Vertiv White Paper

Enabling uninterrupted power: Design for reliability in UPS systems

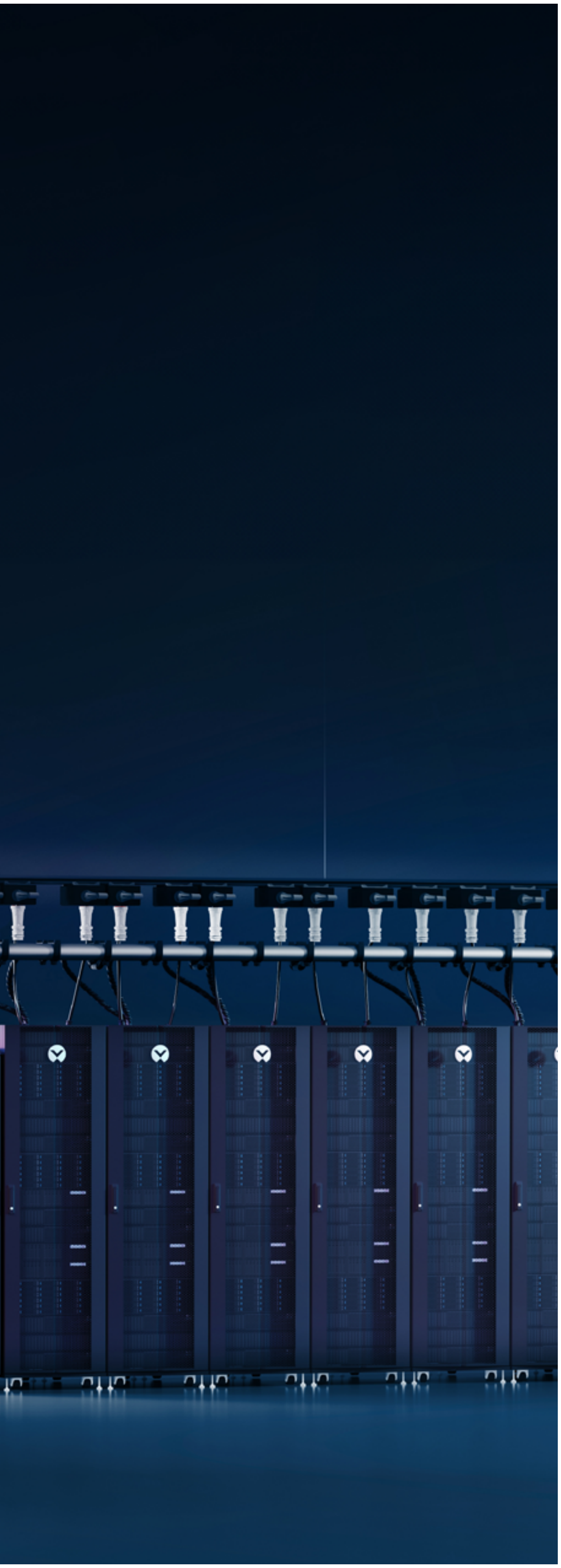

Table of Contents

In this white paper, we consider the advantages of the techniques applied in Designing For Reliability (DFR), a structured approach combining rigorous analysis and advanced testing to facilitate and verify consistent performance of uninterruptible power supply (UPS) systems. Planning and design teams apply the conditions that equipment will face in real-world scenarios for longevity and resilience to minimize weaknesses of products, services, and applications that can lead to premature failures.

While other concepts, tools, procedures, and techniques are also applied as part of Vertiv proprietary methodologies, these are the evident, more common DFR perspectives that practicing engineers outside of manufacturing may be able to best relate to. The scope of these insights is limited to best reflect the closest real-world scenarios by which these are applied for large UPS products and services.

What is “Design for Reliability” (DFR)?

