Total cost of ownership
White paper

Energy storage total cost of ownership comparisons in critical power applications

Introduction

Ensuring clean, quality power is becoming increasingly important as more and more things become electrified and connected. This is especially important in critical power applications such as data center, healthcare, public gathering areas and industrial facilities. Although grid resilience is not a common or daily issue in most areas and geographies, it cannot be guaranteed (See Eaton's Blackout Tracker). With the increasing addition of distributed generation energy resources (DER), there is increasing stress on the grid which can increase the risk of brownouts to full power outages. Similarly, the harmful effects of these power quality issues grows with it. In order to prevent potentially catastrophic and costly damages due to power quality issues, backup power systems — such as uninterruptible power supplies (UPS) — are necessary, very critical systems needing to be integrated into these already critical applications. For decades, the standard valve-regulated lead acid (VRLA) or absorbent gas mat (AGM) gel battery technologies were the only viable energy storage options for UPS systems. However, they came with many drawbacks, including unattractive operational expenditure (OpEx) results. Fortunately, several of the most recent energy storage technologies have finally been able to provide enhanced performance and economic viability compared to the traditional energy storage solutions for UPS. However, one of the best energy storage technologies for short term backup applications, supercapacitors, is a very recent and still widely unknown contender.

This whitepaper will provide a discussion of the practical capital expenditure (CapEx) and OpEx outlooks for current VRLA, lithium-ion (Li-ion), flywheel and supercapacitor technologies with respect to UPS applications. Additionally, this paper includes insights into the additional costs and considerations surrounding energy storage technologies that are sometimes difficult to quantify but are important when making decisions that determine the safety of patients, operators, electrical systems or valuable data.

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Backup energy storage technology considerations

Though the concept of backup energy storage may be simple to grasp, the performance parameters and application-specific concerns around designing, sizing and selecting a storage technology are all but straightforward. There is a wide range of key considerations for UPS energy storage technology. Since energy storage technologies present a diverse range of performance factors, determining the exact technology and system capacity requires a deeper look into the system requirements. Moreover, each energy storage technology also brings with it a unique set of advantages and drawbacks, of which the drawbacks typically translate into impacting CapEx or OpEx for the system.

Key emergency energy storage parameters:

- Power density or specific power (discharge rate in kW/L)
- Continuous charge (kW or Amps at a fixed voltage)
- Energy density or specific energy (kW/L)
- Operating temperature
- Round trip cycling energy efficiency
- Standby/idle energy efficiency
- Discharge response time
- Operational lifetime
- Reliability
- Footprint
- Weight for floor reinforcements and/or shipping cost
- Initial cost of system, components, and accessories (CapEx)
- Ongoing costs of maintenance, repair, cooling, etc. (OpEx)

An important point to note is that unlike many other energy storage applications, such as electric vehicle, grid storage or renewable energy storage, backup energy storage applications favor power density over energy density. These critical power applications generally rely upon energy storage to deliver power immediately after power loss, or a low-threshold voltage state, until a longer-term backup power source is engaged (traditional generators, natural gas turbines or hydrogen fuel cell). Using only energy storage such as batteries, supercapacitors or flywheels is not practical to support kW or MW loads for days on end that could be experienced. Hence, UPS systems' backup power discharge is typically only requiring seconds to tens of seconds, instead of minutes to hours for other energy storage applications. Also, UPS systems are often only used a few times a year, compared to daily or weekly cycles, so measuring energy storage lifetime with a cycle count can be misleading and inaccurate for UPS use cases. Additionally, reliability and performance under stress become much more significant factors for energy storage.

Currently, the UPS energy storage market is in a dynamic state of change, as suppliers and clients are increasingly adopting alternative energy storage technologies aside from VRLA. The main reasons for this trend are that VRLA batteries are typically far less power dense than the latest alternative storage technologies, which means that a VRLA UPS will require more VRLA batteries just to reach the desired discharge power, leading to higher upfront costs. Additionally, the required backup times are shrinking as modern generators are capable of starting and supporting loads in less than 15 seconds. Moreover, VRLA batteries are notoriously harmful environmentally and are one of the heaviest energy storage technologies. Lastly, VRLA and AGM batteries generally need to be replaced every three to seven years (depending on ambient temperature), adding ongoing costs of battery replacement, albeit typically less expensive than replacing a Li-ion battery.

