

Impact of Periodic Cycling on Lithium Battery Performance in Standby UPS Systems: A Case Study of a Vertiv 100 kW UPS

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Abstract — Lithium Iron Phosphate batteries in standby uninterruptible power supply (UPS) applications are susceptible to calendar aging when infrequently cycled, yet empirical field data on performance recovery strategies for large-scale industrial systems remain scarce. This study investigates the performance degradation of a Vertiv 100 kW three-phase UPS paired with two strings of 8 Vision Lithium batteries (100 Ah, 52.4 Vdc each), installed in 2021 at a commercial facility with a stable 45 kW load. After three years of minimal cycling, clients reported reduced backup duration, intermittent battery alarms, and DC breaker trips, attributed to calendar aging effects including elevated internal resistance and capacity fade under prolonged high state-of-charge conditions. A manual discharge/recharge protocol was implemented twice weekly using the site load, with discharge duration recorded across successive cycles. Battery performance recovered progressively, with discharge time increasing from 3 minutes to 18 minutes over 10 cycles, corresponding to a State of Health improvement from 2.68% to 16.10%. Following this recovery, the system was programmed for automatic periodic discharges. These findings demonstrate that periodic cycling effectively mitigates calendar aging in standby LFP systems and provide a practical framework for preventive battery management in low-outage industrial UPS environments.

Keywords: Battery runtime improvement, Calendar aging, Periodic battery cycling, Uninterruptible power supply, Vision lithium battery.



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INTRODUCTION

Uninterruptible Power Supply (UPS) systems are critical infrastructure for maintaining continuous operation of essential services, particularly when paired with high-capacity lithium-ion battery banks designed for extended discharge durations. These systems provide reliable, stable voltage and frequency output, crucial for critical applications such as data centers, medical facilities, and communication networks [1]. The increasing integration of renewable energy sources into power grids further amplifies the need for robust battery energy storage systems, as they mitigate the inherent variability and intermittency of such sources, ensuring grid stability and power quality [2]. While traditionally dominated by lead-acid batteries, lithium-ion battery technologies are increasingly preferred in these applications due to their superior efficiency, extended lifespan, and enhanced compatibility with advanced

power management systems [3].

The degradation of lithium-ion batteries is a complex phenomenon influenced by various factors, including charge/discharge cycles, temperature, depth of discharge (DoD), and cell chemistry [4]. High discharge currents and deep depths of discharge, often associated with unexpected power outages, can accelerate degradation mechanisms such as solid electrolyte interphase (SEI) layer thickening and electrolyte depletion [5]. Excessive cycling beyond recommended DoD levels further increases the risk of battery aging and potential fire hazards [6]. Additionally, the repeated movement of ions within the battery during cycling can physically damage electrodes and electrolytes, leading to reduced capacity and efficiency over time [11].

The internal resistance of lithium-ion batteries is a key indicator of their health and can increase significantly with aging, impacting their ability to deliver sustained power during discharge cycles [7]. Specifically, calendar aging, which occurs even when batteries are not in active use, can significantly contribute to capacity degradation and increased internal resistance, particularly under conditions of high state-of-charge and elevated temperatures [8]. Research on Lithium Iron Phosphate (LFP) batteries has shown that calendar aging during extended rest periods is a dominant degradation factor, significantly affecting the time-dependency of capacity fade in lithium-ion batteries (LIBs) [9], [10].

While laboratory-controlled studies extensively document LFP degradation via accelerated aging, there is a paucity of field-based research on the recovery of 100 kW industrial UPS systems after prolonged calendar aging in low-outage environments [12], [13]. This study addresses this gap by providing a novel empirical validation of manual periodic cycling as a remedial maintenance strategy. Unlike theoretical models, this research provides real-world data on mitigating the passivation of LFP strings subjected to three years of high state-of-charge dormancy, offering a practical framework for industrial health-preservation protocols that can be automated to prevent irreversible capacity loss [3].

