that is carried out on the battery system.

Some of these aspects can be controlled. If the batteries' quality is good (lead acid, 10 years' life), if they are located in a specific room or a conditioned environment (25°C), if they are periodically checked, and if the number of times they deliver energy is minimised, then they will last close to their average life.

However, by using advanced battery care (ABC) techniques, battery life can be extended up to an additional 50%. ABC techniques and algorithms include:

- Floating voltage compensated according

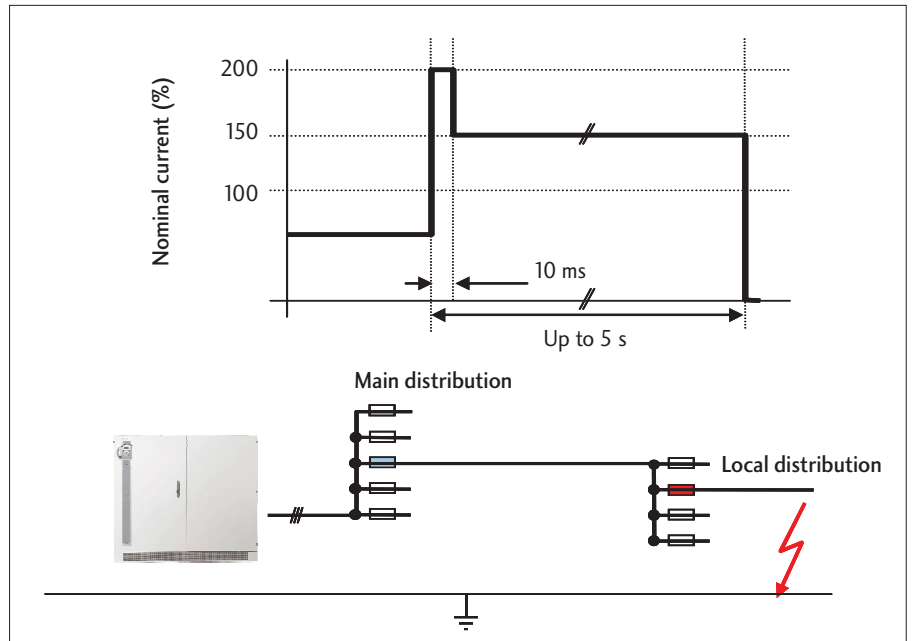


Figure 6: Short-circuit behaviour and fault clearance.

- to the battery temperature.
- Recharge current compensated according to the battery temperature.
- Final discharge voltage (cut) according to discharge time.
- Intelligent recharging cycle.
- Minimal rippling current.
- Automatic and periodical battery test.

When ABC is provided within the UPS, the hospital will guarantee a maximum supply to the critical loads, and will again save money, minimising the early replacement of prematurely aged or wasted batteries.

#### Advanced digital vector control at the inverter

Vector control is a digital control technique based on the mathematical transformation of the time space into a vector space that simplifies and speeds up the management of the analogue signals. The unique and advanced vector control algorithms of some UPS manufacturers applied to the control of the inverter allows the delivery of a perfect waveform shape and an extraordinary dynamic performance before sudden load variations (steps due to disconnection or connection of loads). It also allows a perfect load balance in a parallel configuration.

When applied on advanced design and robust

inverters, the advanced vector control further allows the achievement of outstanding performance of the system with consequent benefits.

**Load balance in parallel configurations**  
Several UPS can be configured in parallel to provide more power or to provide redundancy so the whole system is up in case of individual failures.

When the target is to add power, the system grows modularly, and the configuration is very often called "parallel modular". If, for example, a UPS delivers 20 kVA, the level of load is 90%, and the growth trend is positive, the wise decision is to add another UPS – then the load is shared and each UPS works ideally at 45%.

When the target is to have a redundant system, the extra UPS is there to replace faulty units. The configuration is very often called "modular redundant". If for example the load requires 16 kVA, one UPS of 20 kVA will work at 70% of capacity. Another 20 kVA can be added. If one of them fails, the other is able to take over all the load. Thus, in normal operation, they should ideally be sharing evenly at 35% each. This configuration can feed for example several operating rooms with high reliability and optimal space and cost scales.

Load balance in a parallel configuration is very important for two reasons: stress, and runtime.

- **Stress:** The load balance in normal operation ensures an even usage and thus an even ageing of the electronics, as opposed to unbalanced systems in which one UPS can take on for example a 70% of the load while the other only 30%. This can end up in an early fault of the more stressed UPS. In a parallel redundant configuration, this means that

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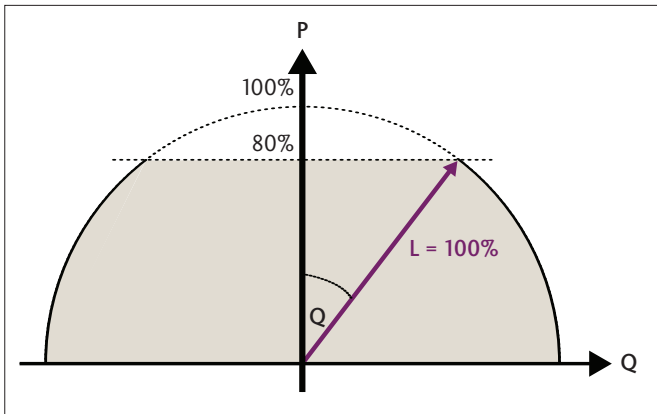


Figure 7: Symmetrical power factor without power de-rating.