VRLA technologies still represent just over 50 percent of the large UPS market as of 2018 and has been shrinking recently due to the leading alternatives with flywheel, Li-ion, and now supercapacitors gaining market share. These three alternatives exhibit the better balances of power density, energy density, energy efficiency, response time, lifetime, recharge rate, temperature range and other key factors of modern energy storage technologies. However, Li-ion and flywheel technology also demonstrate several drawbacks and additional considerations that are non-existent with supercapacitor systems, and these factors ultimately tip the balance of CapEx and OpEx in favor of supercapacitors.

Before proceeding to a CapEx, OpEx, and other considerations discussion, a special note is given for fuel cells, turbines and generators. Typically, these technologies are part of the overall emergency electrical power system; however, their long start times (from seconds to almost a minute) make these technologies unsuitable for the short term, bridge energy storage in UPS applications, but rather in the long-term energy source. Moreover, generators and fuel cells require combustible fuel storage, which is generally considered better to have outside the building, with proper ventilation, and not consume valuable indoor floorspace.

Wide range of initial capital expenditures (CapEx) for energy storage technology

From a CapEx perspective, there is still an attractive argument for VRLA, as they offer one of the lowest upfront cost energy storage technologies. However, a deeper look into the total cost of ownership, cost of oversizing the initial battery system, and the opportunity cost of the additional footprint of VRLA batteries tell a different story compared to other solutions. All the three energy storage technologies previous mentioned tend to be more expensive than VRLA UPS systems upfront, though none of them require the same degree of battery replacement cost and oversizing typical of VRLA system. Hence, for the same power density, VRLA systems are less cost effective when compared to Li-ion, flywheels, or supercapacitors.

Table 1: Eaton UPS energy storage cabinet comparison

Specification	Units	Supercapacitors (20 unit)	Supercapacitors (30 unit)	Lithium-ion	Flywheel
Voltage Range	Vdc	570 to 360	570 to 360	538 to 410	520 to 400
Temperature Range	°C	-40 to +65	-40 to +65	+18 to +28	-10 to +40
Max Power	kW	300	300	150	300
Energy Storage	kWh	1.39	2.09	32.6	1.67
Design Life*	Years	20	20	15	20
Recharge Rate	Amps	150	150	22	15 to 50
Dimensions (W x D x H)	in	24.2 x 33.5 x 84	31.2 x 33.5 x 84	25.6 x 23.6 x 90	30.0 x 30.0 x 73.7
Weight	kg	550	750	550	760

*+28 °C is typically the nominal operation temperature specified to achieve the design life.

Another CapEx aspect of installing a UPS system is the size, weight, added accessory/components and additional HVAC system capacity cost. In the case of flywheels, these systems require a substantial variety of expensive accessories to ensure a long-term and reliable operation. Due to the mechanical nature of flywheels, they also require regular maintenance, which may be covered by a maintenance contract paid for at the time of purchase, or more typically over time in the form of annual service contracts. Flywheels are also necessarily large and heavy to store enough kinetic energy, which leads to higher shipping and freight costs up front.

From a different perspective, Li-ion battery systems are very sensitive to temperature changes and can produce high amounts of thermal energy while discharging and charging. To achieve optimal performance from a Li-ion UPS, additional HVAC resources may be necessary at a facility or cabinet level to ensure that the Li-ion batteries maintain safe and efficient operating temperatures. Because of the dangers of thermal runaway, additional fire-safety and prevention steps may be required when using Li-ion UPS. In some applications, such as healthcare, public gathering areas and industrial environments with inadequate HVAC access, Li-ion UPS may not be viable or too costly to maintain adequate safety constraints.