Design for Reliability (DFR) is a comprehensive approach applied across various areas in creating products, processes, and applications to meet high reliability standards. From an engineering perspective, organizations can achieve consistently high performance and reduce maintenance costs through reliable and efficient solutions by incorporating DFR practices.[1 2]

A consistent and reliable power supply is crucial for business continuity, uptime, and services for companies, industrial facilities, and critical digital infrastructure. In recent years, the inclusion of uninterruptible power supplies (UPS) is an essential requirement and DFR pillar practice. UPS systems provide a continuous power supply and safeguard critical digital infrastructures, regardless of foreseen and unforeseen interruptions.

This design philosophy integrates rigorous analysis, testing, and feedback (e.g., lessons learned) to minimize the risk of failure and enhance systems’ abilities to perform under various conditions. By prioritizing reliability from the conceptual stage to the lifecycle obsolescence, UPS systems can better protect sensitive equipment and critical operations, increasing resilience and securing businesses’ and services’ uninterrupted functionality even in power anomalies or failures.

To differentiate the characteristics and methodologies applied, it is worth noting the defining comparisons when DFR is applied:

- Product reliability is achieved by applying resilient design methodologies such as “Design Failure Mode and Effect Analysis” (DFMEA), lessons learned from customer feedback, and rigorous verification tests. These methods, among others, verify that products can withstand operational extremes. Customization for corner cases further enhances adaptability, meeting the unique demands of diverse customer applications. Advanced reliability analyses validate metrics such as mean time between failures (MTBF) and mean time to repair (MTTR) at different levels (e.g., components and systems).

- Application reliability highlights the benefits of tailored solutions for challenging scenarios. A real example can be related to AI variable loads, wherein UPS systems need to be designed to handle fast dynamic AI power fluctuations with stability and without compromising other parts of the infrastructure. In extreme climate environments, stability can be balanced and reached with derating-free operation at 40°C, adaptive power rating up to 50°C, and active humidity control and correction. [3]

- Process reliability seeks consistency through embedded controls at every stage. Every unit should meet rigorous standard requirements through resilient manufacturing design and production, supplier programs, and customer-driven feedback loops. Creating dedicated processes like HyperCare enhances reliability during product launches with additional testing, proactive monitoring, and customer engagement to preempt potential issues and refine processes.

In the following sections, we review some DFR types, practices, and examples applicable to UPS systems for increased and better longevity, resilience, and total cost of ownership (TCO).

Product reliability

This methodology emphasizes early identification and mitigation of potential failure modes, enhancing product reliability through resilient design practices and implementing lessons learned.

Product design

One key aspect of increasing reliability is harnessing the insights from lessons learned and leveraging "Design Failure Mode and Effect Analysis" (DFMEA) to fortify product designs. This approach enables the development of specific product features that enhance operational integrity and offer substantial customer benefits. For example, features developed for the Vertiv™ Trinergy™ UPS system[4] and Vertiv™ PowerUPS 9000[5] to enhance resilience and reliability are:

Reliability needs	**Vertiv™ Trinergy™ product feature**
Improved fault tolerance under several failure modes on the battery side	Distributed batteries[6]
Enhanced safety and redundancy at every core level	Dedicated segregated controls for each core
Prevent damages to internal cores and prevent fault spread at the system level.	Self-isolating cores through contactor
Continuous operation at full load and overload capability of the booster for high-power and/or long-duration discharges	Continuous-duty booster
Continuous operation at full load and overload capability on the bypass line	Continuous-duty solid-state static bypass switch
High output short circuit capabilities	Dynamic line support feature using internal static bypass switch to clear output short circuits
Minimize downtime and maintain continuous system operation even during maintenance or power upgrades.	Hot service and hot swap features
Precise analysis of power quality issues during disturbances or faults	Enhanced diagnostics: Waveform capture, parametric data, history log

Table 1. Applying design failure mode and effect analysis (DFMEA) as part of product design enables the inclusion of features that further products' reliability.

Choosing a UPS system engineered with these principles means investing in reliability, significantly reducing the likelihood of downtime, and ensuring the continuous operation of critical systems.