METHOD

A. Site Description

This study was carried out on a Vertiv 100 kW three-phase uninterruptible power supply (UPS) system installed at a commercial facility in 2021. The UPS system was configured with two battery strings, each consisting of eight Vision lithium battery modules rated at 100 Ah and 52.4 Vdc. The battery bank was designed to supply backup power to a relatively constant client load of approximately 45 kW during grid interruptions. Over the three-year operational period following installation, the facility experienced very few power outages due to the high reliability of the local electrical supply. As a consequence, the battery system was rarely subjected to discharge events, resulting in infrequent charge–discharge cycling. This operating condition provided an opportunity to examine the performance behavior of lithium batteries in a standby UPS environment where prolonged high state-of-charge conditions may influence battery health.

B. Performance Assessment

Performance monitoring was initiated after the facility operator reported several operational irregularities, including reduced backup duration during power outages, intermittent battery alarm notifications, and occasional DC battery breaker trips. These symptoms suggested a potential decline in the operational performance of the UPS battery system. To investigate the underlying causes, a comprehensive site assessment was conducted. This assessment

involved several steps. First, the installation documentation and configuration records of the UPS and battery system were reviewed to verify system specifications and operational history. Second, operational data logs were analyzed to evaluate battery cycling frequency, recorded backup duration, alarm events, and instances of breaker trips over the system's operating period. Finally, direct measurements of battery discharge duration were carried out under the observed client load conditions to verify the actual runtime capability of the battery system.

C. Intervention Protocol

After identifying infrequent charge–discharge cycling as a likely contributor to the observed battery performance degradation, a controlled intervention protocol was introduced. The objective of this intervention was to restore battery activity through periodic cycling and to evaluate its impact on system runtime performance. The protocol involved performing controlled discharge–recharge cycles twice per week using the facility's existing load as the discharge source. During each cycle, the battery bank was allowed to discharge under normal operating conditions until the system reached the predefined cut-off voltage of 364 V. Once the cut-off threshold was reached, the batteries were recharged to their nominal operating state using the UPS charging system. The duration of each discharge cycle was recorded to monitor changes in battery runtime over successive cycles. These measurements were used to assess the effectiveness of the periodic cycling protocol in improving the operational performance of the lithium battery system.

D. Data Collection and Performance Analysis

Operational data were collected both prior to and following the implementation of the intervention protocol. The primary performance metrics monitored during the study included battery discharge time to the defined cut-off voltage, the frequency of battery-related alarm events, and the occurrence of DC battery breaker trips. These parameters were recorded and compared across successive discharge cycles in order to observe changes in the operational behavior of the battery system. Particular attention was given to variations in discharge duration, as this parameter directly reflects the effective runtime capability of the UPS battery bank under the observed load conditions. The effectiveness of the intervention protocol was evaluated by examining trends in discharge duration over repeated cycles, together with any reduction in alarm frequency and breaker trip incidents. This analysis provided an indication of whether periodic cycling could restore or improve the operational performance of the lithium battery system in a standby UPS environment.

E. Follow-up and Automation

Following the observed improvement in battery runtime after the implementation of the periodic cycling protocol, the UPS control system was configured to perform automatic discharge cycles at predetermined intervals. This automation was introduced to ensure that the batteries continue to undergo regular charge–discharge activity, thereby maintaining their operational readiness and preventing performance degradation associated with prolonged standby conditions. To verify the sustainability of the improvement, the system was continuously monitored through the UPS monitoring interface and operational logs. Key indicators such as discharge duration, alarm frequency, and system stability were periodically reviewed to confirm that the battery performance remained stable over time. Overall, the implemented approach provides a practical and operationally feasible framework for diagnosing and mitigating lithium battery degradation in standby UPS systems operating in environments with infrequent power outages.

F. Flowchart of the Proposed Method

The flowchart of the proposed methodology is presented in Figure 1. It outlines three sequential stages: Performance Assessment, Intervention Protocol, and Follow-Up and Automation, reflecting the diagnostic and remedial approach applied in this study.

