VERTIV WHITE PAPER

Enhancing UPS Reliability With the Advantages of Distributed Battery Systems

Index

Distributed batteries excel in improving the reliability of large modular UPS systems by seamlessly optimizing fault tolerance.

Uninterruptible power supplies (UPS) are critical in maintaining power quality and ensuring continuous availability for various applications. They guarantee a reliable and consistent quality of power supply, safeguarding electronic equipment from disruptions, blackouts, and harmful voltage spikes.

UPS systems are also designed to provide backup electrical power during interruptions or instability in the electrical grid. Depending on the application, this allows for longer-term backup power sources to be started (such as fuel cells and natural gas generators, among others). This use case is also the most typical use of UPS systems in large-scale data centers where business continuity is critical.

The Critical Role of Batteries in UPS and Infrastructure

Batteries lie at the core of UPS functionality during grid outages. UPS systems store energy in the battery during regular grid operations and take energy out of it in the event of a grid interruption. In large-scale data centers, this allows a seamless transition to longer-term backup power like generators, fuel cells, or natural gas generators, mitigating potentially detrimental disruptions of critical IT load.

Batteries can be integrated directly within the UPS frame for lower power requirements.
However, external dedicated battery cabinets are typically needed for higher-powered applications.

Different UPS architectures exist when considering higher power applications, like those frequently seen in large-scale data centers, and other layouts are possible for the resulting system made up of UPS and batteries.

The next section gives an overview of relevant concepts and architectures for large, three-phase UPS systems.

Redundancy

Redundancy configurations in UPS systems are crucial for enhancing reliability and ensuring continuous power supply. The most common redundancy configurations are:

- N Redundancy: No redundant modules or systems exist in an N configuration. The system has a single UPS module, making it more vulnerable to failures.
- N+1 Redundancy: In this setup, there are "N" active UPS modules, each capable of handling the entire load independently. The "+1" represents an extra standby UPS module. If any active module fails or requires maintenance, the standby module automatically takes over, ensuring an uninterrupted power supply to the load.

N+1 redundancy provides reliability and fault tolerance while allowing maintenance or replacement of individual modules without downtime.

- 2N Redundancy: 2N redundancy is a high level of redundancy where two wholly independent and parallel UPS systems are installed. Each system can support the entire load independently. If one system experiences a failure or maintenance, the other system seamlessly supplies power. 2N redundancy offers the highest fault tolerance and reliability, making it suitable for mission-critical applications where downtime is unacceptable.

Monolithic UPS Systems

In a conventional design, a monolithic UPS subsystem may be composed of:

- One component acting as a rectifier.
- One component acting as a battery booster.
- One component acting as an inverter.
- A bypass static switch (STS).

A monolithic UPS is comprised of single or multiple subsystems that behave like a single entity. Monolithic UPS can provide satisfactory power protection for critical loads or can be combined as building blocks into parallel or dual-bus systems.

Monolithic UPS have relatively simple topology and control logic. However, this implies some functional limitations: for example, monolithic UPS are not typically designed to be scaled to increase their installed power and adapt if the user's application significantly changes. Additionally, monolithic UPS usually have no internal redundancy.

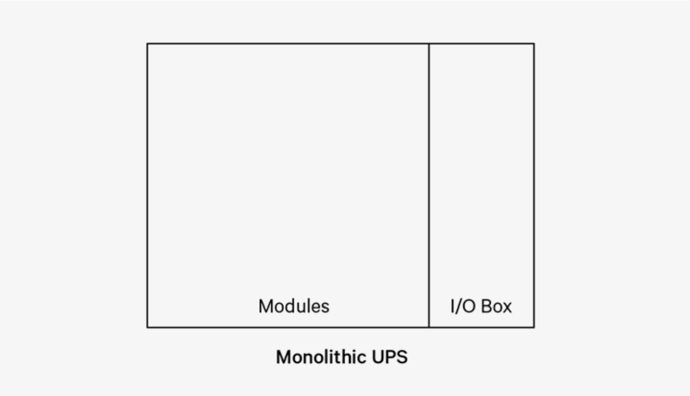

Figure 1. *Conventional monolithic UPS systems design*

Modular UPS Systems

A modular UPS system is made up of a UPS frame that is populated with power modules. Power modules can be arranged in capacity or redundancy configurations. Modular UPS controls allow each power module to be independent from the others. It is often the case that the power modules can be safely removed from, or installed into, a live system (a feature capability known as "hot swapping" and "hot scaling")

Redundancy and scalability benefits:

- Allows the addition of modules for N+1 redundancy.
- Ensures continuous power supply despite module failures or maintenance.
- Prevents initial oversizing via system modification throughout its life.
- Matches capacity or redundancy to load changes.

