EMSYS

Lead Acid vs Lithium Ion in the Data Center

Is Lithium Ion a Viable Alternative to Lead Acid in Mission Critical Applications?

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Summary

At EMSYS Design we specialize in supporting Mission Critical Data Centers with their back-up battery systems. It's an area we've specialized in since 2008 and continue to provide the most advanced solutions on the market. So the emergence of lithium ion in UPS applications was of significant interest to us. We conducted an internal investigation to see if it was prudent to work with our partners to develop a lithium ion solution. This White Paper is a reformatted summary of that investigation. We hope that it can be of use to our customers in their own deliberations of lithium ion's viability in the data center.

Battery Overview

Batteries, simply put, are electrochemical cells that convert chemical energy into electric energy through an electrochemical oxidation-reduction reaction. This redox reaction involves the transfer of electrons from one material to another. These cells are comprised of 3 essential components:

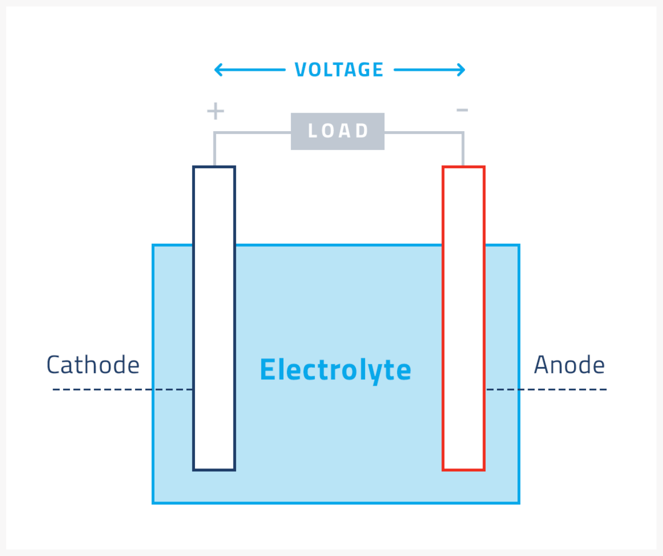

Figure 1: Components of a Cell

- **The Anode:** this is the negative, reducing electrode that releases electrons and oxidizes during the electrochemical reaction.
- **The Cathode:** This is the positive, oxidizing electrode that accepts electrons and is thus reduced in electrochemical reactions.
- **The Electrolyte:** This is the medium for ion transport between the cathode and anode of a cell. Electrolytes for the most part are aqueous solutions that are required for ionic conduction.

This description applies to both lead acid and lithium ion batteries, the difference being the chemical makeup of these 3 essential components. This paper will not examine the underlying reactions of each battery chemistry to draw conclusions- electrochemical cells are complex systems that undergo a series of parallel and concurrent processes so cause and effect presumptions can get fuzzy. Instead this paper will delve into questions of reliability, safety, and longevity from observed outcomes.

Reliability

Given that we understand batteries provide electrical energy by converting chemical energy to electrical, it follows that battery aging will depend on parasitic physico-chemical reactions occurring between the different components. In the case of lead acid batteries, which have been in service for 150 years, these mechanisms are far more understood. The principle cause of aging being positive grid corrosion.

In modern lithium ion batteries the main aging mechanism is growth of Solid Electrolyte Interface layer on the negative electrode. "The formation and growth mechanism of the nanometer thick SEI films are yet to be completely understood owing to their complex structure and lack of reliable in situ experimental techniques."[1]. Understanding SEI evolution over the course of lithium ion battery life is key in formation of protocols which will develop ideal SEI layers (ones that consume minimum lithium during formation and reduce capacity fade over time)[2].

Other modes of failure such as dendrite formation are also under similar study. These unknowns all cast safety and reliability doubts.

