VERTIV

STATIC UPS: THE FUTURE-PROOFED CHOICE FOR A SHIFTING ENERGY LANDSCAPE

Summary

The main role of any Uninterruptible Power Supply (UPS) is to ensure the availability of the critical infrastructure which it supports. Different UPS designs have emerged and the technology continues to be improved and developed.

This whitepaper examines how the static UPS, the dominant technology in most regions, compares with rotary designs when set against the backdrop of changing customer business demands, as well as evolving energy grid and environmental regulations.

Key Findings:

- Static UPS technology is by far the most widely adopted type of large (> 500 kW) UPS technology (three-phase) because of its efficiency and flexibility
- Static UPS also enables the modular configuration of a completely redundant power and control system, sized to match the capacity of the protected equipment
- The design of rotary UPS means equipment is usually a more fixed investment than modular static technology and often needs to be oversized against possible future growth
- Static UPS equipped with Lithium-Ion Batteries (LIB) have several advantages over conventional Valve-Regulated Lead-Acid (VRLA) batteries. They are 70 percent smaller and considerably lighter. LIB also support higher operating temperatures better than VRLA, which can also help cut battery cooling costs
- As electricity grids evolve, the static UPS system can be a good fit for delivering emerging front-of-meter (FtM) and behind-the-meter (BtM) energy storage applications
- Large rotary UPS are often installed before walls of the building are closed. The weight of rotary equipment requires a stronger building structure; there also could be very strict requirements because of the vibration caused by flywheels
- Electronic equipment usually requires less maintenance on average than mechanical equipment. For example, a static UPS system often only requires a single maintenance inspection in a 12-month period

Introduction

Electricity grids continue to evolve. The addition of new renewable capacity is helping countries to meet carbon reduction targets. But solar and wind are intermittent which creates challenges for energy producers, grid operators and end-users. Those challenges are exacerbated by large, centralised fossil fuel and nuclear generating capacity being gradually retired.

Simultaneously, so-called "smart grid" technologies are emerging that bring intelligence and improved monitoring and management. This added intelligence provides opportunities for grid operators but also energy-users in terms of transacting and interacting with the grid in new ways. Battery energy storage is also likely to play a key role in this emerging energy future, helping to level out the intermittent nature of renewables and integrating with smart grid control systems.

Against this backdrop of an evolving and potentially smarter grid, there is still an absolute need for critical infrastructure operators to maintain resiliency and continuity of service. For data centers, hospitals and other large facilities, the first line of defence continues to be uninterruptable power supplies.

However, not all UPS are created equal and a variety of different technologies exist today. It's likely that so-called static UPS – usually based on the use of batteries – will continue to gain momentum over other technologies such as rotary. Batteries, including new lithium-ion technologies, will become more ubiquitous and integral to the functioning of grids in the future. At the same time, technologies that place more reliance on diesel or other fossil fuels are likely to face more environmental scrutiny and regulation.

Challenges exist however. The long purchase cycle – where UPS can operate for more than 15 years – means that expertise and experience in buying new systems varies greatly between customers. Consultants and other third-parties also have an important role to play. Other factors beyond efficiency and sustainability may also play a role, including supplier-bias.

This whitepaper aims to provide more insight and context on the deployment and operation of UPS in large critical infrastructure by describing the different technologies in detail and how static specifically is arguably a more future-proofed technology. It will also address some of the myths around static versus other technologies and how most do not standup to scrutiny.

The Evolution of Static UPS

Static Uninterruptible Power Supply (UPS) system technology has been evolving for several decades. It is typified by the fact that unlike rotary UPS, usually has no large moving parts.

Historically, the static UPS was only available in relatively small or mid-size units of capacity. However, over time, the technology has developed considerably, due in part to the fast development of semiconductors. Static UPS now come in a range of capacities and, as such, can be used for a variety of applications. Focusing on static UPS in large facilities, these systems help to secure availability and provide facility-wide protection for sensitive electronics. They have redundant configurations and dual bus capabilities to make sure critical systems will keep running during power disturbances such as blackouts, brownouts, sags, surges or noise interference.

These UPS systems also allow modular configuration of a completely redundant power and control system, sized to match the capacity of the protected equipment. When power requirements change, capacity is easily added – in 30 to 50 kW building blocks – using hot-scalable designs without any risk to critical loads.