Fault Tolerance:

- Exhibits higher fault tolerance levels in modular designs.
- Isolates module failures through redundant configurations.
- Contains faults within the capacity configurations of each module.
- Localized fault response enhances system resilience.
- Minimizes risk of widespread outages.
- Contributes to the overall reliability of modular UPS designs.

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Distributed or Centralized Batteries: Different Architectures, Different Tradeoffs

One of the most critical decisions in UPS implementation revolves around the battery architecture. **The choice between distributed and centralized batteries significantly impacts system resilience, efficiency, and maintenance.** The decision should not be confined to a mere technical choice. Instead, it should be viewed as a broader decision involving trade-offs at the application level and how the chosen configuration serves the application's or clients' specific needs.

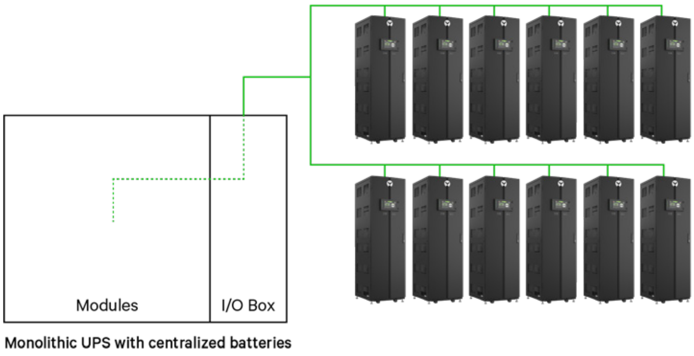


Figure 2. *An example of a centralized battery system with a monolithic UPS.*

Centralized Battery Architecture

In UPS systems involves connecting all batteries to a single point. This architecture presents a more straightforward installation and cost-effective solution concerning the battery system's primary components. However, the cost of ancillary devices (that is, the battery circuit breakers) may be higher; from **a purely technical and performance perspective, centralized battery systems have limitations in terms of fault isolation.**

In single UPS systems, centralized battery architecture can be applied to monolithic and modular UPS.

Distributed Battery Architecture

Takes a modular approach, with each power module paired with its dedicated battery cabinets. This arrangement offers an overall higher load protection and several compelling benefits that will be explained in-depth in the following chapters of this paper.

Monolithic UPS don't have a modular design and, hence, cannot be compatible with distributed batteries in a single UPS system. Distributed battery architecture can be applied to modular UPS systems only, as each battery group is paired to each module of a modular UPS.

Figure 3. *An example of a distributed battery system with the Vertiv™ Trinergy™ modular UPS and Vertiv™ EnergyCore lithium-ion battery cabinets which deliver 5 minute runtime up to 250 kW AC load reducing footprint.*

Nonetheless, not all modular UPS support distributed batteries. Many modular UPS on the market don't offer this possibility, as they have one pair of DC power bars, no matter the number of modules.

Examining System Resilience in Different Scenarios: Centralized vs. Distributed Battery

Distributed batteries enhance the benefits of having a modular UPS system, whereas several tradeoffs must be considered with centralized batteries. Designing a modular UPS system with distributed batteries brings many advantages:

1. Short Circuits Between the Battery Circuit Breaker (BCB) and UPS

The advantages of a distributed battery system become particularly evident when considering potential short-circuit scenarios between the battery circuit breaker (BCB) and the UPS. This fault can occur due to insulation loss of DC power cables because of environmental conditions, equipment malfunctions, external interference, or aging infrastructure.

Centralized Battery

Cause	Short circuit between BCB and UPS
Consequence	Fuses on UPS DC/DC converter blow to isolate the fault
Load protection	UPS is limited; it has no backup power from the battery side

Table 1. Centralized battery scenario

In **centralized battery** architectures where all batteries are linked to a single point, a short circuit between the BCB and the UPS can have severe repercussions, such as disrupting power supply and potentially causing equipment damage or downtime. In such cases, the fuses on the DC/DC converter will blow, and the UPS loses the capability to provide backup power in the event of a mains failure. This vulnerability compromises the system's ability to seamlessly transition to battery backup when needed.

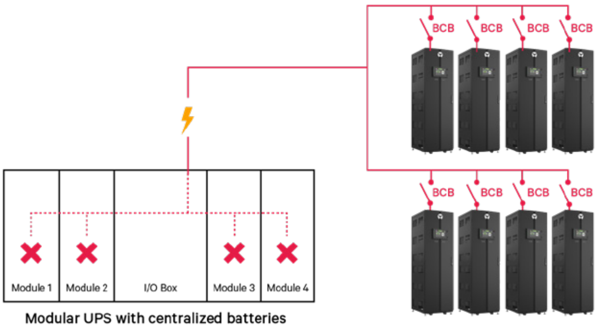


Figure 4. With centralized batteries, all the batteries will be unavailable in case of a short circuit between the BCB and UPS. No backup power is available in case of failure in the mains.