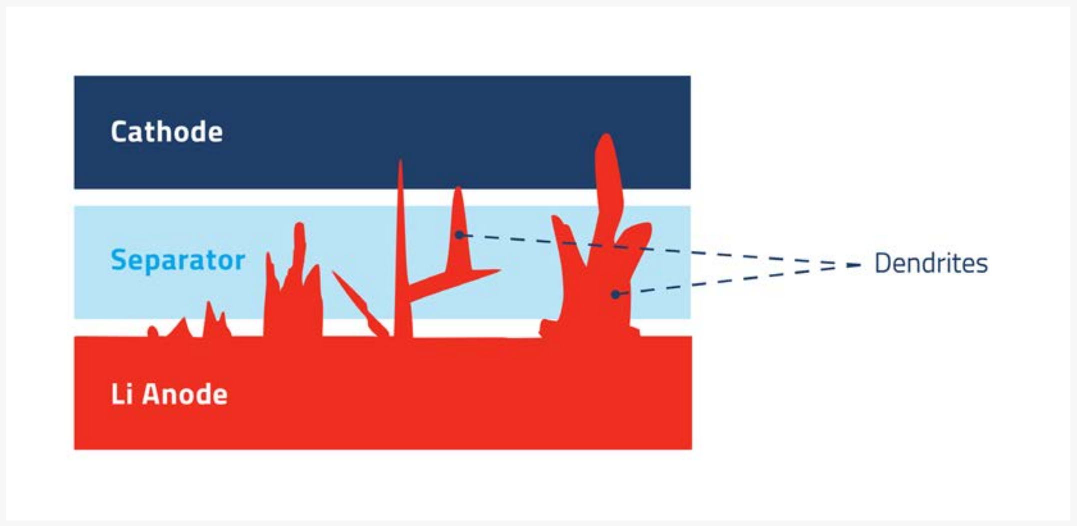

Figure 2: Dendrite formation

Given the considerable uncertainty over aging mechanisms and failure modes in lithium ion batteries, in a theoretical sense, we must rely on empirical evidence. However this empirical evidence is relatively scant. Although the proliferation of Electric Vehicles (EVs) gives us a dataset to look at, the use case and conditions are not entirely transferable to UPS applications. Calendar aging, the predominant force of aging in UPS applications, is accelerated in conditions of higher State of Charge (SoC) and temperature whereas cyclical aging sees severe degradation through mechanical strain in the electrode active materials.[3]

Application of the Precautionary Principle

The precautionary principle is defined as "a broad epistemological, philosophical and legal approach to innovations with potential for causing harm when extensive scientific knowledge on the matter is lacking. It emphasizes caution, pausing and review before leaping into new innovations that may prove disastrous."

Given some of the uncertainties enumerated in the preceding section, we believe the precautionary principle should be applied to lithium ion in stationary back-up power. To illustrate this point we will draw a parallel to nuclear. We chose traditional nuclear as a case study because of the striking similarities shared with lithium ion.

NUCLEAR	LITHIUM ION
Projected Lower TCO- Higher Capex compensated by lower opex	Projected Lower TCO- Higher Capex compensated by lower opex
High energy density	High energy density
High thermal instability mitigated with redundant cooling	High thermal instability mitigated with active management
Environmentally friendly through reduced emissions	Environmentally friendly in relation to lead

So how did projections with nuclear actually manifest in the 1970s?

> "Several large nuclear power plants were completed in the early 1970s at a typical cost of $170 million, whereas plants of the same size completed in 1983 cost an average of $1.7 billion, a 10-fold increase. Some plants completed in the late 1980s have cost as much as $5 billion, 30 times what they cost 15 years earlier." [4]

The major driving force of this price increase was unforeseen regulatory requirements. Projections of lower TCO were never realized because they were predicated on a set of assumptions that failed to capture the risks inherent in nuclear technology. The energy density that made nuclear so attractive also carried with it inherent risks. It was thermally unstable. Stability had to be engineered with backstops. Highly redundant systems were supposed to ensure that the system never lost stability. And yet disasters such as Three Mile Island and Fukushima still occurred. The publicity surrounding failures led to an ever tightening set of regulations:

> "Concerns over safety were addressed by regulators by tightening regulations and requirements for safety equipment. Regulations were only tightened, never loosened. The ratcheting policy was consistently followed. Regulatory ratcheting applied to new plants about to be designed is one thing, but this ratcheting applied to plants under construction caused much more serious problems. As new regulations were issued, designs had to be modified to incorporate them. We refer to effects of these regulatory changes made during the course of construction as regulatory turbulence"[4]

So what kind of risks are inherent in lithium ion systems?

One such recent example of a failure in lithium ion batteries occurred in April 2019 at the APS McMicken facility in Phoenix. The very public investigation found the fire appeared to be caused by dendrite formation that grew from one electrode to the other, causing a short circuit. This led the battery to heat up and catch fire. Dendrite formation is a well known cause of failure that is expected over long periods of time, but nowhere near the severity that caused the short in only a period of 2 years. [5]