Lithium-Ion: The Next Step for Static UPS

One of the most recent developments around static UPS technology is the use of Lithium-Ion batteries (LIB) that offer key advantages over conventional Valve-Regulated Lead-Acid battery (VRLA) batteries.

LIB have been common in consumer electronics for decades, providing compact, lightweight, long-lasting energy storage for cell phones, laptops and tablets. More recently, those same characteristics have driven expanded applications of the technology in cars, airplanes and, increasingly, data centers.

LIB is available for new build, retrofit or modular constructions and the benefits are substantial. LIB are 70 percent smaller and considerably lighter than VRLA counterparts, significantly reducing the footprint of the battery cabinets and, in some cases, enabling in-row battery storage. Additionally, lithium-ion batteries support higher operating temperatures better than VRLA, which can also help cut battery cooling costs.

Perhaps most importantly, depending on chemistry and utilization, LIB can last up to three times as long as VRLA. In most cases, VRLA batteries would need to be replaced multiple times before the first replacement of a LIB. That's significant when you consider the greatest cost and nuisance factor associated with UPS batteries is replacement. Over a ten-year life span, LIB allow up to 40 percent savings in CAPEX compared to VRLA ones.

Box-Out: Use in Grid Energy Storage

A new use case for UPS technology is emerging. Rather than just being used to provide resiliency and continuity of service, UPS systems also have the flexibility and capacity to provide energy storage capabilities. Static UPS system can be a good fit for delivering both ront-of-meter (FtM) and behind-the-meter (BtM) energy storage applications and there is often no reason why the customer shouldn't notice any difference in day-to-day operations.

Static UPS also has advantages over rotary when it comes to grid energy services. A static UPS always has full online protection for the load but can also intelligently decide how much power to take from the mains or batteries. Rotary grid support is less sophisticated and is usually dependent on switching on diesel generators which can result in additional emissions.