Verification and validation tests

Verification and validation tests are critical in verifying that UPS systems adhere to stringent performance standards. These tests are methodically designed to confirm the reliability and durability of product specifications. To undergo these rigorous tests and authenticate the resilience of new platforms, 30 MW-prototypes were built to verify and validate both Vertiv™ Trinergy™[7] and Vertiv™ PowerUPS 9000 UPS[8] systems.[9]

Engineering validation tests (EVT) and design validation tests (DVT) rigorously assess and confirm product specifications. Through this process, UPS systems are validated against a spectrum of operational conditions to establish their capability to perform reliably in real-world scenarios.

Additional reliability tests

Additional tests proactively simulate critical conditions that a UPS might encounter. Some of the additional tests that can be performed to simulate and verify UPS resilience performance in harsh real-world scenarios are:

Reliability needs	Reliability tests
Seismic resilience and general durability	Structural tests
Electrical resilience	Voltage surge and sag tests to ascertain electrical resilience
Long-term reliability over years of operation	Highly accelerated life testing (HALT) provides accelerated aging scenarios.
Product integrity during storage in harsh environmental conditions	• Low and high-temperature storage test • Humidity and heat storage test
Product integrity during operation in harsh environmental conditions	• Low and high-temperature operation test • Humidity and heat operation test
Packaging is appropriately designed to protect the product in bad transportation conditions.	Lean, (accidental) fall, and stacking tests
Resilience to vibration during storage or operation	Random vibration test
Product ability to work in not clean conditions	Wet dust test

Table 2. Examples of additional reliability tests vis-à-vis the potential real-world scenario

Each of these tests validates features and enhancements at the product's level of reliability. Following the examples of Vertiv™ UPS systems, these tests have been performed on the new large-power UPS platforms. The majority of the tests were conducted at a Vertiv reliability lab using dedicated machinery to simulate specific conditions at specific sites.

Figure 1. A sample of a low-temperature storage test after two hours (top) and 16 hours (bottom)

Figure 2. Wet dust test

Corner case testing

In recent years, diverse applications have emerged, and customers have requested specific requirement customizations that, while outside the off-the-shelf UPS features and requirements, are critical for their respective operations. These specific conditions have been addressed through engineer-to-order complex (ETO-C) solutions, tailoring systems to handle these corner case applications.

For Vertiv corner case testing is directly linked from:

- Customer feedback
- Lessons learned from the field as analyzed with scrutiny by the company's technical support and engineering teams
- Market trends

These serve as the basis and direct line to understanding customers' evolving needs, especially compared to the readily available standard UPS specifications in the current market. In addressing these changing needs, manufacturers gain valuable insights into emerging market demands, providing the position to innovate and enhance systems' reliability and adaptability continuously. This regular interaction with customers keeps manufacturers aware that products remain at the forefront of research, technology, and market relevance.

Moreover, these customizations contribute to the evolving resilience and adaptability of the existing and new platforms, facilitating innovation in reliability not merely as a feature but as a foundational characteristic.

Site-related conditions and requirements assessments

To maintain product integrity, the site conditions and requirements need to be assessed, strengthened, and anticipated to maintain the overall reliability of UPS systems. This evaluation of the environment considers the daily operating conditions where the equipment will be installed. This also prepares the systems to perform under real-world and potentially extreme circumstances, addressing challenges posed by varying external conditions such as dust, temperature fluctuations, and humidity.

Additional design features must be implemented to test for operational integrity in rigid site conditions and increase resilience. Designing products to withstand these factors means that the UPS can be relied on even in harsh environmental conditions.

Environmental condition	**Additional elements for resilience**
Dusty environments	Protections for dust, avoiding accumulation in likely areas for collection and validated by the debris test.
Environments with high temperatures and/or wide temperature variations	• Extended temperature ranges (0 to 50°C) • Temperature control with automatic derating management
Humidity management	Humidity sensing for control and correction within specific limits.

Table 3. The site's conditions for installing and deploying equipment should be anticipated, tested, and evaluated for increased resilience.