In contrast, the **distributed battery** configuration is more robust under this scenario. In the event of a short circuit between the BCB and the UPS, the impact on the system is localized. Specifically, only the group of batteries connected to the affected circuit would be rendered unavailable, while the remainder of the distributed batteries would remain operational. The impact of the short circuit being isolated prevents a complete system shutdown, ensuring continued power supply to the loads connected to the unaffected battery groups. Fault containment and resilience of distributed batteries significantly elevate system availability, in contrast to the previously mentioned vulnerabilities inherent in centralized architectures.

Distributed Battery

Cause	Short circuit between the BCB and UPS
Consequence	Fuses on the UPS DC/DC converter blow to isolate the fault only in the involved module.
Load protection	Higher; UPS still has backup power from the battery side.

Table 2. Distributed battery scenario

Real scenarios of short circuits between BCB and UPS will be explained in-depth in the following paragraphs.

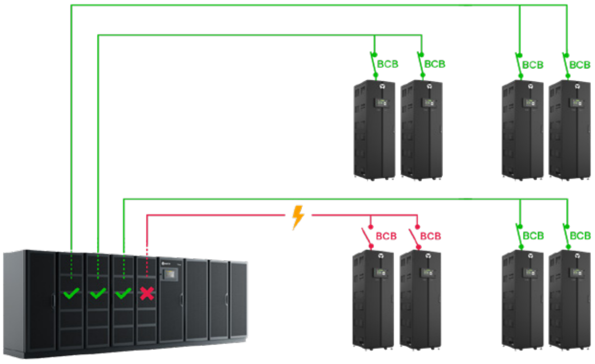


Figure 5. With distributed batteries, only the affected group of batteries will be unavailable in case of a short circuit between the BCB and UPS. The rest of the batteries continue to be available for backup power.

2. Battery Failure Isolation

Battery faults in UPS systems can arise in various scenarios, presenting critical challenges to the reliability and performance of the backup power infrastructure. These faults can manifest as insulation losses, short circuits, or other malfunctions within the battery architecture. The UPS can interface with the BCB, controlling the BCB trip in certain conditions for additional safety.

Case 1: BCB Can Clear the Fault

In a **centralized battery** setup, if a battery cabinet fails and the BCB can isolate the fault, the load continues to be supplied through batteries at full load but for a limited runtime due to reduced capacity with one fewer battery cabinet.

On the other hand, in a **distributed battery** setup, if a battery cabinet fails and the BCB can isolate the fault, the load continues to be supplied through batteries at full load. Initially, the impacted core draws energy from the remaining batteries and, subsequently, continues to provide at full load with the remaining core operating in overload.

Case 2: BCB Is Unable to Clear the Fault

If the battery fault cannot be cleared within the BCB, distributed battery architectures can still provide a higher level of fault tolerance than centralized ones. In **centralized** setups, if the BCB cannot isolate, a single failure within the battery bank can propagate within the DC power distribution, potentially blowing DC/DC converter fuses and resulting in a loss of battery backup power.

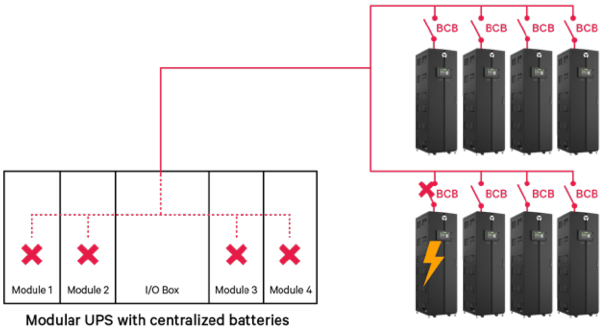


__Figure 6.__ If the BCB cannot clear the battery fault, the impact will affect the backup power of the entire load in a centralized architecture.

In contrast, **distributed** batteries increase the system's resiliency level. Due to their electrical isolation from one another, the impact of a failure in one specific group of battery cabinets remains contained. This containment minimizes the reach of the failure, ensuring it does not cascade into broader system-wide outages.