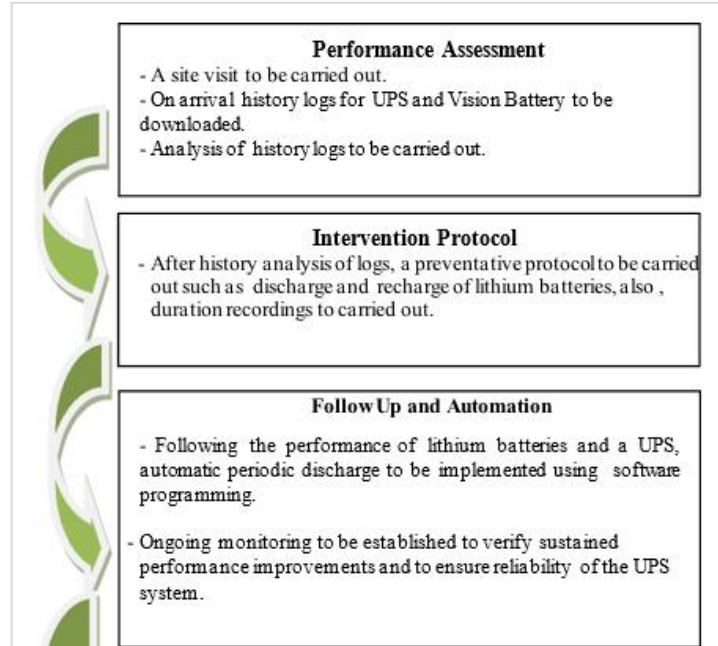


Figure 1. The flowchart of the followed methodology.

RESULT AND DISCUSSION

The site configuration consisted of a 100 kW Vertiv uninterruptible power supply (UPS) system connected to two battery strings, each installed in a separate rack and populated with eight lithium battery modules rated at 100 Ah and 52.4 Vdc. The UPS supplied a relatively constant output load of approximately 45 kW throughout the observation period, with no significant load variation recorded. During the investigation, several controlled discharge and recharge cycles were carried out at different time intervals and on different operating days in order to evaluate the behavior of the battery system under repeated cycling conditions. Figure 2 shows the overall operational configuration of the UPS and lithium-ion battery installation used in this study.

The performance recovery of the Vision Lithium Iron Phosphate (LFP) system was quantified using Energy Capacity (E) and State of Health (SOH). For a constant power discharge, the energy delivered is calculated as:

$$E = P \times t \quad (1)$$

where P is the stable client load (45 kW) and t is the discharge duration in hours. The SOH is estimated as the ratio of measured energy capacity to the nominal rated energy capacity E_{rated} :

$$SOH = \frac{E_{measured}}{E_{rated}} \times 100\% \quad (2)$$



Figure 2. UPS and Li-ion battery setup during operation

Given the system configuration of two strings of 8 battery modules at 100 Ah and 52.4 Vdc (calculated as $2 \times 8 \times 100 \text{ Ah} \times 52.4 \text{ V} = 83.84 \text{ kWh}$), the nominal rated energy E_{rated} is 83.84 kWh [1], [3]. Table 1 presents quantitative performance recovery and state of health estimation.

Table 1. Battery Performance Recovery and State of Health Estimation

Cycle Number	Duration (t) (min)	Energy (E) (kWh)	Calculated SOH (%)	Improvement (%)
1	3.0	2.25	2.68	-
3	7.5	5.63	6.71	+150
6	12.0	9.00	10.73	+300
10	18.0	13.50	16.10	+500

Note: Representative value based on the observed 3-to-18-minute recovery trend during the intervention protocol

Figure 3 presents a dual-axis plot showing the relationship between discharge duration (in minutes) and cycle number throughout the intervention period. As illustrated in the figure, an increase in the number of charge discharge cycles is accompanied by a corresponding increase in battery runtime. This trend indicates that repeated cycling had a positive effect on the operational performance of the lithium-ion battery system. During the course of the study, the measured discharge duration gradually increased from an initial runtime of approximately 3 minutes to a final runtime of about 18 minutes. This improvement suggests that periodic cycling helped restore the effective capacity of the battery bank after prolonged standby operation.