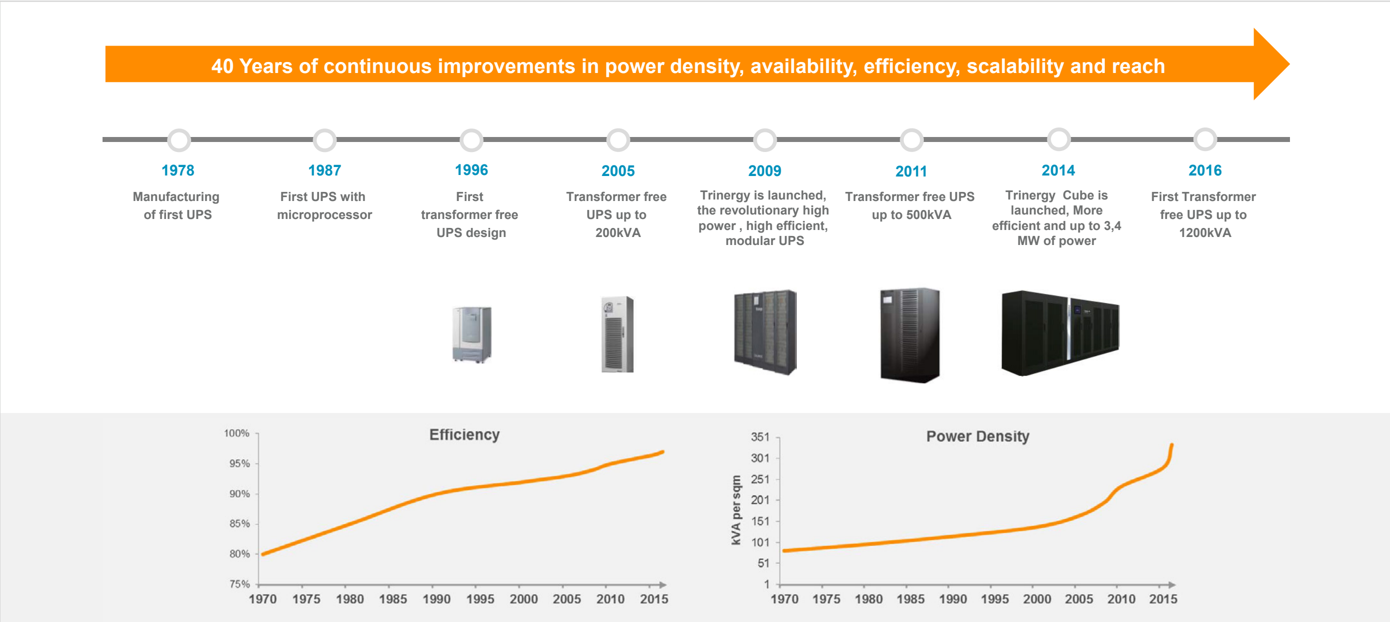

Figure 1

Static Versus Rotary

Static UPS technology is by far the most widely adopted type of large (> 500 kW) UPS technology (three-phase) because of its efficiency and flexibility. However, in some regions – including Germany – there is still a small bias towards rotary technology. There are several reasons for the continued prevalence of rotary technology in some regions including the fact that rotary has a longer legacy and was initially more suitable for installations with larger power needs. However, from a global perspective, static has now become the technology of choice in many regions for reasons that will be further explained in this paper.

Rotary Overview

The term "rotary UPS" is used to cover a range of different technologies, including use of a flywheel as well as batteries. But the one thing they have in common is that the distribution of power to the load involves some form of rotating device. For example, this could take the form of a motor generator. The technology was developed during a time when power factor issues were a problem in large critical infrastructure. However, these power factor issues have been largely dealt with now in critical facilities and, as such, one of the main benefits of rotary UPS are no longer so prevalent.

Some of the other issues around rotary UPS include:

- Under normal operation, the synchronous machine runs as a motor to drive the kinetic energy source
- If the diesel fails to fire within 3-5 seconds, the critical load will have to drop out if there is no redundant UPS available since the kinetic energy backup is limited in seconds
- As well as maintenance costs for these units being exceptionally high, the initial UPS cost can be 30 percent more compared to an equivalent static UPS

Understanding the specific advantages of static over rotary requires a deeper analysis of the two technologies and how they differ:

	STATIC UPS	ROTARY UPS
Description	• Load is fed directly from a static inverter • Both batteries and flywheels can be used as energy storage, but usually batteries are used • Online double conversion	• Load is fed directly from a synchronous generator • Both batteries and flywheels can be used as energy storage, but usually flywheels are used • Line interactive technology (more frequent use of flywheel and generator also for frequency variation)
Investment	• Modular, flexible investment (many building blocks)	• Not modular, fixed investment (few large building blocks)
Efficiency	• Up to 99.5% in ECO mode • Up to 98.5% average operating efficiency • 96.8% in VFI mode @ 50% load, 96.5% in VFI mode at 30% load	• Up to 97% in Line Interactive mode • Drops below 90% at 50% load with connected flywheel • Drops below 85% at 30% load with connected flywheel
Maintenance	• Electrical components, less maintenance, longer life • Static UPS usually require one maintenance visit per year • Rapid components replacement on site	• Mechanical components, more complex maintenance, shorter life • Maintenance schedules for rotary UPS also include frequent inspections
Backup Time	• Battery backup time: 60 s to 30 min and above	• Flywheel backup time: 8 to 20 s (frequent genset startup)
Rating	• Up to 3.4 MW in a single unit, up to 27 MW in a parallel system with many building blocks	• Up to 3 MW in a single unit, up to 20 MW in a parallel system with less flexibility
Output PF	• Up to 1 all leading and lagging without de-rating	• Up to 0,9 all leading and lagging without de-rating (less flexible)
Short Circuit Current	• Up to 3x rated current at the inverter output (only when no bypass is available) • Up to 100 kA of withstand rating on the bypass	• Up to 17x rated current (but still not capable of interrupting a circuit breaker)
Total Footprint and weight	• Smaller including li-ion batteries and genset. Consists of smaller components, so the installation is easier.	• Bigger including flywheel and generator. • Large rotary UPS often must be installed before walls are closed of the building. • Weight of rotary requires a stronger building structure; for flywheels there also could be very strict requirements because of the vibration.

Table 1

Some of these comparative factors require an expanded analysis:

Capital Costs

The design of rotary UPS means that they are usually a more fixed investment than modular static technology. Rather than being able to be expanded as the load increases, rotary systems usually need to be oversized initially in preparation for possible future growth. As such, there is often a significant percentage of 'stranded capacity', which in some circumstances, may never be efficiently utilized.

