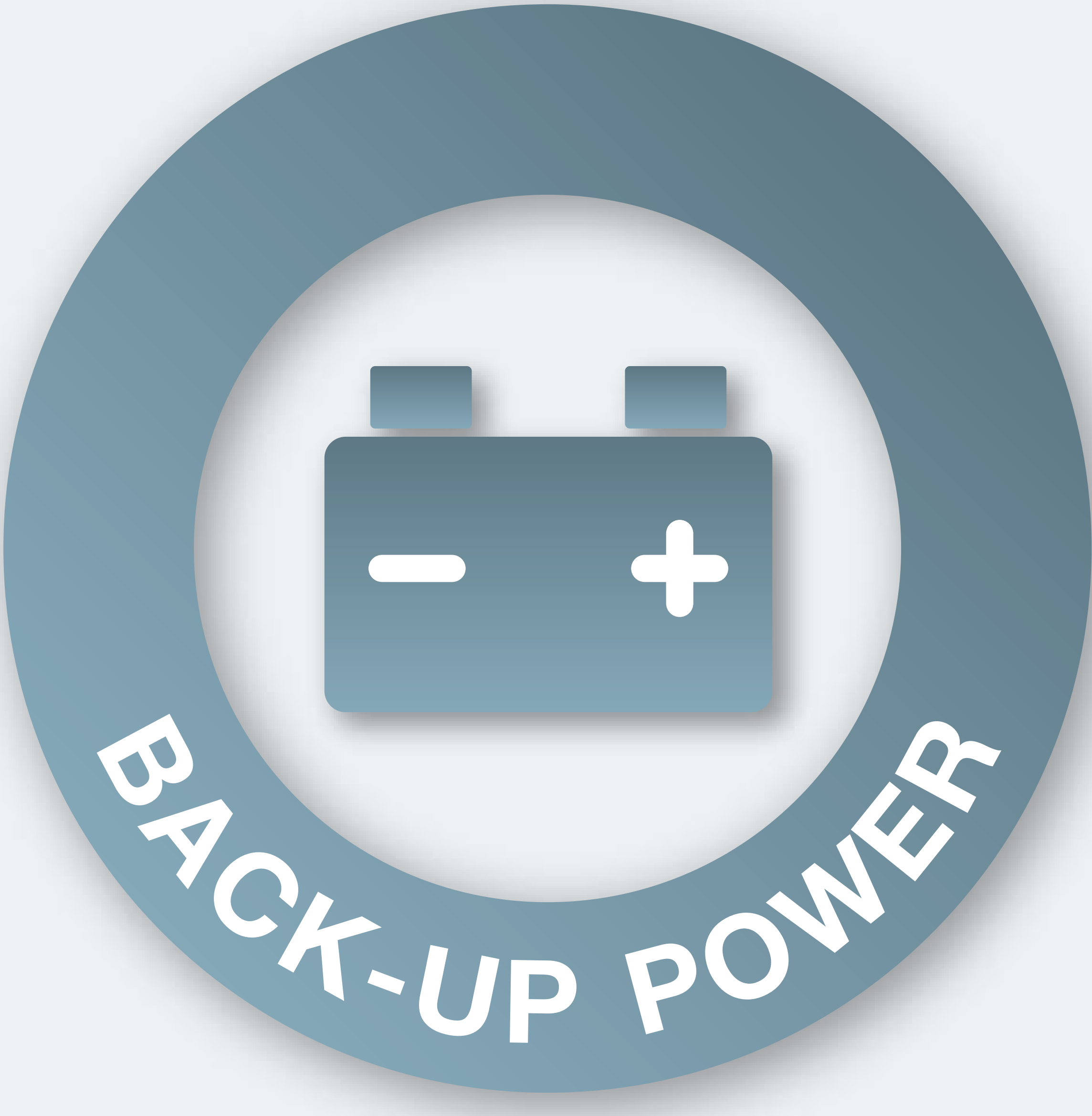
WHITE PAPER

The Benefits of Lithium-Ion battery technology in UPS applications

Back-up power

By Antonio Tamiozzo



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Introduction

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While many innovative and efficient UPS topologies have been introduced over the last 20 years, the Valve Regulated Lead Acid (VRLA) battery has remained the only back-up storage system solution for UPS critical applications for nearly 50 years. The rapid evolution of the Lithium-Ion battery technology over the last decade has provided several advantages, such as energy efficiency, environmental friendliness, and space savings.
These aspects can contribute to the reduction of the Total Cost of Ownership of many UPS applications and provide a reliably available back-up power solution in a reduced footprint, with an extended life time and reduced maintenance.

