Battery Technology for Single Phase UPS Systems: VRLA vs. Li-ion

White Paper 266

Revision 1

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Executive summary

Lithium-ion battery prices have decreased over the years and are now becoming a viable option for UPS applications. This paper provides a brief overview of li-ion batteries in comparison to VRLA batteries for single-phase UPS applications. A 10-year total cost of ownership (TCO) analysis is also provided showing li-ion is 53% less than VRLA despite their capital cost premium. A sensitivity analysis reveals the TCO drivers.

Introduction

Lithium-ion (li-ion) batteries have been used commercially for over 20 years in various applications[1]. Why then have they not been commonly adopted as batteries for single-phase UPSs? The answer lies in the fact that, like all other applications, li-ion cells[2] weren't available that provided UPS vendors with the right balance of price, energy density, power, safety, and reliability for single-phase UPS applications. However, advancements in li-ion chemistries and technologies over the last 10 years have provided UPS vendors with realistic options. These advancements have largely been due to requirements set forth by the electric vehicle industry. **Figure 1** shows an example of a li-ion battery for a single-phase UPS application. The UPS Module is shown above its Li-Ion battery module.

Figure 1

Li-ion battery module (at bottom) for 1-phase UPS (on top) applications

Li-ion batteries do offer legitimate benefits over VRLA (valve-regulated lead-acid) including:[3]

- Fewer battery replacements (perhaps none) required over the life of the UPS eliminates the risk of downtime posed by battery replacement
- About three times less weight for the same amount of energy
- Up to ten times more discharge cycles depending on chemistry, technology, temperature, and depth of discharge
- About four times less self-discharge (i.e. slow discharge of a battery while not in use)
- Four or more times faster charging, key in multiple outage scenarios

However, li-ion batteries also have two main drawbacks compared to VRLA:

- Higher capital expenditure (capex) for the same amount of energy due to higher manufacturing cost and cost of required battery management system
- Stricter transportation regulations

This paper provides a brief overview of li-ion battery characteristics compared to VRLA. We then analyze the capital cost, operational cost, and total cost of ownership (TCO) between these two battery types.

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[1] http://www.sonyenergy-devices.co.jp/en/keyword/ (last accessed on 2/28/16)

[2] Note that the term "cell" refers to the smallest building block of a battery. Batteries are composed to two or more cells and they are packaged according to specific applications such as for use with UPS.

[3] http://batteryuniversity.com/learn/article/whats_the_best_battery (last accessed on 2/28/16)

Li-ion battery overview

Lifetime
How long a battery lasts before you need to replace it is what really matters when it comes to battery lifetime. However, it's important to understand the different metrics suppliers use to measure lifetime. Of particular importance is **service life**. This is the estimated time a battery will last before it reaches 80% of its energy capacity, the common definition of end of life for batteries. Service life assumes the battery is operating under "real world" conditions for a stated application and is therefore highly variable. In contrast, **calendar life** is the estimated time a battery will last if it were to remain trickle charged for its entire life with no power outages at a specified temperature, usually 25°C (77°F). VRLA batteries have a service life in the range of 3-6 years whereas li-ion batteries can have a service life upwards of 10 years (estimated using accelerated life testing). Note that it will be several years before data on actual service life becomes available for newer li-ion batteries, however, some li-ion batteries offer warranties in the 10 year range as a hedge against the lack of service data.

Temperature
Both lead acid and lithium-ion batteries will see a degradation in calendar life and cycle life as the temperature rises. However, in general, li-ion service life is less affected by higher temperatures than lead acid. Many of the li-ion batteries being used in UPSs are designed for higher average temperatures (e.g., 40°C/104°F) and are capable of reaching the specified service life at those higher temperatures.

Footprint
Due to the higher specific energy of li-ion batteries, they are much smaller in terms of footprint or volume compared to VRLA. This space savings is especially attractive for longer runtime applications with more compact external Li-Ion battery pack compared to the external VRLA battery pack.

Weight
The higher energy density of li-ion contributes to its lighter weight compared to VRLA. This makes handling of the external battery packs easier during the installation or replacement.

Battery monitoring
Battery monitoring systems (BMS) are usually not part of a VRLA battery solution for single phase UPS systems due to its high costs. However, li-ion batteries come with a BMS by default because these batteries require full control of charging and discharging to prevent unsafe temperatures inside the li-ion cells.

Safety
Safety is top of mind when it comes to batteries especially when it comes to li-ion batteries. The important thing to remember about UPS applications is that UPS vendors need to work closely with reputable li-ion vendors to find the best combination of chemistry, technology, cell packaging, and battery management for specific UPSs.

All battery types, by definition, store chemical energy, so every battery if mishandled (e.g., thrown in a fire) or overcharged has the potential for being a hazard by releasing hazardous materials or igniting a fire. Lithium-ion batteries have been thought to be more volatile due to reported cases of fire and due to their much higher specific energy combined with a greater sensitivity to being over charged. Improperly managed, a lithium-ion battery will reach a "thermal runaway" state more easily as it has a lower cell resistance and higher energy storage capacity than a lead acid battery.