There are also other costs related to rotary to consider. For example, while manual bypass switches are usually built into most static UPS – to disengage the UPS during maintenance operations – this equipment is often separate in rotary UPS deployments.

Efficiency

Discussions around UPS efficiency can be quite subjective. For example:

- UPS rarely run at 100 percent design load
- Typical load for a UPS is in the range of 30 - 70 percent
- UPS in a data center (dual bus architecture) usually run with a load which is 50 percent maximum*

However, the efficiency curves in the image below (Figure 2) show that while the efficiencies at full load are similar, static UPS have a very significant advantage at partial load, while rotary UPS efficiency drops.

In addition, the flywheel in a rotary system is a rotating energy storage which must be kept spinning, therefore it permanently lowers the UPS, efficiency when it's connected and running.

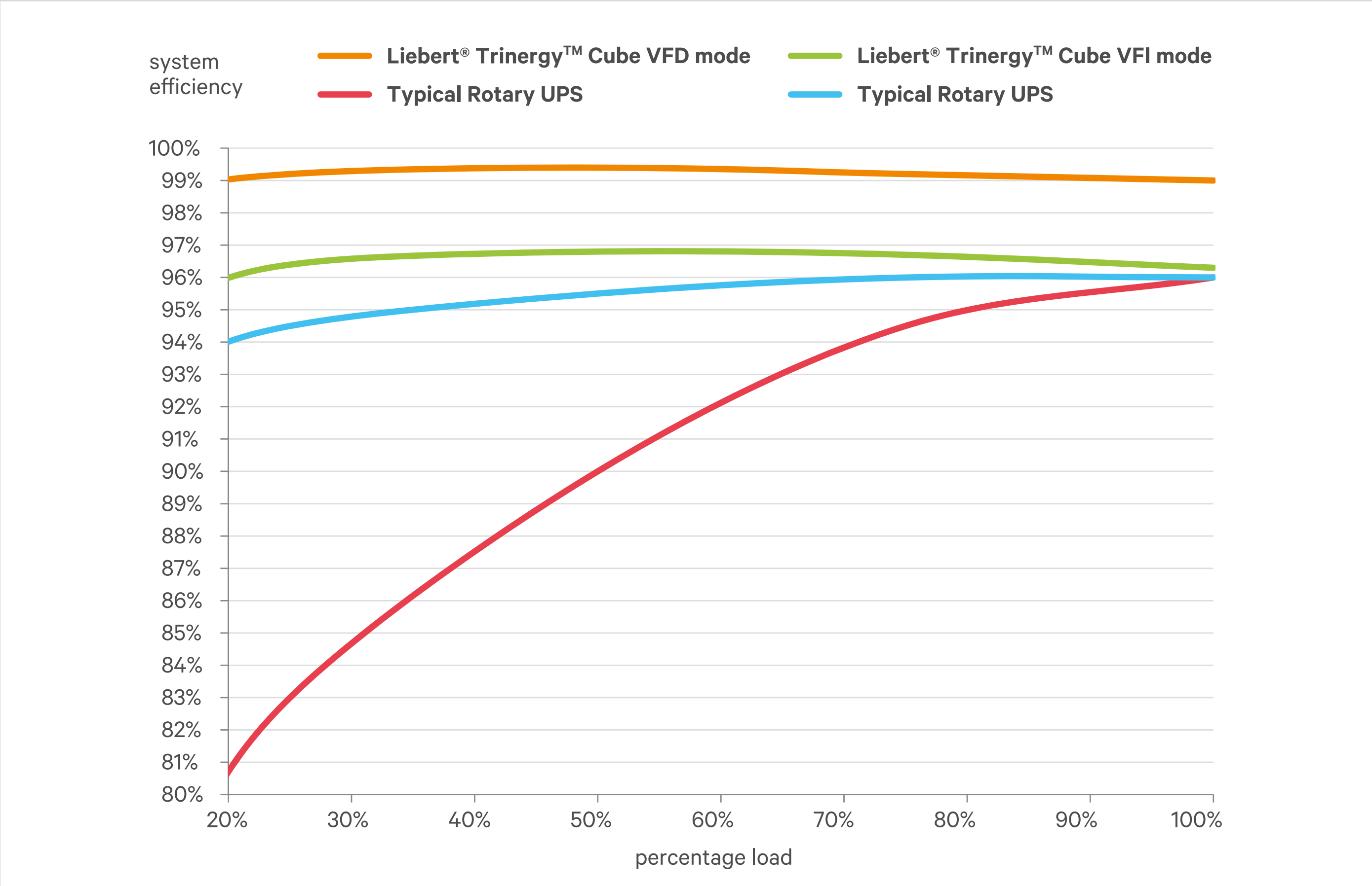

Figure 2

The higher efficiency of static UPS provides significant benefits for customers, as it decreases the power losses and guarantees high energy savings.