Contents

The battery technology used in UPS applications

A battery is an electrochemical energy storage system which generates a potential difference, causing an electric current to travel through a circuit until the energy is exhausted.
Batteries can be divided into two categories:

- primary batteries: once they are empty, they cannot be recharged and returned to their initial, fully-charged state (non-rechargeable batteries),
- secondary batteries: also known as accumulators, they can be recharged and returned to their initial, fully-charged state.

A battery charger adapted to each specific battery technology should be used.

The lead acid battery is the most commonly used type of battery for stationary applications. According to the Eurobat classification, the typical working life time of a lead acid battery is between 3 and 12 years. The duration of its cycle life time is usually poor even if it can reach a good level of performance in cycling applications.
The lead acid battery offers a mature, well-researched technology at a low cost. There are many different types of lead acid batteries available, such as the valve-regulated lead acid battery or VRLA (enclosed in sealed housing which includes a pressure relief valve), which requires less maintenance.

VRLA batteries can be further divided into two categories: AGM (absorbent glass mat) batteries, where the electrolyte is absorbed by a fibre glass mat, and GEL batteries, where the electrolyte is a special gel capable of withstanding high temperatures, used in specific applications.
A disadvantage of lead acid batteries is the decrease of their working capacity during high power discharges. For example, if a battery is discharged within one hour, only about 50 % to 70 % of its rated capacity remains available.
Other drawbacks include a lower energy density (lead has a heavy specific weight) and the use of lead, a hazardous material prohibited or restricted in some specific environments or applications. Advantages include a favourable cost / performance ratio, easy recyclability and a simple charging technology.

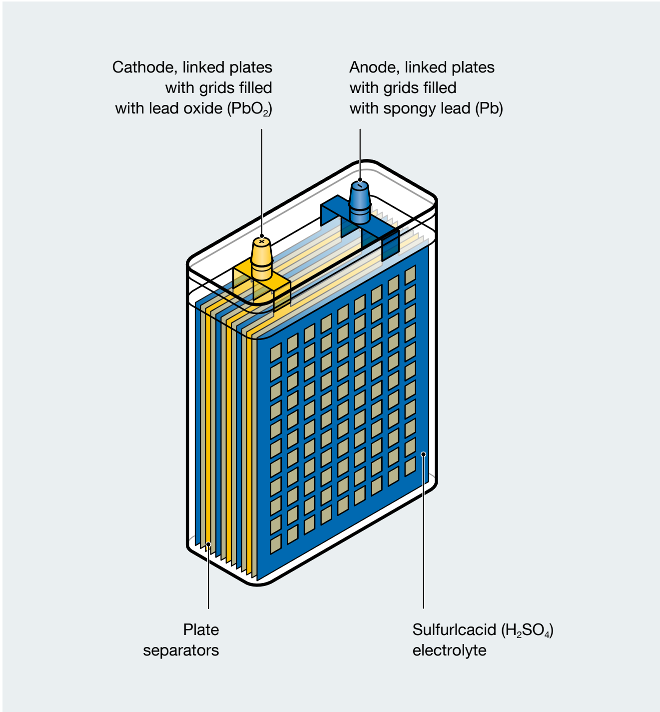


Fig. 1 - X-ray view of a VRLA battery.

The Lithium-Ion battery (Li-Ion)

The Lithium-Ion battery (or Li-Ion battery or LIB) was introduced commercially by Sony in 1991.
It has three main components: the positive and negative electrodes and the electrolyte.
The **negative electrode (anode)** is primarily composed of **graphite**. A **Li-Titanate** anode (which can be combined with any other cathode) has also been developed for better safety and battery performance, but with a significantly lower energy density.
The **positive electrode (cathode)** is composed of a **metal oxide**.
The Lithium-Cobalt oxide (LCO) offers a higher energy density but presents safety risks, especially when damaged. This chemical composition is widely used in consumer electronics.
The lithium iron phosphate (LFP), the lithium manganese oxide (LMO) and the lithium nickel manganese cobalt oxide (NMC) batteries offer a lower energy density, but are inherently safer.
The **electrolyte** is composed of a lithium salt in an **organic solvent**.