However, much progress has been made over the years making them safer and much more comparable safety-wise to other commonly used battery types. Chemistry changes and cell packaging improvements have made them more stable. Manufacturing processes are mature and the materials used are more durable. Battery management schemes are well tested and field proven to keep lithium-ion batteries from being over charged or over heated. The prolific use of lithium batteries in hundreds of millions of portable electronics, smart phones, and electric vehicles is positive evidence for their level of safety.

Because lithium-ion battery systems are much more sensitive to how they are charged and discharged, all include a battery management system, or BMS. Microprocessors, sensors, switches, and their related circuits make up this system. It constantly monitors at the cell level battery temperature, charge level, and charge rate to protect against short circuits and overcharging. The system is also instrumental in protecting the cells from damage by preventing the voltage from going too low on discharge. The BMS provides the UPS and user with accurate information about battery status, health, and available runtime.

Transport Regulations

There are various regulations around shipping any kind of battery including li-ion or VRLA. These shipping regulations tend to be stricter with li-ion chemistries due to the higher energy densities and higher volatility of certain chemistries.

Despite that regulations vary by locale, a good guide for understanding air shipment restrictions and requirements is the International Air Transport Association (IATA) and their "Dangerous Goods Regulation" (DGR)[4] which describes air shipment mandates by size, weight, and number. The transport of lithium-based batteries is divided into non-Class 9 hazardous material and Class 9 hazardous material[5]. Non-Class 9 involves the shipment of smaller, low volume quantities while Class 9 involves the shipment of larger numbers and sizes of batteries. Labeling, packaging, and any unique handling requirements are described for each class.

Remember that batteries of all types face certain requirements and restrictions. Batteries shipped inside equipment typically have to be shipped disconnected, for example. While all of this may seem onerous to the end user or reseller, it is the manufacturer of the system that typically assumes the burden and responsibility for ensuring compliance through proper design, certification, labeling, user documentation, and packaging.

Recyclability

The US Government considers Li-Ion batteries not to be hazardous and, therefore, is safe for disposal in landfills. Li-ion batteries do not contain mercury, lead, cadmium, or any other material deemed to be hazardous.

Both Li-Ion and VRLA battery types are recyclable; however, at present it is much easier in most regions of the world to recycle lead acid than larger format li-ion batteries used in UPSs and electric vehicles

There are many recyclers who will take smaller lithium-ion batteries. However, at the time of this writing, most smaller format batteries are simply collected and then sent off for shredding and incineration where some of the materials used in the production might be recovered. Much of the material ends up in landfills. From a purely financial viewpoint, recycling lithium-ion batteries to recover the very small

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[4] http://www.iata.org/publications/dgr/Pages/index.aspx (last accessed on 1/19/2016)

[5] http://batteryuniversity.com/learn/article/shipping_lithium_based_batteries_by_air (last accessed on 2/26/16)

amount of lithium metal and other more common, but less valuable metals (aluminum, nickel, etc) is not worth the effort. Research is on-going to improve the recycling economics and governments are beginning to encourage, incent, or outright require the collection and proper recycling of batteries.

Financial analysis

Using total cost of ownership (TCO) as a metric is gaining traction in certain IT investments like UPS maintenance. In the case of li-ion batteries, certain power cell chemistries and technologies present a favorable TCO over a 10 year period compared to VRLA batteries. This happens to be the typical life span range of a UPS before replacement is needed.

Assumptions

Table 1 provides a list of battery attributes relevant to this TCO analysis.

Table 1

Battery attributes used in TCO analysis

Battery attribute	VRLA	Li-ion
Chemistry	Lead-acid	NMC
Rated power capacity	1.5 kVA	1.5 kVA
Runtime at 25°C (77°F)	22 minutes	19 minutes
Battery service life at 25°C (77°F)	4 years	10 years

Table 2 provides a list of the assumptions used for this analysis.

Table 2

TCO analysis assumptions

Assumption	VRLA	Li-ion
UPS load	1,350W	1,350W
UPS service life	10 years	10 years
Operating temperature	25°C (77°F)	25°C (77°F)
Years at which batteries are refreshed during UPS life	Year 4 and 8	Not required
Price of external battery pack for the required runtime	$730*	$1,200
Internal and External replacement battery cost for the given required runtime	$840 / replacement	-
Battery replacement labor cost	$200 / replacement	Not required
Cost of capital[6]	0%	0%

* This is only the external battery pack price of the VRLA UPS to match the runtime required. The capital expense of the internal battery pack of VRLA UPS is not considered in this calculation.

[6] The cost of capital is a rate of return on money and is used in cash flow analysis to determine the present value of future cash flows over a number of years. As the cost of capital increases, the TCO decreases (e.g. 20% cost of capital). The maximum TCO is calculated when the cost of capital is 0%. To simplify the analysis in this paper, we assumed a cost of capital of 0%.