Figure 4 presents a dual-axis chart that combines a bar graph and a line plot to illustrate the variation of delivered energy and the estimated State of Health (SOH) over successive discharge cycles. As shown in the figure, the calculated SOH increases progressively with the amount of energy delivered during each cycle. This relationship indicates that the

repeated charge discharge process contributed to the gradual recovery of the effective battery capacity throughout the intervention period.

The findings from this case study provide valuable insight into the operational challenges and maintenance requirements of lithium battery-based UPS systems in standby applications. Despite being a relatively new installation, the Vertiv 100 kW UPS with Vision lithium batteries exhibited significant performance degradation after only three years, primarily due to the lack of regular discharge cycles. This degradation manifested as reduced backup time, increased alarm frequency, and unexpected DC breaker trips, all of which compromise the reliability of critical power infrastructure.

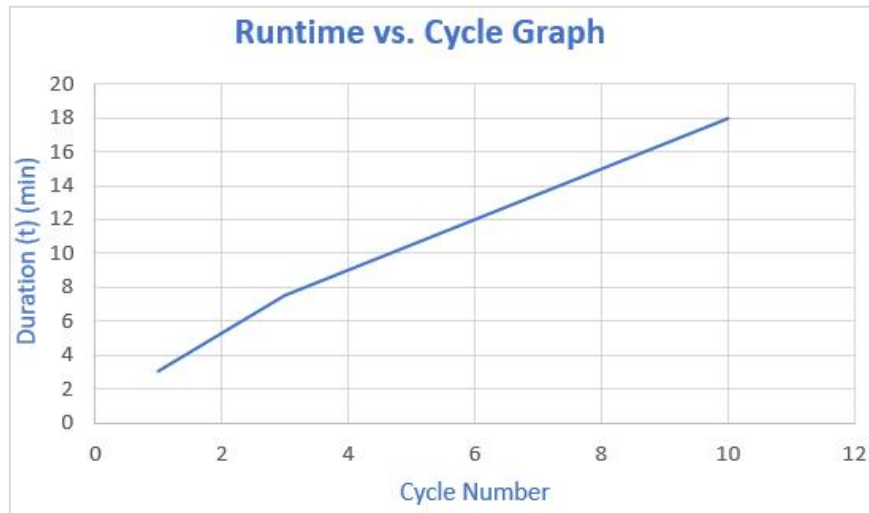


Figure 3. A dual-axis plot showing Duration time (min) and Cycle number over the intervention period

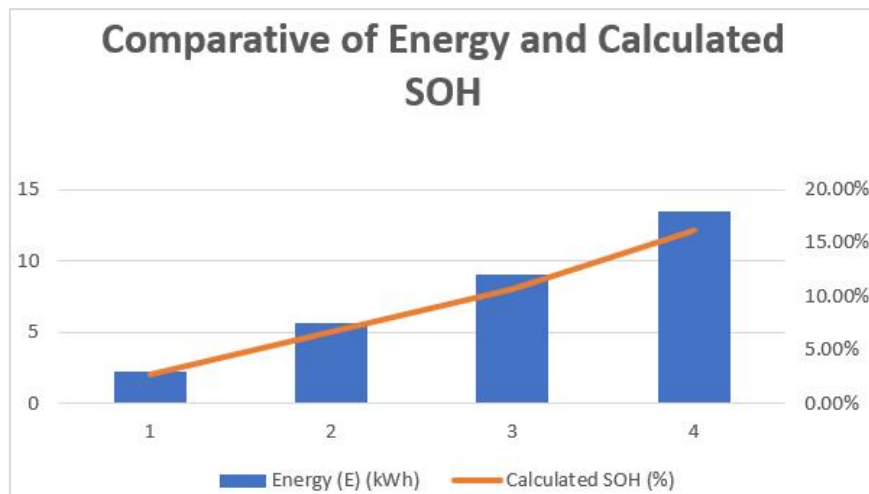


Figure 4. A dual-axis chart depicting Energy and SOH

A key observation is that the minimal occurrence of power outages, while seemingly advantageous for system longevity, ironically contributed to the premature decline in battery performance. Lithium batteries, unlike some traditional chemistries, require periodic cycling to maintain optimal capacity and health. The infrequent cycling in this scenario led to passivation and capacity loss, underscoring the necessity of integrating regular discharge/recharge routines, even in environments with stable loads and rare outages. The intervention of manually cycling the batteries demonstrated a clear recovery in performance,