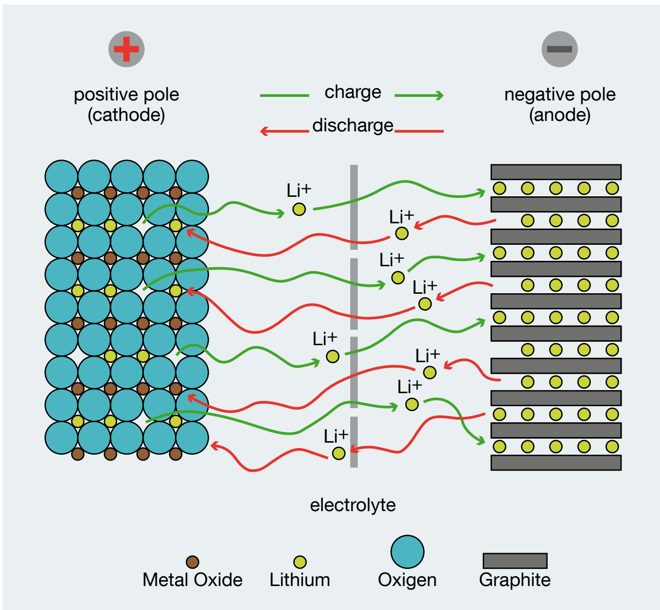
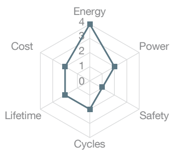
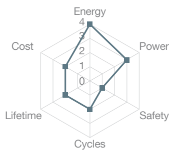
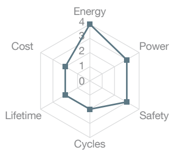
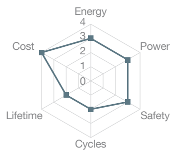
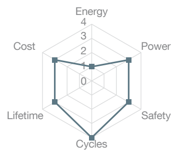
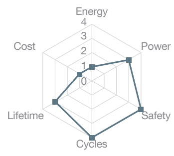


Fig. 2 - The Lithium-Ion cell operating scheme.

The Safety of Lithium-Ion batteries

Depending on the choice of material for a Lithium-Ion battery, its voltage, energy density, working life time and safety can vary dramatically. The table below summarises and assesses the different chemical compositions which can be used for the cathode.

Name	LCO	NCA	NMC	LMO	LFP	LTO
Full name	Lithium Cobalt Oxide	Lithium Nickel Cobalt Aluminium Oxide	Lithium Nickel Manganese Cobalt Oxide	Lithium Manganese Oxide	Lithium Iron Phosphate	Lithium Titanate
Cathode	$LiCoO_2$	$LiNiCoAlO_2$	$LiNiMnCoO_2$	$LiMn_2O_4$	$LiFePO_4$	e.g.: LCO, LMO, NCA
Anode	Graphite	Graphite	Graphite	Graphite	Graphite	$Li_4Ti_5O_2$
Cell voltage	3.7 V	3.6 V	3.8 V	3.6 V	3.3 V	2.3 - 2.5 V
Thermal runaway temperature	150 °C	175 °C	200 °C	250 °C	250 °C	Theoretically No thermal run away
Energy density Wh/kg	150 - 250	200 - 250	150 - 220	100 - 170	80 - 140	50 - 85
Chemistry comparison	LCO 	NCA 	NMC 	LMO 	LFP 	LTO 

Most metal oxide electrodes are thermally unstable and will decompose at **higher** temperatures, releasing oxygen which can lead to a thermal runaway condition. In UPS applications, the most commonly used electrode chemical compositions are the lithium manganese oxide (LMO) and the lithium nickel manganese cobalt oxide (NMC), which offer the best compromise between performance and safety levels currently available on the LIB market.
Li-Ion batteries are connected in series to obtain a voltage compatible with the UPS range, and they are equipped with a monitoring unit to avoid over-charging or over-discharging **phenomena**. A voltage balancing circuit is also installed to monitor the voltage level of each individual cell and prevent voltage deviations between the different cells.

Different Li-Ion cell designs are available:
- cylindrical,
- pouch,
- prismatic.

The prismatic cell design is considered to be the safest as it is equipped with several mechanisms such as a safety function layer, a multi-layered separator, a safety vent, a safety fuse and an over-charging safety device.

Prismatic Pouch Cylindrical

WP 052 A GB

Fig. 3 - Different Li-Ion cell designs.

The benefits of using Lithium-Ion batteries in UPS applications

Li-Ion batteries have a higher gravimetric and volumetric energy density, which means that a Li-Ion battery solution is lighter and requires less floor space than a lead-acid battery solution.
For a typical datacentre scenario with a back-up time requirement of a few minutes, the footprint savings are between 30 % and 70 %, freeing up space for additional IT equipment or rooms to accommodate future power upgrades, while the weight savings are between 50 % and 80 %, so that no additional spending for reinforcement is necessary.
The calendar life (over 15 years) and the cycle life (thousands of cycles) of a Li-Ion battery are very good, even at high temperatures.
With a high round-trip efficiency and no oversizing required for short back-up times (typical in UPS applications), it is clear that the Li-ion technology has several technical advantages.