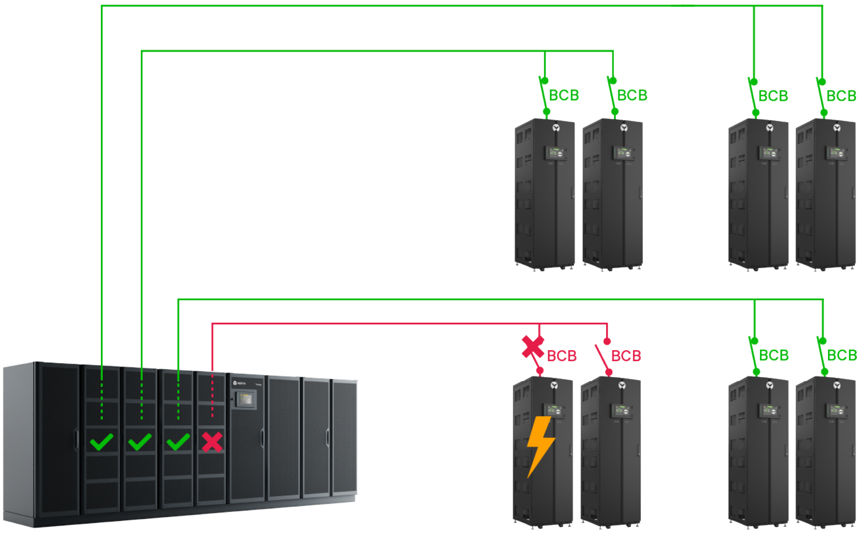


__Figure 7.__ If the BCB cannot clear the battery fault, the fault will be localized within a single battery branch.

3. Cost of DC Power Protection (BCB)

In **centralized battery** setups, each BCB must be sized to withstand the current of "N-1" strings. In case of an internal short circuit of a single battery string, all the other battery strings will insist on the failed one, and there is the risk of exceeding the maximum capability of the protection device associated with the failed string. According to global standards, the protection devices' sizing must be done to ensure current interruption without rupture.

This introduces significant challenges regarding the cost and availability of components as the number of battery cabinets increases. For instance, in a setup with four battery cabinets (see Figure 9), the BCBs must accommodate the current of three cabinets. In comparison, they need to handle the current of seven cabinets in a configuration with eight cabinets (see Figure 8 of a monolithic UPS with eight battery cabinets). While some Li-Ion battery cabinets already include BCB, in most applications, BCB is an external device to be sized according to the above criteria. This necessitates using BCBs with considerably higher current ratings, which can substantially drive up DC power protection costs.

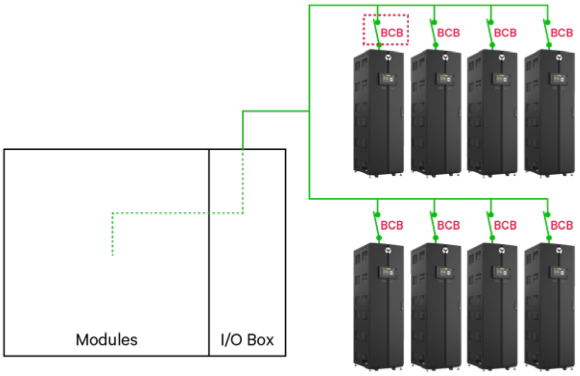


Figure 8. *In centralized battery setups, each BCB must be sized to withstand the current of N-1 strings (in this illustration, 11 strings). This results in higher costs for DC power protection.*

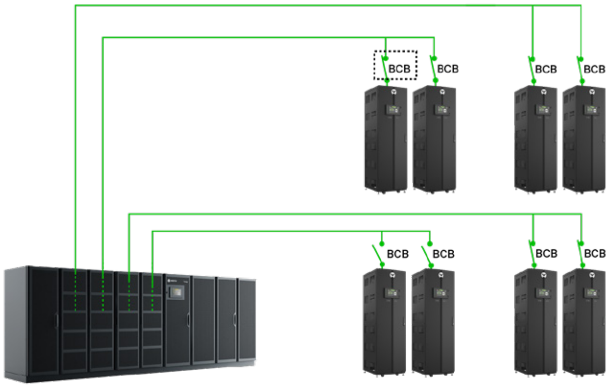


Figure 9. *In distributed battery setups, each BCB is sized to withstand the current of N-1 strings (in this illustration, two strings). This results in lower costs for DC power protection.*

This is different for distributed battery architectures. In spreading battery modules across separate cabinets, each BCB only needs to handle the current of its corresponding cabinet group, significantly reducing the current load and the associated costs. Distributed battery systems are typically associated with increased cost, but that is only sometimes the case when looking at the overall solution cost.

4. BCB Configuration

Distributed battery architectures provide benefits in maintenance scenarios, particularly when considering the installation configuration of the BCBs. In a **centralized battery** setup where all batteries converge simultaneously, only one BCB for the entire battery bank introduces a substantial vulnerability. This configuration results in a single point of failure, and the breaker can only disconnect all batteries simultaneously. Servicing or replacing batteries in this scenario can be challenging as all the battery cabinets will be disrupted by any activity related to a single battery cabinet. Hence, it won't be possible to have backup power from batteries during service or the replacement of one or more battery cabinets.