‘All efforts should be made to keep the UPS system up to maximum reliability by engaging the adequate preventive maintenance routines recommended by the manufacturer.’

the redundancy is lost. In a parallel modular configuration, this means that the system crashes down due to overload and the load is not protected any more.

- Runtime:** The batteries included in the UPS are sized to deliver the required runtime for a certain level of load. But if one UPS is supporting more load, in the case of a blackout, it will exhaust the stored energy before the others, and thus the UPS will “disappear” before it should. In a parallel redundant configuration, this means that extra autonomy (two systems) is lost. In a parallel modular configuration, this means that one system does not supply power, so the system crashes down due to overload and the load is not protected any more.

**Short-circuit behaviour**

A key feature of such an advanced vector control is the ability to support high short-circuit currents for a relatively long time, which in a centralised architecture allows an orderly trigger of circuit breakers and protection downstream. The selectivity of the circuit breakers can be appropriately



Figure 9: Temperature trends.

designed to isolate the fault rather than isolating the whole installation. For example, a 200% nominal current for 10 ms is an outstanding value that will achieve this goal (Fig. 6). In the hospital, this ability, appropriately matched by the electrical design of the breakers’ values and distribution, will guarantee maximum quality and continuity to the critical loads in case of a short-circuit elsewhere. If, for example, there is a short-circuit in a medical device which is located in laboratories and which is connected to a centralised distribution, the UPS ability to keep up the output will allow the fault clearance by giving the protection close to the device enough time to trigger. If the UPS was not able to stand up the high current it would protect itself (and the bypass) by simply shutting down, cutting the supply to the whole installation downstream.

**Symmetrical output power factor**

A UPS with advanced vector control algorithms can also achieve a symmetrical output power factor.

The Output Factor of a UPS is the ratio between the active power (W) and the

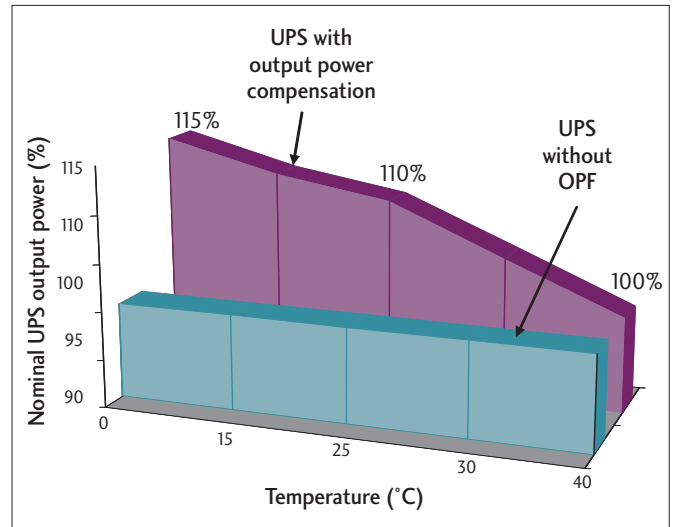


Figure 8: Extra power available in advanced designs.

apparent power (VA) that the UPS is able to deliver. The higher the OF is, the better use of the investment, since with the same hardware more active load can be protected.

UPS systems were originally designed and optimised to work with rather inductive loads such as motors, transformers, and simple switched mode power supplies (SMPS) as the front end of many computer devices and systems. The range of 0.6-0.9 of the IT systems has led to the almost universal adoption of the 0.8 lag PF rating e.g. 100 kVA/80 kW. However, recent pressure on Power Factor Correction has led to the development by SMPS manufacturers of power supplies with PF = 1, at least in theory. The reality is that this excellent behaviour of the power supply is only achieved at full load, something that very rarely occurs, since systems are not fully completed or fully functional. The PF becomes then a leading one (capacitive load) and a non-advanced UPS can suffer a severe de-rating, either being unable to support the load from the very beginning, or suffering overload. Brute force alternatives used by some manufacturers are to force the end user to invest in an oversized UPS or to adjust (hardware) the output stage of the UPS with its consequent service disruption and cost of the modification.

A symmetrical output power factor allows the UPS to work with leading (capacitive) and lagging (inductive loads) indistinctly without power de-rating (Fig. 7), even if the compound power factor of the loads vary with time. Such UPS systems do not require de-rating for leading power factors and can be connected to any load within the nominal kVA and kW rating of the UPS regardless of power factor. The clear benefits are the optimal behaviour of the system with no unexpected overload conditions that would disrupt the protection of the critical loads, and savings for the hospital.

