Technology: Lithium-Ion Battery

GENERAL DESCRIPTION

Mode of energy intake and output

Power-to-power

Summary of the storage process

The cathodes of lithium-ion batteries usually consist of metal oxides on an aluminium current collector. Common material combinations include LCO (lithium cobalt oxide), LMO (lithium manganese oxide), NMC (lithium nickel-manganese-cobalt oxide), as well as LFP (lithium iron phosphate). The anodes are predominantly made of carbon or a mix of carbon and silicon on a copper current collector. Alternatively, lithium titanate oxide and silicon are used in specific applications. Common carbon materials are e.g. graphite, hard and soft carbon. Anode and cathode are divided by a separator but connected by an ion-conducting electrolyte that contains lithium salts like $LiPF_6$.

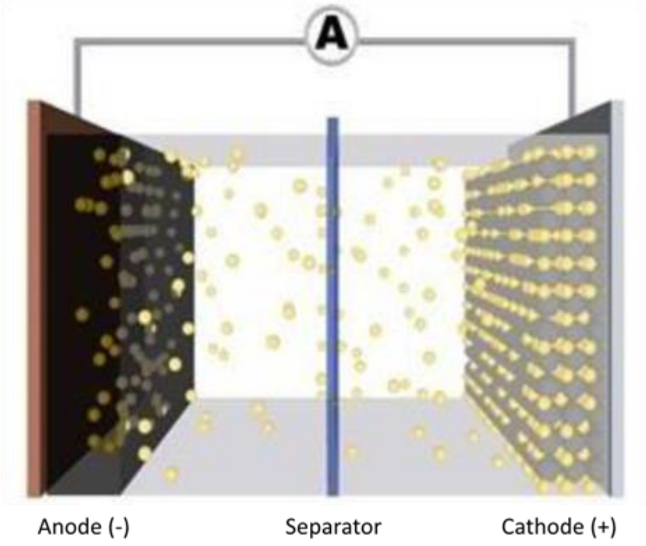

Figure 1: Schematic view of a lithium-ion cell (© Karlsruhe Institute of Technology)

The composition and combination of anode, cathode and electrolyte significantly influence the lithium-ion cell's characteristics such as voltage, capacity, maximum current, temperature dependency, ageing, safety, and price.

While charging, the positive cathode releases stored lithium ions into the electrolyte and electrons into the circuit. The positive lithium ions move towards and into the anode, accumulate there, and pick up another electron. During discharging, this process is reversed. This reversible insertion of ions into a material, called intercalation, is the key difference to other battery chemistries (based on the conversion of chemical to electrical energy, e.g. in lead-acid or NiCd batteries), and responsible for the high efficiency, long lifecycle, and special characteristics of lithium-ion batteries, like their pronounced ability to cope with partial charges.

System Design

Lithium-ion cells of various form factors, such as cylindrical, prismatic, or pouch cells, are integrated into battery modules, several modules are combined into a battery pack through serial and parallel connection of cells. A battery management system (BMS) is used to control, monitor, and protect the battery pack while enabling critical functions such as state of charge (SoC) estimation and equalisation of the cells. The battery packs can be modularly built to scale from W to MW of power and from kWh to MWh of energy.

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The integration of a battery into a system design or between power source and consumer can be realised by means of suitable power electronic converters or charge controllers, either on the DC voltage level (e.g. for photovoltaics) and/or via inverters on the AC voltage level (e.g. for power grids).

Focus on provision of power or energy

Power and energy. Typically, Lithium-ion battery packs operate at a C-rate of 0.5-2.

Suitable fields of application

Buffer storages in combination with renewable energies, load management (peak shaving), grid services (especially frequency control), emergency power supply. Due to their high cost, Lithium-ion batteries are mainly used in short-term energy storage in the order of hours to few days.

State of development/commercial availability

Li-ion battery technology was developed for mobile electronics applications. It has found its way into electric mobility, primarily owing to its high gravimetric and volumetric energy density, high efficiency (90 % upwards), and high number of possible cycles. Due to this success in portable electronics and electric mobility, li-ion technology is now also used in (utility scale) stationary storage applications.

Further optimisation efforts aim at increasing their energy density, system level efficiency (especially through intelligent controlling), and optimising design and manufacturing processes to lower the cost while increasing the lifetime.

Its Technology Readiness Level ranges from 6 (new variants) to 9 (commercially available variants).

TECHNICAL SPECIFICATIONS

Specific energy storage density	kWh/m^3 200-700 Wh/l 30-55 kWh/m^3 (HC container)	kWh/t 140-300 Wh/kg 50-65 kWh/t (HC container)
Specific power density	kW/m^3 < 25 (HC container)	kW/t < 100 (HC container)
Typical/feasible storage size	kWh_{out} Easily scalable 1 Wh to hundreds of MWh	kW_{out} Easily scalable 1 W to hundreds of MW
System efficiency	70-95 % round trip efficiency (AC)	
Storage efficiency	98-99 % (Coulombic efficiency, DC)	
Storage duration	< 12 Hours	
Response time	< 1 s	
Service life (maximum)	Cycles 1,000-10,000	Years < 15
Loss per time in %	< 2 per month	

Notes

This battery technology offers high energy density and good performance in terms of efficiency and lifetime. At the same time, it does not exhibit any memory effect. This means that even after several partial discharges, the battery's capacity does not decrease, it rather allows for a disproportionately higher number of cycles at a greater increase in available energy than with most other types of battery. This is particularly valuable for grid services and combination with renewable energies. The cells are also subject to degradation (loss of capacity and performance due to ageing), which can be taken into account in the product life cycle. Crucial factors for the characteristics and service life of a lithium-ion battery are, among other things, cell chemistry, the build quality of the battery cells, and the usage profile. The maximum depth of discharge of lithium-ion batteries can reach up to 100 percent, most batteries on the market, however, range between 70 and 95 percent. The maximum number of cycles depends on the ambient conditions and peaks at an ambient temperature specified for each particular battery (typically 15-25°C). Therefore, larger systems are often installed in air-conditioned rooms/stations.

ECONOMIC SPECIFICATIONS

Cost of operation and maintenance (based on investment/kW and kWh): Low maintenance cost, replacement of power electronics after 7-12 years.

Cost of energy provided in concrete applications:

Example 1: Small-scale 2-20 kWh residential storage, investment approx. 1,500-2,000 €/kWh; results in approx. 0.25-0.40 € per kWh stored, assuming 280 cycles per year and 15 years of use.

Figure 2: Home storage for increased solar self-consumption and integration into the electricity market: sonnenBatterie eco 8.2 with 8 kWh of capacity and 1.5 kW of output (© sonnen GmbH)

Example 2: 112 kW/280 kWh district storage combined with PV sytem for buffering and emergency power supply (no diesel generator required). Investment 1,000-1,500 €/kWh; results in approx. 0.20-0.25 € per kWh stored at a service life of 6,000 cycles.

Figure 3: Electricity storage container by RRC power solutions for buffer storage and emergency power supply at a municipal site in Saarland, Germany (© RRC power solutions GmbH)

Example 3: Large-scale 5 MW/5 MWh storage for provision of primary control power, investment cost approx. 850-950 €/kWh, 20 year service life. Capacity price (positive and negative) about 3,000 €/MW/week (depending on tender).

Figure 4: WEMAG storage, 5 MW/5 MWh, participating in the primary control energy market, first commercial battery storage in Europe, situated in Schwerin, Germany (© Younicos AG)