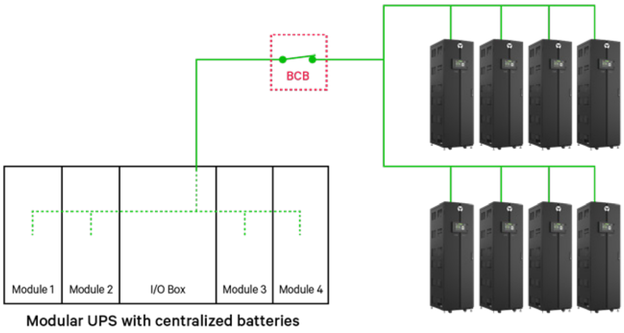


Figure 10. *In centralized battery setups, there is a single point of BCB failure and disconnection for all batteries. This means that an issue with the BCB affects the entire battery bank, resulting in a complete loss of power supply.*

In the case of **distributed battery** setups, even when there's one BCB per UPS module or core considering a modular UPS, the overall system has better serviceability and superior fault containment capability. The key distinction lies in the presence of multiple battery strings in distributed setups, which eliminates the vulnerability associated with a single point of failure: each group operates independently. This configuration ensures continued power supply from battery groups unaffected by faults, enhancing system reliability and minimizing the risk of total outages.

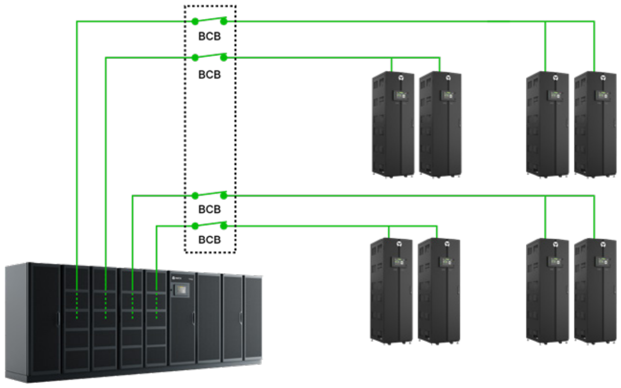


Figure 11. In distributed battery setups, multiple BCBs allow the battery groups to operate independently. This means that an issue with one BCB does not affect the entire backup power system, allowing the other batteries to carry the load of the failed battery bank.

Conversely, regardless of whether batteries are centralized or distributed, individual BCBs can be installed for each battery cabinet or group of batteries. This design eliminates single points of failure and disconnection. Downtime is significantly minimized, leading to enhanced system availability, but costs are higher. However, even with this configuration, in centralized battery systems and monolithic UPS systems, the UPS can't control each BCB individually, as monolithic UPS have centralized logic.

Scenario: Insulation Loss or Short Circuit Between BCB and UPS During Regular Operation Without Mains Failure

Centralized Battery System

1. A short circuit occurs between BCB and the UPS.
2. The UPS DC/DC converter fuses blow to isolate the fault.
3. The UPS can still operate in double conversion mode or other operational modes but loses the capability to provide battery backup power.
4. This vulnerability compromises the system's ability to seamlessly transition to battery backup when needed, particularly in a mains failure.

Distributed Battery System

1. A short circuit occurs between the BCB and the UPS.
2. As a result of the short circuit, fuses in the affected UPS module's DC/DC converter blow.
3. The impact of the failure is confined to the subsystem where it started, allowing the rest of the system to remain fully operational.
4. The system remains fully operational, ensuring continued power from the batteries of unaffected UPS modules.

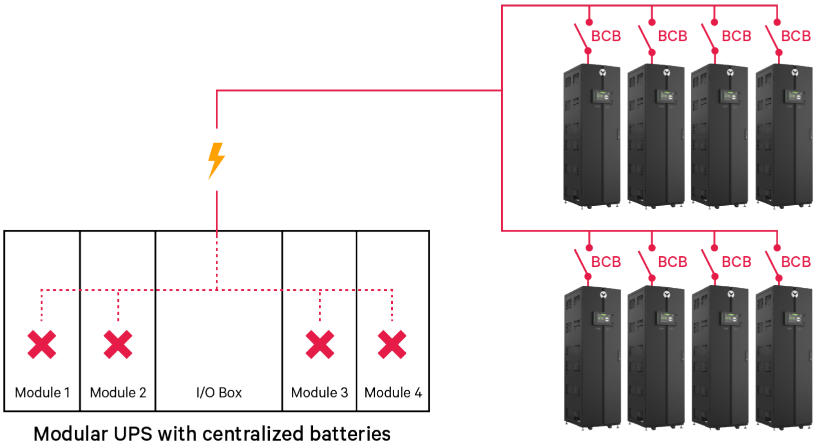
Scenario: Insulation Loss or Short Circuit Between BCB and UPS During Battery Discharging for Mains Failure

These scenarios underscore the critical differences in **response and reliability** between centralized and **distributed battery systems** in UPS configurations. The distributed approach maximizes the system's capability to ensure an uninterrupted power supply, enhances system resilience, and minimizes the risk of critical load instability. As the demand for dependable power grows, the choice between centralized and distributed battery systems becomes increasingly vital, affecting overall UPS performance and operational continuity.