Advanced reliability analysis

Advanced reliability analysis validates the reliability of individual components and entire systems. This essential analysis comprehensively explains how components (e.g., circuit boards) and systems perform under various conditions and meet stringent reliability standards.

For analysis, tools like electronic reliability prediction software provide accurate life predictions for electronic hardware at the component, board, and system levels in early-stage design. They are employed to simulate MTBF and availability. These tools enable engineers to predict component performance and identify potential weaknesses even before they impact system operations. Additionally, the overall electrical reliability is assessed through rigorous simulations to provide a comprehensive view of system endurance and capability. This is extremely important in considering scenarios of facilities handling AI loads where fast variable loads affect the entire power train, not just the UPS itself.

Metrics such as mean time between failures (MTBF) and mean time to repair (MTTR) data are not just theoretical estimations. Initially modeled, these metrics are subsequently verified against real-world performance data and information collected from field units. This dual approach—combined with sophisticated modeling with empirical data—facilitates a resilient validation of the system's reliability, offering a reliable foundation for predicting system behavior.

Application reliability

This methodology tests and assesses that systems perform as intended in each customer-specific operational environment, resulting in dependability and user satisfaction.

The application reliability of UPS systems demands an approach that goes beyond standardized solutions. Different operational environments and application requirements necessitate tailored equipment to maintain high-reliability standards. Some applications demand precise powering and conditioning due to high-performance computing (HPC) loads, while others operate under extreme temperature ranges that require resilient thermal management. Considering that all specific varying conditions need to be addressed, the UPS systems would have to be flexible and powerful enough to respond and support the operational needs of specialized applications, enhance longevity, and facilitate consistent performance tailored to each unique environment.

AI load demands

AI load profiles have power demand patterns that deviate considerably from traditional loads, presenting new challenges for grid stability and power infrastructure. Unlike conventional IT loads, which typically maintain a steady demand with small manageable fluctuations, AI applications demonstrate rapid and intense load variations driven by clusters of graphics processing units (GPUs). These drastic power fluctuations bring momentary overloads, with abrupt cycles and synchronization across multiple GPUs, and can apply considerable strain on the grid if unmanaged. Addressing these rapid changes for facilities with continuous uptime demands necessitates advanced UPS solutions to handle dynamically demanding profiles.

To illustrate an example, a representative GPU power profile shows that during peak demand, GPUs can experience power surges reaching 130% to 150% of nominal load for durations as brief as 0.4 milliseconds. This is followed by a sustained high demand at 100% to 125% for up to 50 milliseconds. These peaks can synchronize across GPUs, racks, or entire rows, intensifying the aggregate power draw. Power can drop below 100% for approximately 2,000 milliseconds at lower demand levels, occasionally dipping between 10% and 30% over similar periods.