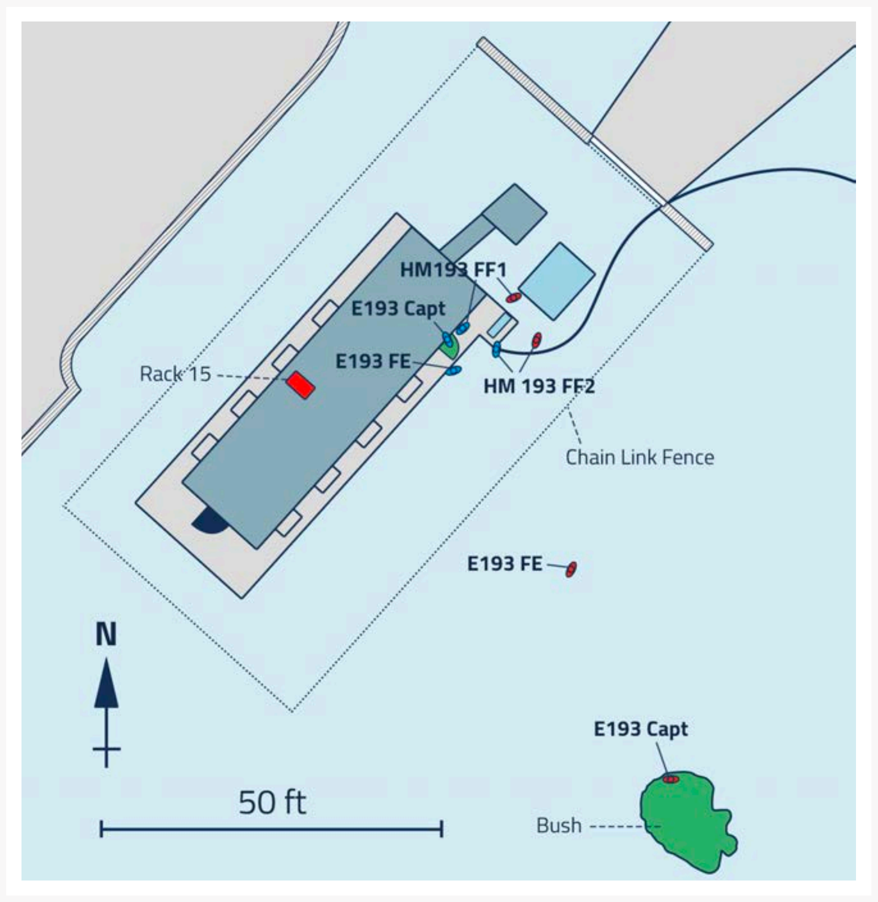

Figure 3:
Diagram representing the location of firefighters just before the deflagration event. Approximate positions prior to the deflagration event are displayed in blue, and approximate positions after the deflagration event are displayed in **red** [6]

The UL report following the event describes the incident when firefighters got to the scene:

> “At the moment of the deflagration event, the firefighters outside the hot zone described hearing a loud noise and seeing a jet of flame that extended at least 75 ft outward and an estimated 20 ft vertically from the southeast-facing door [7]. In the event, E193 Capt and E193 FE were ballistically propelled against and under the chain-link fence that surrounded the ESS. E193 Capt came to rest approximately 73 ft from the opened door beneath a bush that had ignited in the event.” [6]

Particularly worrisome was that the lessons learned were primarily centered around disaster mitigation, and NOT prevention, further exemplifying the lack of understanding and reliability still surrounding this technology.

Because of this we see "regulatory turbulence" posing a very real threat with adoption of lithium ion battery systems. As more and more systems get deployed, it's inevitable that disasters such as the one at APS will occur. The dramatic nature of these failures, as detailed in the UL report, lend themselves to onerous regulation. Dramatic disasters unavoidably lead to publicity, and this publicity, in turn, invites overly stringent and burdensome regulation; and in the case of data center providers, has the added potential to cause irreparable damage to their image of stability. We watched this turn of events unfold in nuclear, albeit on a much larger scale. We make no assertions that lithium ion batteries carry the same, or even comparable level of risk as nuclear power. They don't. We do, however, see striking similarities between the underlying principles of both technologies and are thus wary of unforeseen expenses and regulatory turbulence that may arise with mass adoption. Because of this, we believe the precautionary principle is particularly applicable in this case.

Implications on TCO

We believe that many current TCO projections are inaccurate. Although on the surface the numbers add up and the projections are attractive, they rely on assumptions that stand on shaky ground. Important points to consider include:

Longer Battery Life

The principle driving force we've seen to lithium ion adoption is that the customer will see lower annualized battery capex, the higher upfront cost being compensated with a longer lifespan. The design life of lithium ion batteries is often listed as 15 years. This figure is used in TCO calculations and is compared against 5-7 years for lead acid batteries. However, lead acid batteries with a 5-7 year "realized life" tout a "design life" of 10 years. This design life is not used in TCO calculations because we have a large amount of data to understand that batteries in the field don't perform like batteries in optimal lab conditions. So what we effectively see is an apples to oranges comparison. Lithium ion batteries certainly have a longer operating life than their lead acid counterparts, but is it enough to offset the higher upfront capital requirements? In our eyes, there isn't enough data to draw a conclusion here.