Supercapacitor-based UPS provide high power density in a relatively small and lightweight package, generally without requiring any additional accessories/components. Supercapacitors have much lower internal resistance compared to Li-ion batteries and generate much less thermal energy during discharge or while charging. The electrostatic nature and environmentally safe materials used also allow for longer operational life with virtually no maintenance and low-cost disposal.

Operational expenditures (OpEx) also vary

Upfront costs aren't the only considerable factors amongst UPS energy storage technologies. Other factors include annual maintenance, cooling costs, unplanned downtime, battery replacement, downtime, a risk of failure, and footprint. In these regards, both flywheels and Li-ion batteries require additional expenses compared to supercapacitors.

Flywheels require regular maintenance and service to operate, leading to scheduled downtime and expert labor expenses. Also, the large size of a complete flywheel system for a given power output occupies potential revenue generating space, such as with a data center or industrial facility. Though less commonly thought of, the high speeds of the flywheels and potential risk of failure could lead to additional OpEx if many such systems are deployed. Though the percentage chance of failure may be low for a single system, that same chance spread over many systems may exceed a threshold of concern and require inclusion in an OpEx analysis.

Li-ion battery UPS also incur OpEx expenses in the form of HVAC and battery management systems to keep the batteries at an optimal temperature. The OpEx cost of Li-ion UPS depends on the difference between the required operating temperature of the cabinet/facility and the Li-ion batteries. Due to the lower standby and cycling energy efficiency, HVAC systems may have to handle more heat energy. Moreover, the lifetime impact of elevated temperatures and risk of thermal runaway for Li-ion requires the ambient temperature to remain within a very specified band. This can contribute to higher cooling costs. Therefore, a Li-ion UPS must be kept at a temperature allowing an adequate margin during operation to prevent excessive, and possibly catastrophic, Li-ion cell temperatures.

Operating temperature factors into the OpEx, as well as the CapEx. ASHRE has stated that raising temperatures by 5 °C can reduce cooling costs by 50 percent, but also the HVAC equipment required to maintain the raised temperature by 50 percent. Selecting energy storage technologies of operating at higher temperatures can drastically reduce both CapEx and OpEx.

Supercapacitors should not require any additional cost or maintenance during their lifespan and are one of the most power dense energy storage solutions suitable for UPS applications. Moreover, supercapacitors exhibit long operation life with an extremely low failure rate and capacity loss over time. The OpEx cost for supercapacitors is virtually non-existent.

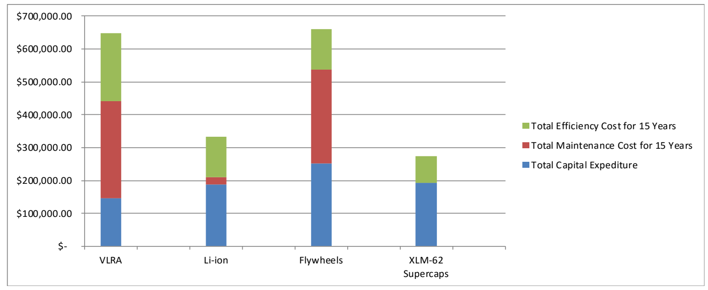

Figure 1

Total CapEx and OpEx 15 year lifetime cost comparison between different energy storage technologies to support a 600kVA UPS with a 30 second minimum backup time

Conclusion

VRLA battery-based UPS have been a standby ensuring that critical electronics and electrical systems aren't harmed by unexpected power loss for many decades. However, there are now several viable energy storage technologies that are closing the gap between initial cost and operational costs, compared to traditional VRLA batteries. Of these latest solutions, supercapacitors present an attractive combination of reliable UPS performance, CapEx, and OpEx — without the risk factors and failure modes present in Li-ion and flywheel solutions. Previously, supercapacitors may have been easily overlooked in favor of alternatives, but a detailed analysis of the total cost of ownership and additional considerations can illustrate key benefits of integrating supercapacitors in backup power and peak power shaving applications.

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