Capital expense

The initial battery expense, at year 0, includes the battery material costs and installation costs. **Table 3** breaks down the capital expense for both battery solutions.

Table 3

Capital expense breakdown

Capital expense	VRLA	Li-ion	% change
Battery material costs	$730	$1,200	Li-Ion 64% more capex than VRLA
Installation cost	$200	$200	Same capex
TOTAL	$930	$1,400	Li-Ion 51% more capex than VRLA

Operational expense

The operational battery expenses start at year 1 and continue till year 10. For the single-phase UPS systems, the major driver for operational expenses is the battery refresh costs. **Table 4** breaks down the operational expense for both battery solutions. Note that in an application like distributed IT/edge data centers, with multiple remote offices, battery replacement can cost between $200 and $250. These types of offices don't typically have service personnel. Therefore, a managed service provider is sometimes contracted to procure replacement batteries, travel to the site, replace the battery, and recycle the old batteries. Even if this activity is in-sourced, one can expect a total cost of about $200 per replacement.

Table 4

Operational expense breakdown

Operational expense	VRLA	Li-ion	% change
Battery replacement cost at Year 4	$840	$0	Li-ion 100% less opex than VRLA
Battery replacement labor cost at Year 4	$200	$0	Li-ion 100% less opex than VRLA
Battery replacement cost at Year 8	$840	$0	Li-ion 100% less opex than VRLA
Battery replacement labor cost at Year 8	$200	$0	Li-ion 100% less opex than VRLA
TOTAL	$2,080	$0	Li-ion 100% less opex than VRLA

TCO

The 10-year TCO considers the capital and operational expenses above. The li-ion battery solution has a 53% lower 10-year TCO than the VRLA solution. **Table 5** breaks down the TCO for both battery solutions.

Table 5

TCO breakdown

TCO	VRLA	Li-ion	% change
Capital expense	$930	$1,400	Li-ion 51% more capex than VRLA
Operational expense	$2,080	$0	Li-ion 100% less opex than VRLA
TOTAL	$3,010	$1,400	Li-ion 53% less TCO than VRLA

Sensitivity analysis

We independently varied various cost factors to assess the variability and magnitude of change they have on TCO. For example, we varied VRLA service life from 3 to 7 years which resulted in changes in TCO savings ranging from 29% (1 VRLA battery replacement) to 65% (3 VRLA battery replacements).

The two major drivers for VRLA replacement cycle are the temperature and the charge-discharge cycles.

Based on this sensitivity analysis, the factors that most influence the TCO comparison between VRLA and li-ion are:

- VRLA service life
- UPS service life

It's important to note that while each of these can independently cause a significant change in TCO between both battery solutions, a combination of a few of these factors can swing a decision to adopt one or the other. In particular, the VRLA service life, being shorter than li-ion, becomes a big lever in combination with the UPS service life. For example, a VRLA life of 4 years in combination with a UPS life of 8 years results in only a single battery refresh. However, increasing the UPS life by only 2 years results in two VRLA battery refreshes, a significant change in TCO in favor of li-ion.

The CAPEX calculated in this model, is based on the additional external battery pack to be used in VRLA UPS to match the default runtime provided by Li-Ion battery pack for comparison. If the standard runtime of the reference VRLA UPS (5 minutes), is compared with the standard runtime of the Li-Ion UPS (19 minutes), the TCO will be in favor of VRLA UPS.

Conclusion

It is safe to say that Lithium-ion battery prices will continue to decrease, new chemistries and technologies will be brought to market, and improvements will be made to existing ones. With this backdrop and the analysis presented in this paper, Lithium-ion battery systems for single-phase UPS applications offer compelling benefits. While some li-ion solution prices are too high to justify switching from VRLA, there are some that present a favorable 10-year TCO.

About the authors

Victor Avelar is the Director and Senior Research Analyst at Schneider Electric's Data Center Science Center. He is responsible for data center design and operations research, and consults with clients on risk assessment and design practices to optimize the availability and efficiency of their data center environments. Victor holds a bachelor's degree in mechanical engineering from Rensselaer Polytechnic Institute and an MBA from Babson College. He is a member of AFCOM.

Martin Zacho is a Senior Engineer in Energy Storage Technologies at Schneider Electric, Secure Power, IT Business. He holds a Bachelor degree in Computer System Engineering from University of Southern Denmark. He started out at Schneider Electric in 2000 (American Power Conversion at the time) working with Hydrogen Fuel Cells. After 3 years he switched to firmware control and FPGA programming for the Symmetra line products. He has been involved in all aspects of energy storage technologies since 2008 with special focus on energy storage for large 3 phase UPS's. The relevant technologies being lead acid batteries, ultra-capacitors, flywheels and various lithium based technologies. He is a member of The Danish Standardization Committee regarding energy storage.

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