Example with a 2000 kW load:

STATIC UPS

- Average efficiency: 97% (or up to 98% with dynamic online (VI) mode on Liebert® Trinergy™ Cube)
- Power losses: 61.85 kW
- Energy losses: 541.8 MWh/year

ROTARY UPS

- Average efficiency: 94%
- Power losses: 127.65 kW
- Energy losses: 1118.2 MWh/year

**Reserve designs can achieve higher utilisation of 75%.*

Energy Losses Over 10 Years

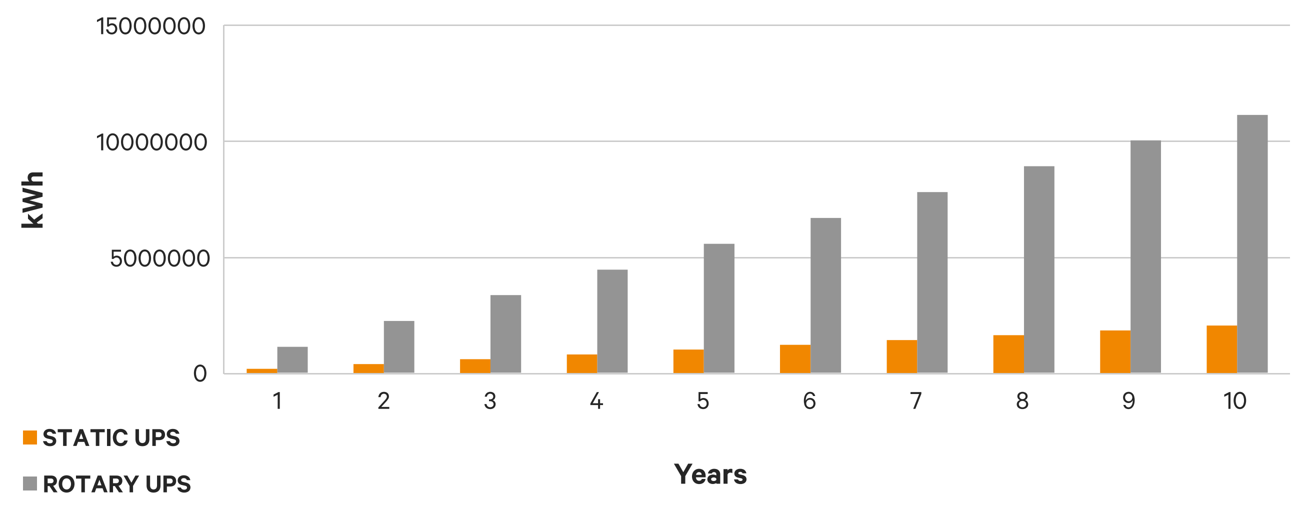

Figure 3

Maintenance

It's a generally held view that electronic equipment requires less maintenance on average than mechanical equipment. For example, a static UPS system often only requires a single maintenance inspection in a 12-month period. By comparison, a rotary system could include frequent checks on specific areas such as diesel engine starter systems and cooling systems; for some suppliers this could even necessitate weekly or monthly inspections.

Other maintenance issues for rotary include:

- The site must plan the inclusion of a suitable lifting device to accomplish the required regular bearing replacement of the flywheel
- Grease is required for bearings which can mean more regular cleaning
- Every 5-7 years a revision is necessary and, for some suppliers, equipment may need to be transported back to the factory; this results in a longer time to repair, more difficult maintenance and higher costs, in addition to a long downtime if a redundant unit was not included.

Runtime and Reliance on Diesel

One of the characteristics of some rotary systems is a significantly shorter runtime compared with a static UPS. If a grid power outage exceeds the shorter runtime of the rotary UPS, then the generators will initiate to support the load. For example, in the UK, there are on average 7.7 mains failures or brownouts per month that could require a diesel generator to be started when using rotary UPS with a flywheel.