	VRLA Battery	UPS Lithium Ion Battery
Nominal voltage	2.0 V/cell	3.8 V/cell
Voltage range	1.6 - 2.4 V/cell	3.0 - 4.2 V/cell
Volumetric energy density	100 Wh/L	250 Wh/L
Gravimetric energy density	30 - 50 Wh/kg	100 - 170 Wh/kg
Discharge efficiency	100 % at 20-hr rate 80 % at 4-hr rate 60 % at 1-hr rate	100 % at 20-hr rate 99 % at 4-hr rate 95 % at 1-hr rate
Cycle life	300 - 500	> 3000
Calendar life (at 25 °C)	5 - 7 years	15 - 17 years
Calendar life (at 35 °C)	2 - 3 years	6 - 9 years
Operating temperature	15 - 25 °C	0 - 40 °C

Financial analysis of Lithium-Ion batteries

To examine the economic benefits of using LIB systems in UPS applications, the Total Cost of Ownership (TCO) of VRLA and LIB systems is compared based on the following, real-life scenario: a redundant UPS system with a power of 200 kVA with a 150 kW load for a back-up time of 8 minutes.
The following table presents the input data.

UPS	UPS size	2 x 200 (redundant)	kW
	Average output load	75 %	% Pn
	Back-Up time	8	min
	Life expectancy	15	years
LABOUR	Operator cost	100	€/h
	Replacement speed	6	block/hour
ENERGY	Cost of Energy	0.0762	€/kWh
REAL ESTATE	Cost of Rent	288	€/m²/year
LIB SYSTEMS	LIB cabinets needed per UPS	1	Nb.
	LIB unitary cabinet footprint	0.39	m²
	LIB total nominal capacity	34.68	kWh
	LIB cost	600	€/kWh
VRLA BATTERIES	VRLA cabinets needed per UPS	2	Nb.
	VRLA unitary cabinet footprint	0.7	m²
	VRLA total nominal capacity	92.88	kWh
	VRLA cost	120	€/kWh
BATTERY CALENDAR LIFE	LIB	17	years
	VRLA	7	years
FLOATING POWER	LIB	14	W
	LIB consumption per year	122	kWh
	VRLA	64	W
	VRLA consumption per year	556	kWh
MONITORING SYSTEM	LIB	Already included	
	VRLA	80	€/block
	Installation time	0.03	hours/block
AIRCON	COP	3	
FINANCIAL	Cost of capital (WACC)	10 %	%

CAPEX considerations

It is assumed that the battery systems will perform a limited number of charge/discharge cycles during their working life (30 full charge/discharge cycles over 15 years of operation, at a rate of 2 full charge/discharge cycles per year).
For short discharge times of up to a few dozen minutes, the capacity of LIB systems is much higher than that of VRLA systems (which are oversized to ensure they can provide the capacity required by the load). To provide a back-up time of 8 minutes with a load of 150 kW, it is necessary to use either a 34.68 kWh (136 cells, 63 Ah) LIB system or a 92.88 kWh (516 cells, 90 Ah) VRLA system per UPS.
The 2016 market price for a high purchase volume is 120 €/kWh for VRLA systems and 600 €/kWh for LIB systems (for a typical scenario for a large EPC/contractor). While the LIB price per kWh is 5 times higher than the VRLA price, it only requires 37 % of the installed capacity.

The initial battery purchasing price of a 34.68 kWh, 136 cells 63 Ah LIB system is 20,800 € while the purchasing price of a 92.88 kWh, 516 cells 90 Ah VRLA system is 11,150 € per UPS.

For a more accurate comparison, a BMS (battery monitoring system) is included as part of the VRLA system, assuming a BMS market price of 80 €/12Vblock. The VRLA BMS system cost is 6,680 € per UPS; whereas the BMS is already included in the LIB system's standard scope of supply.

With a calendar life of 17 years we can assume that, with a limited number of charge/discharge cycles, the actual working life of the LIB system is close to 15 years. On the other hand, the VRLA system will need 2 replacements during the UPS life time (at years 7 and 14).