Space Savings

Currently a selling point in lithium ion is that the smaller footprint of the batteries will mean more space can be put to productive use in the data center. However, space savings certainly won't be realized as the batteries will need adequate isolation to prevent fires from spreading. These requirements have already been implemented in many localities.

Lower Expected Failure Cost

With more stationary deployments over time, we'll begin to get a better idea of failure rates and damages associated with failure. These can then be included as an expected cost of outage and damage. Currently many lithium ion TCO reports address safety concerns by citing a low number of failures and attributing this to the built-in management systems- but this is misleading because the number of lithium ion batteries deployed in UPS applications is far lower than that of lead acid batteries. It is absolutely expected that there are less cases of lithium ion failures than lead acid failures, but this does NOT indicate more safety; it's just a product of uncertainty. After all, absence of evidence is not evidence of absence. With management systems, lead acid batteries carry a lower expected cost of failure- that is because the chance of critical failure (and resulting damage) is lower due to fundamental laws of nature.

Recycling Costs

Additionally at end of life, operators won't be receiving credits for recycling batteries as they receive with lead acid batteries, but instead will be forced to pay for recycling. Lead from lead acid batteries has a 99% recycle rate whereas lithium is somewhere around 5%. The infrastructure in recycling lithium just isn't there.[7]

Lower Opex

Another selling point is lower opex due to less required maintenance, but this may be misleading as well. Our case study on nuclear suggests that regulatory turbulence poses a very real risk in adoption of lithium ion battery systems. As lithium ion batteries see larger stationary deployments, the costs associated with their deployment will certainly increase. Volatile technologies come with risk. Those risks require mitigation measures, and those measures adversely affect the economics. Projections predicated on optimistic assumptions don't account for this, and in turn may remain just that, projections.

Closing Thoughts & Outlook

Although we continue to look at developments in lithium ion, we do not see the use case in mission critical applications in the near future. We see the drive for lithium ion development and improvement to be pioneered in the motive space and high cyclical use cases like solar farms, power shaving, etc. We expect industries and firms that can localize the cost of failure to serve as data collection points for manufacturers who will analyze those failures and work towards making the technology more safe and reliable. As the saying goes, pioneers get slaughtered and settlers prosper.

We see lead acid to continue serving in mission critical backup power for the foreseeable future. The pioneer phase is long gone and further developments in pure lead technology show promise in extending battery life by reducing positive grid corrosion. Voltage equalization through active management shows evidence of substantially mitigating premature failure, further reducing the gap between “design life” and “realized life”. (See our White Paper on Battery Monitoring for more information on Charge Balancing). There are simply far less unknowns, and the improvements in the technology are rooted in a more fundamental understanding of the chemistry. We understand the allure of new technology, it’s at the core of our company’s culture, but we also understand the importance of stability above all else in the industry we serve. As of this paper’s publishing, we would be uncomfortable offering our customers a lithium ion solution and having the confidence to stand behind its safety and reliability. We just don’t have enough data or the requisite fundamental understanding of the underlying technology to do so.

References

[1] Wang, Aiping, et al. “Review on Modeling of the Anode Solid Electrolyte Interphase (SEI) for Lithium-Ion Batteries.” Nature News, Nature Publishing Group, 26 Mar. 2018, www.nature.com/articles/s41524-018-0064-0.

[2]An, Seong Jin, et al. “The State of Understanding of the Lithium-Ion-Battery Graphite Solid Electrolyte Interphase (SEI) and Its Relationship to Formation Cycling.” Carbon, Pergamon, 9 Apr. 2016, www.sciencedirect.com/science/article/pii/S0008622316302676.

[3] Keil3, Peter, et al. “IOPscience.” Journal of the Electrochemical Society, IOP Publishing, 6 July 2016, iopscience.iop.org/article/10.1149/2.0411609jes.

[4]Cohen, Bernard L. “Costs of Nuclear Power Plants — What went Wrong?” The Nuclear Energy Option, Plenum Press, 1990, www.phyast.pitt.edu/~blc/book/chapter9.html

[5] Spector, Julian. “APS Details Cause of Battery Fire and Explosion, Proposes Safety Fixes.” Greentech Media, Greentech Media, 5 Aug. 2020, www.greentechmedia.com/articles/read/apsbattery-fire-explosion-safety-lithium-mcmicken-fluence.

[6] McKinnon, Mark B., et al. UL Firefighter Safety Research Institute, 2020, Four Firefighters Injured In Lithium-Ion Battery Energy Storage System Explosion - Arizona.

[7] “Energy Department Announces Battery Recycling Prize and Battery Recycling R&D Center.” Energy.gov, 2019, www.energy.gov/articles/energy-department-announces-battery-recyclingprize-and-battery-recycling-rd-center.

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