The limitations of centralized battery systems become more pronounced as the power rating of the UPS increases. In scenarios demanding higher power capacity, the concentration of all batteries at a single point introduces challenges in fault isolation. Distributed battery systems remove similar risks when scaling up the application size.

Centralized Batteries: Short Circuit Between BCB and UPS During Mains Failure Scenario

Case 1	Generator not yet started	→	**Loss of critical load**
Case 2	Generator with partial load	→	**Possible loss or damage of critical load**



Distributed Batteries: Short Circuit Between BCB and UPS During Mains Failure Scenario

Case 1	Generator not yet started	→	**No loss of critical load**
Case 2	Generator with partial load	→	**No loss or damage of critical load**

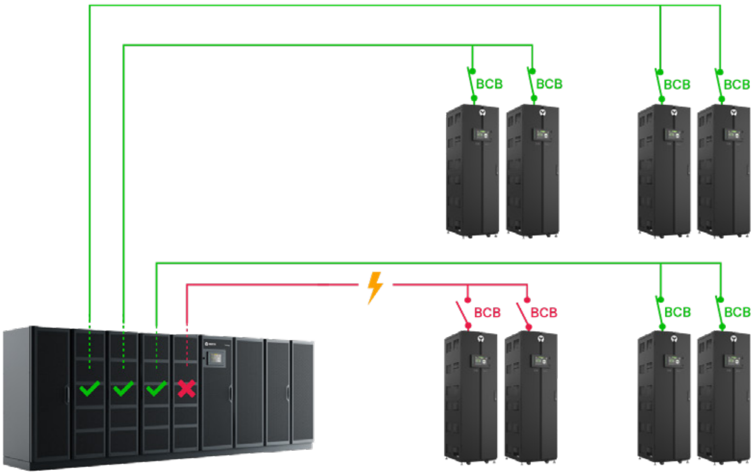


Figure 12. *A comparison of centralized battery systems (top) and distributed systems (bottom) during real-world mains failure scenarios.*

	Load Protection in Case of Insulation Loss or Short Circuit Between BCB and UPS	
	Centralized Batteries	Distributed Batteries
Monolithic UPS	Low, possible loss or damage to the critical load	
Modular UPS	Low, possible loss or damage to the critical load	Very high, no loss or damage to critical load

Table 3. *Comparisons of monolithic and modular UPS systems with centralized and distributed battery architectures in relation to load protection.*

Case 1: Generator Not Yet Started - No Power on Main Input and Bypass Lines

When the generator has not started yet, and the primary input and bypass lines lack grid power, the following chain of events happens if insulation is lost or in case of a short circuit between the BCB and UPS.

Centralized Battery System

1. Batteries are discharging during a mains failure.
2. Insulation loss or a short circuit occurs between the BCB and the UPS.
3. The UPS DC/DC converter fuses blow as a protective response to the insulation loss or short circuit.
4. With blown fuses, the UPS cannot supply the load via the batteries.
5. The UPS attempts to transfer the load to the bypass line.
6. As the generator has not yet been started, there is no power on the bypass line.
7. The outcome is a loss of power to the critical load due to the inability to transfer to the bypass line without generator power.