OPEX considerations

For an accurate comparison of the two scenarios, the battery room temperature is assumed to be the same (25 °C) in both cases, although it should be noted that LIB systems are more tolerant to high temperatures, therefore operating costs can be reduced as less energy is required for cooling.

Only the renting costs are examined, while the difference in cooling costs is not considered here.
Due to their high energy density, LIB systems can provide significant space savings compared to VRLA systems (they take up a lower volume of space for the same B.U.T., and have a higher efficiency). This is particularly significant for systems installed in datacentres with high real estate costs.
With a cost of rent of 288 €/m^2 per year (slightly below the European average), the difference between the VRLA footprint (around 1.4 m^2) and the LIB footprint (around 0.39 m^2) is approximately 9,500 € over 15 years.

To summarise: the table below shows the cash flow for a 200 kVA system based on the table "Financial Analysis of Lithium-Ion batteries" on page 6.

Year	**VRLA**						**LIB**						**Cash flow LIB vs VRLA**
	CAPEX		OPEX		Total Cash Flow	NPV	CAPEX		OPEX		Total Cash Flow	NPV	
	1st Installation	Repla-cement	Real estate rent	Power consumption			1st Installation	Repla-cement	Real estate rent	Power consumption			**Delta NPV**
0	-€ 42458	€ 0	-€ 806	-€ 24	-€ 43288	-€ 39353	-€ 44656	€ 0	-€ 225	-€ 2	-€ 44882	-€ 40802	-€ 1449
1	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 40040	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 40989	-€ 950
2	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 40664	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41159	-€ 496
3	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 41231	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41314	-€ 83
4	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 41747	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41455	€ 292
5	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 42215	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41582	€ 633
6	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 42642	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41699	€ 943
7	€ 0	-€ 25731	-€ 806	-€ 24	-€ 26562	-€ 55033	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41804	€ 13229
8	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 55385	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41900	€ 13485
9	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 55705	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 41988	€ 13718
10	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 55996	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42067	€ 13930
11	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 56261	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42139	€ 14122
12	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 56502	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42205	€ 14297
13	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 56720	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42264	€ 14456
14	€ 0	-€ 25731	-€ 806	-€ 24	-€ 26562	-€ 63079	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42318	€ 20761
15	€ 0	€ 0	-€ 806	-€ 24	-€ 831	-€ 63260	€ 0	€ 0	-€ 225	-€ 2	-€ 226	-€ 42368	€ 20892

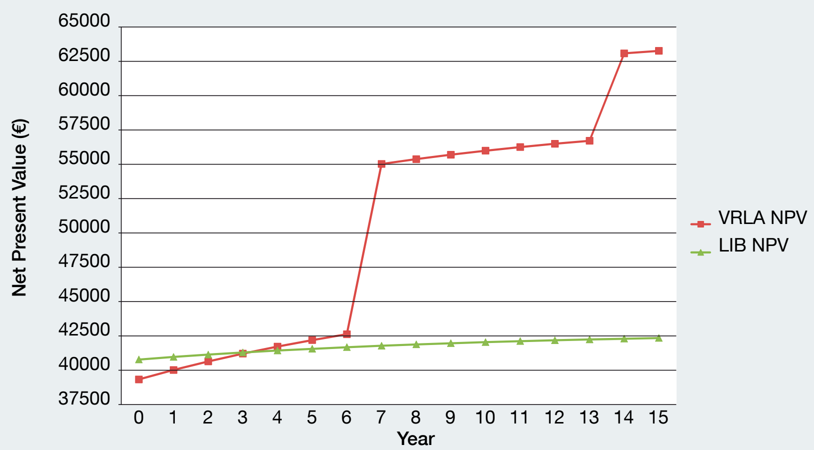


Fig. 4 - LIB vs VRLA system cash flow in a 200 kVA redundant UPS application.

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Conclusion

Taking into consideration all the assumptions made above, a 200 kVA UPS LIB system becomes more competitive than a VRLA system after 4 years by reducing the Total Cost of Ownership of the UPS system.

The decreasing trend of Lithium-Ion battery prices will continue, driven by the booming electric vehicle market, while battery safety is steadily improving. All these factors make the LIB system a winning solution for UPS applications requiring a compact, innovative protection.

About the author

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Antonio Tamiozzo received a BSc degree in Electronic Engineering from the University of Padua, Italy, in 2001.
He has been working for Sicon s.r.l. (part of the Socomec Group) since 2001, where he has worked both in the R&D and photovoltaic business units.
He is currently the Market and Product Manager for UPS back-up power solutions.
His major research interests are related to the choice of new innovative back-up power solutions for UPS systems.

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