with backup durations improving from 3 minutes to 18 minutes over multiple cycles. This rapid improvement supports the notion that battery degradation in standby applications can be, to some extent, reversible if addressed promptly. However, reliance on manual intervention is not sustainable for long-term maintenance, especially in mission-critical environments. Programming the UPS for automatic periodic discharges represents an effective preventive strategy to sustain battery health and system reliability. This approach not only restores performance but also minimizes the risk of unexpected failures, aligning with best practices for battery management in modern UPS installations.

The observed performance recovery can be theoretically linked to the mitigation of SEI layer thickening, a primary mechanism of calendar aging during prolonged high state-of-charge dormancy [4]. In low-outage environments, Li-ion batteries remain continuously at float voltage near full charge, which accelerates electrolyte depletion, promotes SEI layer growth, and increases internal resistance over time [7]. The periodic cycling intervention likely disrupted the passivation layer on the electrodes by reactivating lithium-ion intercalation pathways, facilitating improved ion mobility and reducing system-level impedance [13]. This aligns with Arrhenius-based aging models, which suggest that while calendar aging is time- and temperature-dependent, periodic active cycling can help maintain the kinetic pathways of the cells. While this study provides critical field data, it is limited by its focus on a single 100 kW UPS installation and a specific battery brand. Furthermore, as an industrial field study, individual cell-level internal resistance was not measured via electrochemical impedance spectroscopy, but was instead inferred through macro-level runtime performance. Future research should include multi-site comparisons, ambient temperature correlations, and electrochemical impedance spectroscopy measurements at the cell level to further refine the optimal periodic cycling frequency and validate the recovery mechanisms observed in this study. In summary, the study emphasizes that the reliability of lithium battery UPS systems in standby roles is contingent upon proactive maintenance practices, particularly routine cycling. Operators and facility managers should recognize the importance of such protocols, even when actual outage events are infrequent, to ensure uninterrupted power protection and extend battery service life.

CONCLUSION

This study examined the declining performance of a Vertiv 100 kW UPS system equipped with Vision lithium batteries installed in 2021, which showed reduced backup duration and increased alarm occurrences after three years of operation with minimal cycling. The results indicate that infrequent discharge activity in standby UPS applications can lead to premature battery degradation, characterized by reduced discharge capacity, an estimated State of Health (SOH) decrease to 2.68%, and increased internal resistance, even when the batteries are rarely used. These findings highlight the importance of periodic cycling as a preventive maintenance measure, particularly in systems operating under stable grid conditions with very few power interruptions. The implementation of a controlled discharge–recharge protocol performed twice per week resulted in a noticeable improvement in battery performance. The measured discharge duration increased from approximately 3 minutes at the initial stage to about 18 minutes after ten cycles, corresponding to an estimated SOH improvement from 2.68% to 16.10%. This result confirms that regular cycling can partially restore usable battery capacity and improve runtime performance in lithium-ion batteries that have experienced prolonged standby operation. The observed recovery can be associated with the mitigation of capacity fade and impedance growth, which are commonly reported degradation mechanisms in lithium-ion cells maintained under extended float conditions. In such environments, calendar aging becomes the dominant aging process, making periodic cycling necessary to maintain electrochemical activity and to limit the gradual increase in internal resistance that occurs even without frequent discharge events. Overall, this case study provides practical insight into the maintenance requirements of lithium-ion battery

systems used in UPS applications and demonstrates that scheduled cycling can be an effective strategy to maintain long-term reliability and operational readiness in low-outage environments.

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