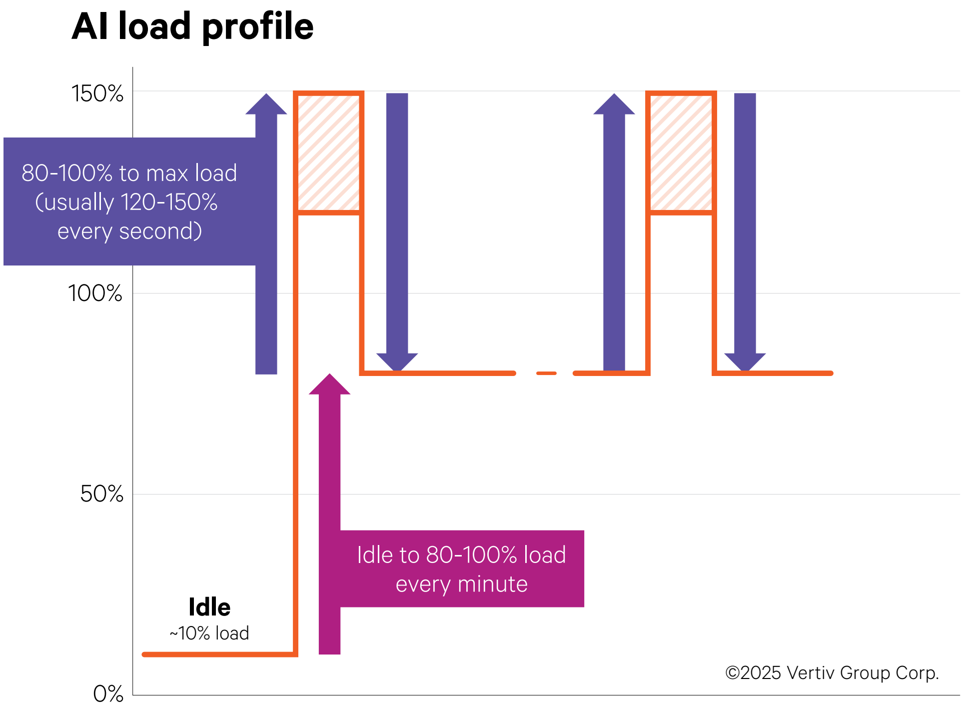

Figure 3. GPUs can have drastic power fluctuations during peak demands, drawing intense aggregate power across all connected systems, such as entire racks, rows, and other GPUs.
Source: 2024 Vertiv AI Roadshow

These rapid fluctuations present new challenges, highlighting the need for UPS systems to accommodate the specific requirements of AI applications.[10] With advanced UPS solutions deployed, engineers and operators on the ground can aim to maintain stability and reliability in response to these changing load profiles with concrete solutions.

AI application challenges	Solutions with specific UPS features for handling AI loads
Power fluctuations Occur as graphics processing unit (GPU) clusters' requirements shift from idle to overload in milliseconds.	Rely on large UPS overload capabilities designed to support the drastic shifts. Leverage control algorithms on UPS in two possible scenarios: • The user wants to avoid hitting the electrical source or local generators, which are not sized to withstand large power swings. • The user wants to avoid hitting the battery to prevent premature failure due to small but frequent discharge/recharge cycles.
Thermal cycling Rapid temperature changes in components due to varying workloads.	Adopting a centralized large UPS that is resilient by design and tested to increase reliability in extreme conditions and corner cases. Adjusting fan speed control algorithms in UPS and other power components to manage thermal cycling effectively.
Increasing power density Confined spaces demand more processing power, pushing traditional power protection technologies to their limits.	Installing large UPS optimized for high power and integrating other power train elements.

Table 4. Above are some examples of changing power requirements as more companies and facilities encourage the use of AI for their respective operations, and the solutions that UPS systems offer to address these evolving concerns.

High temperatures and humidity levels

UPS systems are generally housed in climate-controlled environments, with temperatures maintained around 25°C and humidity levels carefully monitored.[11] However, cooling failures or unexpected environmental conditions can lead to spikes in both temperature and humidity. These risks are especially pronounced in regions with consistently high temperatures and humidity, where the stability of cooling systems is critical for optimal UPS operations. In such conditions, it is essential to have systems designed to maintain performance and reliability even when environmental controls are compromised.

A UPS capable of operating in harsh ambient conditions offers significant advantages in terms of flexibility and reliability, especially in environments where temperature and humidity are prone to fluctuations. Engineers reduce the risk of system downtime by maintaining optimal performance even when cooling systems fail, or environmental conditions exceed normal ranges.

The key features of the UPS that enhance this resilience include:

- High operating temperature without derating: Full operation without derating up to 40°C with a power factor of 1, enabling maximum performance even in elevated temperatures.
- Automatic temperature detection and derating: Capability to handle temperatures up to 50°C by automatically adjusting UPS power to prevent component strain and maintain reliability under extreme heat.
- Humidity management: Humidity sensors and controls allow the UPS to actively regulate internal humidity, reducing it when necessary to protect against potential moisture damage.

These features collectively provide a resilient solution for reliable power management in challenging environments.