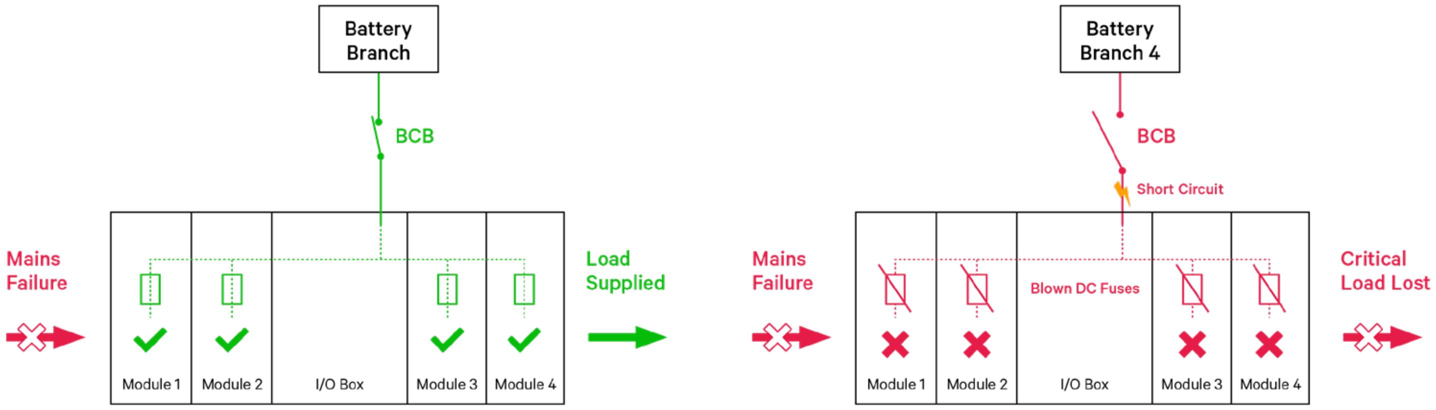


Figure 13. *Centralized battery system scenario showing the initial condition (left) and after a short circuit between BCB and UPS (critical load lost, right)*

Distributed Battery System

Batteries are discharging during a mains failure.

1. In case of insulation loss or a short circuit, only fuses in the affected UPS module's DC/DC converter will blow.
2. The impact of the failure is confined to the subsystem where it originated.
3. The rest of the system remains functional, enabling continued power supply through the batteries.
4. For partial load supply, the remaining modules operate in nominal operation or, to meet the total UPS rating, the remaining modules work in overload.
5. The distributed battery setup ensures an uninterrupted power supply for an extended period.
6. The extended power supply period allows more time for the generator to initiate and assume the load.

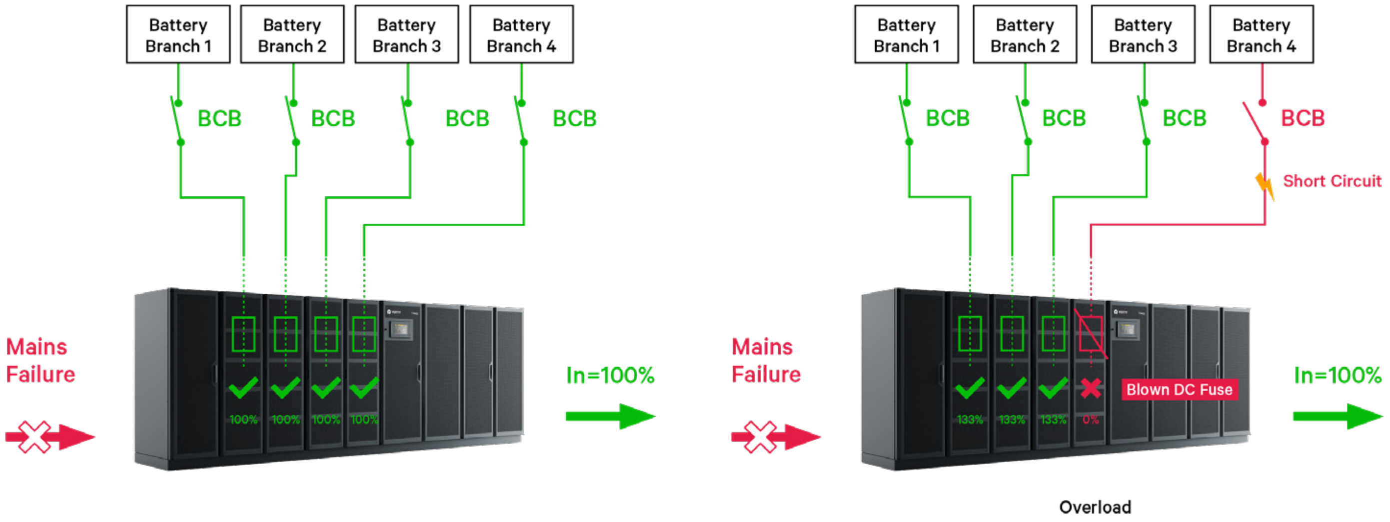


Figure 14. *Distributed battery system scenario showing the initial condition (left) and after the short circuit between BCB and UPS (overload operation, right)*