**Advanced designs of power rating**  
Through careful and sophisticated design, some UPS systems can deliver more power

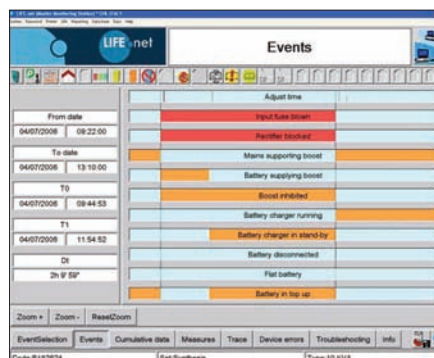


Figure 10: Events analysis.

under controlled temperature environments. Rated at 40°C, when such UPS systems are working at 20°C, they can deliver up to 10% or 15% more active power (Fig. 8). The design and the components inside the UPS system can manage as a normal working condition what for other UPS systems would be an overload condition. The preferred temperature can be easily achieved in modern IT rooms.

UPS systems that can deliver an additional 10% of their nominal power in 20°C environments can help optimise the investment or/and react smoothly under overload conditions that would force other UPS systems to enter a bypass mode. The benefit for the hospital is obviously a financial saving and maximised uptime of critical systems.

### Advanced remote diagnostics and monitoring service

It is clear to most managers that UPS systems have to be maintained. UPS systems are formed of sophisticated apparatus protecting critical loads. This must never be forgotten, yet quite often the systems are regarded as commodities and are neglected.

Preventive maintenance routines will prevent a failure in the UPS due to statistical ageing or waste of components, and therefore minimise the corrective maintenance, which normally appears as a crisis. The availability of the load is very tied to the availability of

the UPS and the batteries, since in case of mains failure or power degradation the loads will suffer or just receive no power. Therefore all efforts should be made to keep the UPS system up to maximum reliability by engaging the adequate preventive maintenance routines recommended by the manufacturer.

Proactive maintenance is an advanced concept that allows the anticipation of possible problems between preventive operations, thus improving the Mean Time To Intervene (early detection of faults) aspect, and, when linked to a remote diagnostic capability, drastically reduces the Mean Time To Repair aspect. Proactive maintenance has a tremendous positive effect on the availability of the UPS system.

Advanced systems such as LIFE.net (Chloride commercial name) can make use of the IP network of the hospital to allow communication with a control centre in which specialised service technicians of the manufacturer supervise, 24 hours a day, every day, the critical UPS systems of the hospital.

For example, such a system allows the detection of trends in load increase, and in temperature (Fig. 9), and decisions can be made and actions can be taken before these trends create a crisis.

Remote diagnostics can be achieved (Fig. 10) and the cause of a problem determined. This means the problem might be remotely fixed immediately, and also that if a service technician has to go on site then it

will be known in advance what needs to be done to recover the system immediately.

Reports containing detailed information and recommendations can be periodically submitted to the key people in the hospital to keep them up-to-date with the status and operation of the system and batteries and to allow for a certain degree of financial planning (e.g. battery replacement before the average lifespan due to the reasons already described, system power enlargement due to load growth, etc).

In summary, by using an advanced remote monitoring and diagnostic system such as LIFE.net, the hospital can be sure that the service time and operational functionality of its UPS power protection systems are maximised.

### Summary

Reviewed in some depth in this article are recent breakthroughs in UPS design and utilisation, along with advanced technical issues. The link between the technical aspects and the impact on the functionality of the whole system has been established (see summary in Table 1). If maintenance and technical managers in the hospital incorporate these aspects in their decision criteria when implementing means of protection of critical loads, they will achieve a clear contribution to that ultimate goal of the hospital: to provide the best possible care for patients. ■

Table 1: Summary of key concepts.

Technological aspect	Relevant performance or behaviour	Technical impact	Benefit for the hospital
IGBT rectifier.	Low THDi.  Input PF = 1.	Smaller diesel generators.  Thinner cabling upstream.	Savings in cabling and smaller diesel generators allow better distribution of financial resources.
Advanced battery care.	Floating voltage and recharge current compensate according to the battery temperature. Final discharge voltage (cut) according to discharge time. Intelligent recharging cycle. Minimal rippling current. Automatic and periodic battery test.	Extended life of the battery.  Improved reliability of batteries.	Savings in battery replacement allow better distribution of financial resources. Maximisation of support for critical services, e.g. for operating theatres.
Advanced digital vector control.	Perfect load balance in parallel systems.  High short-circuit current (e.g. 200% in during 10 ms, 150% during 5 s). Symmetric output factor for maximum behaviour with variable PF loads.	Optimal availability and runtime of modular and redundant parallel configurations. Optimal fault clearance downstream. Maximum power in all types of loads and changes.	Maximum uptime for critical loads. Savings in UPS size or modifications due to load power factor or changes over time allow better distribution of financial resources.
Advanced power rating designs.	Temperature output power compensation: 10%–15% more active power can be delivered.	Fewer overload conditions. Smaller UPS needed.	Maximum uptime for critical loads. Savings in UPS size allow better distribution of financial resources.
Advanced remote diagnostics and monitoring service.	Trends detection. Early fault detection. Remote fix.	Improved availability (MTTI and MTTR) of UPS. Proactive planning (load, battery change...) Total control by the hospital maintenance manager.	Maximum uptime for critical loads.