Process reliability

This methodology facilitates consistent, high-quality outcomes, minimizing variability and defects. In the context of striving for overall reliability, process reliability is just as critical as product reliability. This aspect focuses on the precision and consistency of manufacturing and assembly processes, which are fundamental to delivering a dependable product.

High-quality processes lead to fewer defects, enhanced performance, and greater customer satisfaction. This section will delve into the measures and standards that oversee manufacturing and assembly processes alongside rigorous quality controls implemented at every stage. These protocols are essential in seeing that each product adheres to the highest reliability standards from initial production to deployment. As manufacturers focus on process reliability, products consistently deliver the expected dependable performance.

Embedded quality processes and controls

Quality needs to be embedded into every phase of the process, specifically seeing that each product produced meets stringent reliability and performance standards. This approach begins with adherence to QMS and certifications such as ISO9001[12] and Saudi Standards, Metrology and Quality Organization (SASO),[13] establishing a solid foundation for guidelines that can be followed.

Key product and process quality metrics such as field failure rate (FFR) and first pass yield (FPY), need to be monitored to establish that the products consistently perform as intended. Quality labs and root cause analysis (RCA) processes are important to facilitate continuous improvement, while warranty management and detailed analysis of failures in the field further drive product enhancements.

Supplier quality is critical in maintaining the integrity of the supply chain. Using a supplier approval checklist, conducting regular audits, and implementing improvement programs are just some measures that coincide with seeing all components meet rigorous standards. The suppliers' performance needs to be tracked through key performance indicators (KPIs) to monitor their respective contributions to the overall quality goals.

Resilient quality controls need to be deployed in **manufacturing quality** to manage non-conformities proactively and adhere to standard work procedures to prevent issues such as leaks and torque tool errors. This approach maintains that every product leaving the facilities is held to the highest standard.

Significant emphasis needs to be placed on **customer quality.** Processes and actions like the Red Flags process, customer meetings, audits, and site visits are important to maintain a close relationship with the customers and that their feedback directly informs quality improvements.

Design quality must be integral to the new product development and introduction (NPDI) process. Participating in Process Failure Mode and Effects Analysis (PFMEA) strives to identify and mitigate potential design risks early in the development cycle, leading to more reliable products.

While not exhaustive, the last in this list is **service quality.** This is continuously monitored through KPI dashboards and project issue management tools, maintaining service level agreements (SLAs) to meet customer expectations even long after the product has been deployed.

This structure emphasizes quality integration throughout the entire product lifecycle and across all aspects of the business, making and maintaining the highest possible reliability.

HyperCare: Enhancing product reliability

The HyperCare phase is an intensive, time-bound Vertiv process developed to facilitate reliability during the critical initial launch of new UPS platforms, designed to provide "peace of mind" for early adopters.

HyperCare addresses potential hidden issues across the value chain through proactive management and comprehensive support, reinforcing confidence in the product's reliability from the outset.

Key activities of HyperCare:

- **Preparation and factory phase:** A deep understanding of customer and project requirements is established, with additional testing and quality checks at the manufacturing level to ensure reliability from the earliest stages.
- **Execution and delivery phase:** HyperCare extends beyond production, involving quality controls during shipping, installation, and commissioning, with dedicated teams onsite to oversee proper setup.
- **Observation and functional supervision:** Continuous, proactive monitoring of installed units through advanced logging and diagnostics tools for early detection of anomalies, enabling immediate action if required.

Internally, HyperCare focuses on accelerating the learning curve, adopting a proactive, detail-oriented approach, and encouraging teams to consistently question how improvements can be made. This shared understanding across functions supports continuous improvement, resilience, and reliability from product launch onward.

HyperCare serves as a value-added offering for customers, showcasing the advantages of preventive maintenance and reliability. This structured approach aligns all teams to anticipate and address challenges, seeking to maintain that UPS systems perform reliably and deliver long-term value for customers.

Conclusion

Design for Reliability (DFR) has been demonstrated as a comprehensive engineering methodology, measuring and maintaining that products, processes, and applications consistently meet the highest reliability standards. By integrating DFR across all stages of development, reliability for resilient designs, rigorous quality assurance, and tailored solutions that address diverse challenges can be achieved.