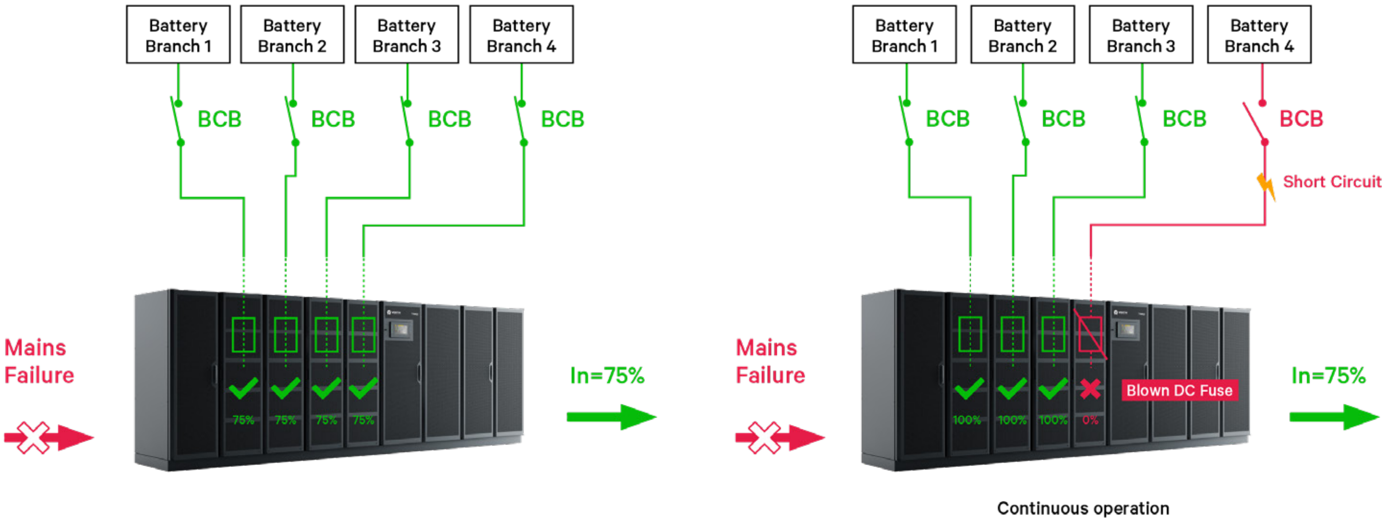


Figure 15. *Distributed battery system scenario of the initial condition (left) and after the short circuit between BCB and UPS (continuous operation, right)*

Case 2: Generator Started, Partial UPS Load Transition

In a contrasting scenario where the generator has just begun supplying power to the primary input and bypass lines, but wherein the UPS is still feeding the load via the batteries, the UPS undergoes a transition while simultaneously drawing more and more power from the mains input on the one hand, and less and less power from batteries on the other hand.

Centralized Battery System

1. Batteries are discharging.
2. The UPS transitions to the bypass line while attempting to maintain power delivery.
3. As the generator has not taken all the load yet, this situation leads to a load step, causing potential voltage or frequency distortions.
4. The load step introduces risks, including voltage or frequency distortions that can damage the load or disrupt critical operations.

Distributed Battery System

1. Batteries are discharging while the UPS is undergoing the load transition, drawing more power from the main input and less power from the batteries.
2. As a result of the short circuit, fuses on the affected UPS module's DC/DC converter blow.
3. The distributed battery system maintains its ability to supply the load through the remaining functional modules.
4. The remaining modules operate in nominal operation for partial load supply. To meet the total UPS rating, the remaining modules work in overload.
5. This seamless power supply allows the UPS to transition from battery to generator, including rectifier walk-in where available.
6. This process occurs without subjecting the generator to sudden increases in power demand, effectively mitigating the risk of load impact on the generator.

Conclusion

The analysis of different battery configurations for UPS systems shows that distributed batteries should be preferred with modular UPS systems, especially for significant power ratings.

Looking at the implications of real-world scenarios, distributed batteries maximize the reliability and benefits that come with modular UPS designs.

The logic behind this preference is rooted in the seamless integration of distributed batteries with the modular design principles of UPS systems. This integration optimizes fault tolerance, leveraging the decentralized distribution of battery modules to align with the modular UPS structure. The result is a system that facilitates targeted maintenance interventions and heightened resilience in the event of potential failures. Choosing a distributed battery setup for a modular UPS results in entirely individual power modules, maximizing fault isolation, minimizing downtimes during maintenance, and optimizing BCB configurations for cost-efficiency.

In examining scenarios, from insulation loss during mains failure to regular operation, there is an underlying indication of the robustness and dependability of distributed batteries within modular setups.

The distributed architecture minimizes the impact of potential failures and ensures a continuous power supply to critical loads. UPS system configurations with distributed batteries maximize system availability by:

- Enhancing fault tolerance.
- Improving performance under several failure modes.
- Improving serviceability by performing maintenance on individual subsystems without interruption for load protection.

Enhanced system availability is vital in critical environments, where applications must be available and protected 24 hours a day, 7 days a week.. Responding to the escalating need for scalable and reliable power solutions, distributed batteries enhance the modularity of modular UPS systems. The inherent strengths in fault tolerance, maintenance efficiency, and system resilience position distributed batteries as the ideal architecture in mission-critical applications. Choosing a distributed battery architecture with a modular large-power UPS amplifies UPS systems' performance and maximizes uninterrupted operations in critical power scenarios.

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