Although many facilities operators prefer to avoid switching the load to the generators if it can be avoided – there are risks associated with this switch-over – it hasn't been a significant problem in the past. However, greater scrutiny of the contribution of diesel emissions to air pollution – which has resulted in the prospect of bans on some diesel vehicles in parts of Germany – could see greater scrutiny of all forms of diesel emissions. As such, the fact that static UPS can handle more low-level grid interruptions without resorting to generators, could be an even more important feature of the technology in the future.

Short Circuit

In case of output short circuit, conditioning with downstream protective devices is key to ensure timely fault clearance. It is true to say that rotary UPS can supply good levels of short circuit fault protection, but this usually requires expensive devices able to withstand the high current peaks. The static UPS technology approach to short circuits is easier and less expensive but still provides an uncompromised power protection in case of fault events.

Figure 4 below outlines the different short circuit scenarios:

Proper coordination of protective devices in the UPS distribution system means that only the fuse (or circuit breaker) directly upstream of a fault will operate to clear the fault itself.

When proper coordination is designed, the UPS-downstream fuse/circuit breaker has to intervene only if both the load and the panelboard protections fail, which is a rare scenario.

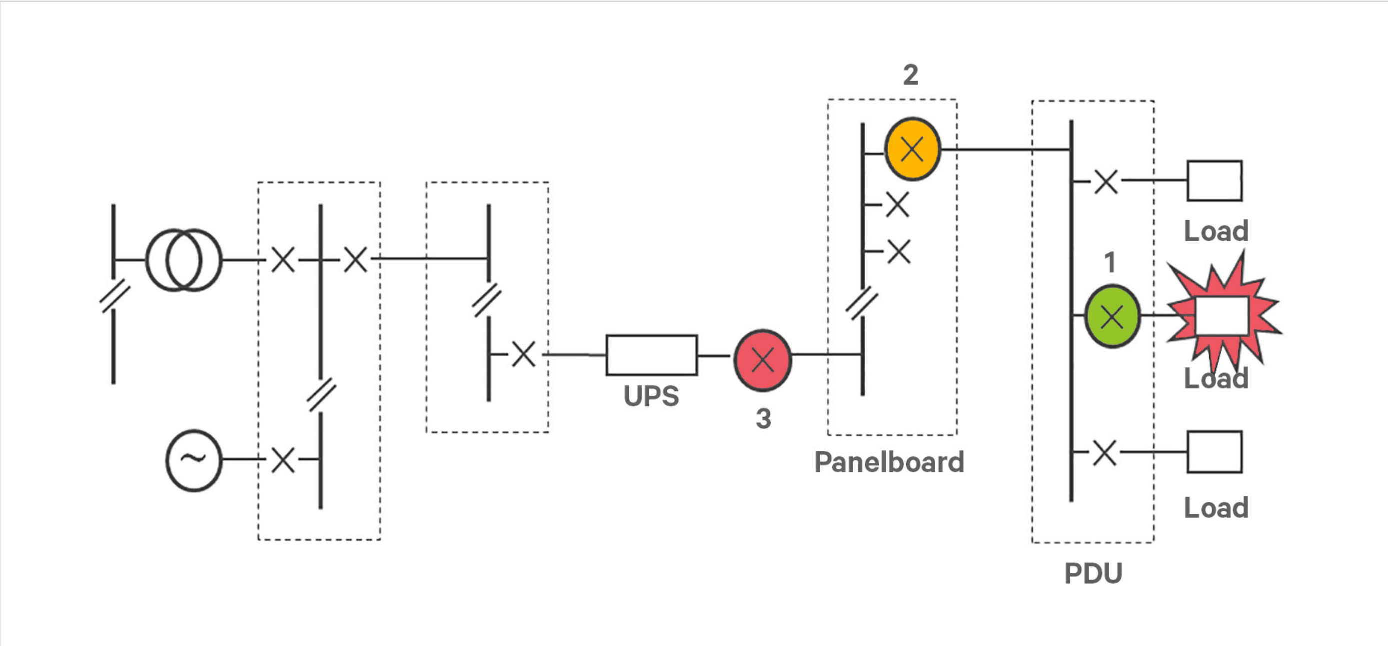

Figure 4

Fault 1 and 2:

Panelboard or PDU fault: both rotary and static UPS, with a proper selectivity coordination, are adequate for the protective devices to interrupt the fault

Fault 3:

UPS-downstream fault: there are three sub-cases:

- If the mains is available, both static and rotary UPS are adequate
- If the mains is unavailable, the static UPS is on battery mode and circuit breakers are used, both the rotary and static UPS will not be able to interrupt the fault
- If the mains is unavailable, then the static UPS is on battery mode. If the fuses are used, then the load may be interrupted for both static and rotary even if they are adequate for the fault interruption

Static Versus Rotary: The Myths and the Reality

As with any technology purchasing decision, buyers will rely on a combination of factual research but also opinion and other subjective input. There continue to be a number of 'myths' surrounding the comparison between static and rotary UPS. However, most of these assertions do no stand up to scrutiny.

MYTH	REALITY
Rotary units have high efficiency at full load, up to 97%	The data center's typical load is 30 - 40% and **rotary UPS suffer from poor efficiency at partial/low loads**. Higher standby losses, higher operating costs.
Rotary have a reduced need for air-conditioning given no or fewer batteries	Rotary have higher losses and, due to the presence of PDUs in the same room, often require additional cooling. **Static UPS have intrinsically lower losses** resulting in relaxed requirements for air-conditioning.
Fewer or no batteries means rotary UPS require less maintenance	Rotary UPS have mechanical components: lower MTBF, higher MTTR and need more maintenance. Maintenance costs are usually >30% higher for diesel rotary UPS. Flywheels are **complex mechanical and electronic equipments**, with expensive maintenance for bearings replacement.
Fewer batteries means rotary UPS require less space	Batteries backup time is 30 s ÷ 30 min (and above) while **flywheel backup time is just 8 ÷ 20 s**.
Rotary has a lower total footprint	Considering the total installation footprint for both static and rotary UPS, the result is that the footprint of the **static UPS system is smaller** or, in the worst case, just a little bit bigger.
No batteries means their maintenance is eliminated	Using **li-ion batteries, which need much less maintenance and have a much longer life**, allows for saving beyond maintenance and replacement costs, even cooling costs thanks to their ability to operate in a wide temperature range.
Rotary UPS handle non-linear loads better	The **fast PWM inverter** is the source offering by far the lowest output impedance in the presence of harmonics. It is the best source on the market in terms of its aptitude to minimize the voltage distortion caused by non-linear loads. **Alternators are always oversized** to provide low impedance.
Higher short circuit current withstand rating	In the typical real case of downstream distribution made up of many lines, static UPS, combined with proper coordination of the protections, are able to let the protective devices interrupt the fault.
Rotary UPS has lower TCO	By considering the rotary UPS higher initial capital cost, lower efficiency at typical data center loads and higher maintenance costs, the **TCO calculation results strongly turn down that argument**.
Possibility to have IP Bus parallel configuration	Static UPS can have **reserve power architecture** (also referred to as "catcher bus architecture"), which are typically less expensive and guarantee a similar evaluated MTBF, full isolation and an even higher MTBF measured on field.

Table 2

Conclusions

Static and rotary UPS technologies have fulfilled important roles in ensuring availability and resiliency in critical infrastructure. However, as outlined in detail in this whitepaper, there are clear and persuasive reasons why the static UPS is a more future-proofed choice. It can provide high levels of back-up capability while also delivering the efficiency and flexibility for a rapidly changing energy landscape. The key benefits of static UPS include:

- **Modularity**. Static UPS can grow as facility requirements grow. This has significant cost and efficiency benefits as it lowers initial capital costs and reduces the likelihood for un-used or stranded UPS capacity throughout the life of the facility.
- **Less reliance on diesel**. There is growing scrutiny over the use of diesel in transport (some German cities are considering bans on diesel vehicles) and it is possible that this will eventually include diesel for non-transport use cases. Static UPS are often deployed in conjunction with diesel generators but they are not as closely coupled as some rotary designs. Importantly, they can handle more low-level grid issues without requiring generators to be engaged.
- **Grid energy storage revenue generation**. Static UPS are usually based around battery technology (including emerging lithium-ion batteries) that are now being harnessed for grid energy storage opportunities.