In facilitating the continuous provision of power, the UPS and its related products, applications, and processes deliver reliable power protection solutions that minimize downtime and enhance the longevity of components, systems, and facilities. DFR, as an approach applied, safeguards critical systems and drives continuous improvement and adaptability to meet the evolving demands in a dynamic world.

References

[1] Ansys Inc. (n.d.). “What Is Design for Reliability (DfR)?” Accessed on July 2024 at https://www.ansys.com/blog the-what-why-when-who-and-how-of-design-for-reliability.

[2] Schenkelberg, F. (n.d.). “Introduction to Design for Reliability.” Accessed on July 2024 at https://accendoreliability.com/introduction-design-for-reliability/.

[3] Vertiv. (n.d.) “Vertiv™ PowerUPS 9000 480V.” Product page. Accessed on November 2024 at https://www.vertiv.com/en-us/products-catalog/critical-power/uninterruptible-power-supplies-ups/vertiv-powerups-9000-480v/.

[4] Vertiv. (n.d.). “Vertiv™ Trinergy™.” Accessed on July 2024 at https://www.vertiv.com/en-us/campaigns/vertiv-trinergy-campaign/.

[5] Vertiv. (n.d.) “Vertiv™ PowerUPS 9000.” Product page. Accessed on November 2024 at https://www.vertiv.com/en-emea/products-catalog/critical-power/uninterruptible-power-supplies-ups/vertiv-powerups-9000/.

[6] Vertiv. (March 2024). White paper. “Enhancing UPS Reliability With the Advantages ofw Distributed Battery Systems.” Accessed on July 2024 at https://www.vertiv.com/en-emea/about/news-and-insights/articles/white-papers/enhancing-ups-reliability-with-the-advantages-of-distributed-battery-systems/.

[7] Vertiv. (n.d.). “Vertiv™ Trinergy™ UPS, 1500-2500 kW 480V UL 3-Phase Modular Large UPS.” Accessed on November 2024 at https://www.vertiv.com/en-us/products-catalog/critical-power/uninterruptible-power-supplies-ups/vertiv-trinergy/.

[8] Vertiv. (n.d.). “Vertiv™ PowerUPS 9000.” Accessed on November 2024 at https://www.vertiv.com/en-emea/products-catalog/critical-power/uninterruptible-power-supplies-ups/vertiv-powerups-9000/.

[9] Vertiv. (March 2024). White paper. “Enhancing UPS Reliability With the Advantages of Distributed Battery Systems.” Accessed on July 2024 at https://www.vertiv.com/en-emea/about/news-and-insights/articles/white-papers/enhancing-ups-reliability-with-the-advantages-of-distributed-battery-systems/.

[10] Raggi, T. and Heber, B. (Sept. 30, 2024). “Evaluating the performance of Vertiv™ large UPS systems with AI workloads.” Accessed on October 2024 at https://www.vertiv.com/en-emea/about/news-and-insights/articles/educational-articles/evaluating-the-performance-of-vertiv--large-ups-with-ai-workloads/.

[11] Power Control. (Feb. 22, 2019). “What constitutes a poor UPS environment?” Accessed on July 2024 at https://www.powercontrol.co.uk/news-blog/blog/what-constitutes-a-poor-ups-environment/.

[12] ISO/TC 176/SC 2. (n.d.). “ISO 9001.” Accessed on October 2024 at https://committee.iso.org/sites/tc176sc2/home/projects/published/iso-9001-2015.html.

[13] Saudi Standards. (Last modified Oct. 8, 2024). “Certificates of Conformity.” Accessed on December 2024 at https://saso.gov.sa/en/sectors/certificates/compliance_certificate/pages/default.aspx.

VERTIV™

Vertiv.com | **Vertiv Headquarters,** 505 N Cleveland Ave, Westerville, OH 43082, USA

SL-80062 (02/25)