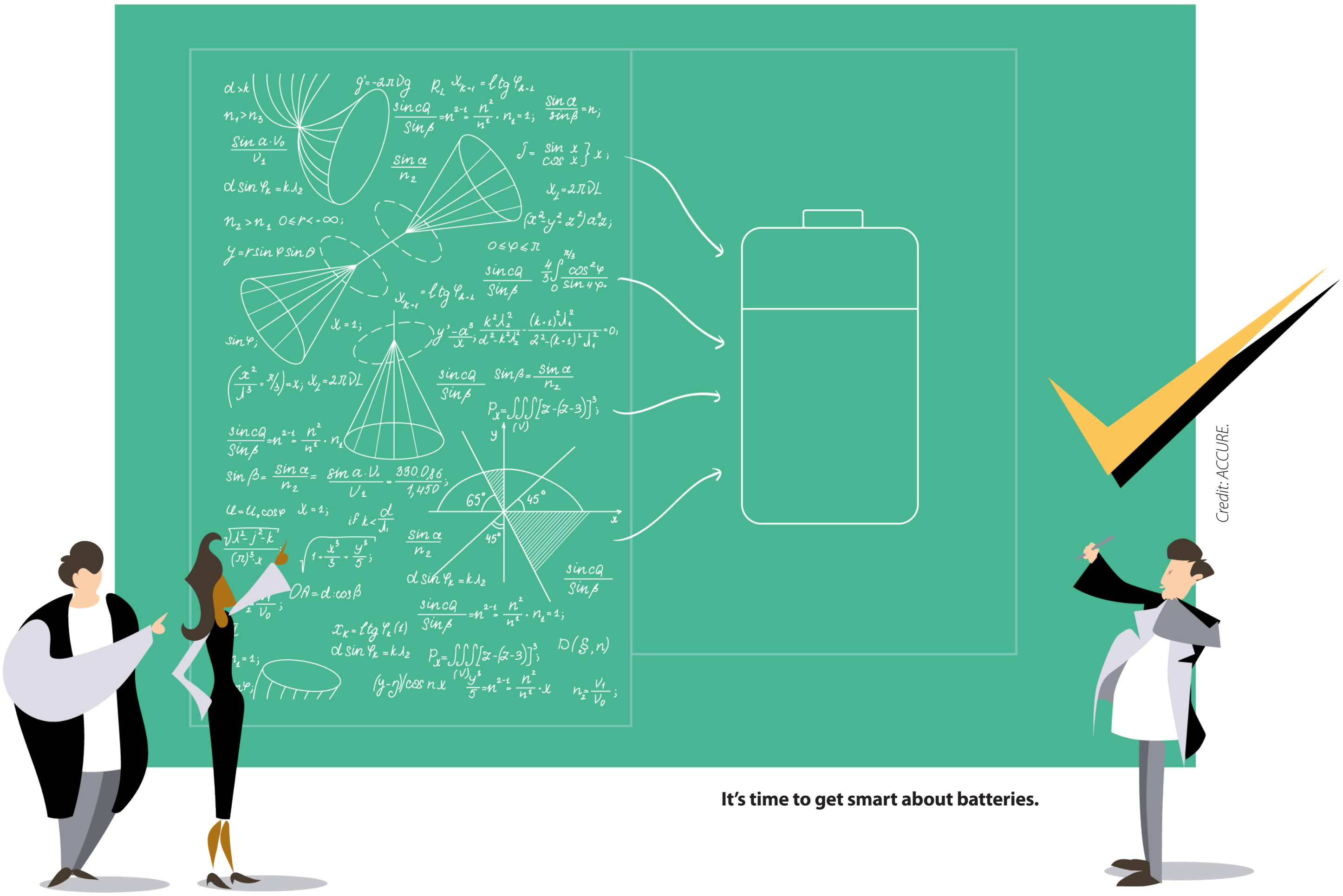
Battery safety - why it's important and what we can do about it

Safety | With the great demand for lithium batteries comes great responsibility to install and use them safely. Although much of that responsibility lies with manufacturers, Dr Kai-Philipp Kairies of ACCURE Battery Intelligence discusses how a combination of data gathered from the field and analytics embedded in software can make batteries safer to operate while maximising value.



It's time to get smart about batteries.

Credit: ACCURE.

The incredible success story of LIB…

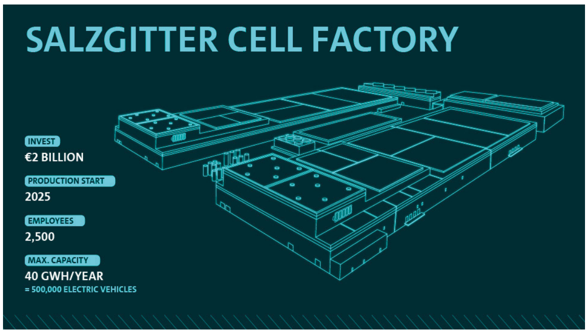
The energy and mobility world are accelerating on the path to decarbonisation. One of the most important assets for this transition are energy storage systems, particularly lithium-ion batteries (LIB). To put the incredible success of this young technology into perspective, the annual production capacity of the recently announced Volkswagen SalzGiga factory (40GWh) in Salzgitter, Germany, will be larger than the world's total LIB demand in 2013. Just let that sink in for a moment.

There are many reasons for the dominance of LIB in the energy and mobility world. One major advantage over other battery technologies is the flexibility. LIB cell types have been successfully used in electric cars, ships, buses and large-scale storage systems, allowing for synergies and scaling effects. But certainly, the strongest drivers of LIB were the stark increases in energy density and the (until recently) continuously falling prices.

…and why we need to talk about safety

The focus on ever-increasing battery energy densities and cost reductions, combined with a dizzyingly fast ramp-up of global production capacities has brought LIB into countless applications. As more industry players enter the market and deploy at a rapid pace, safety incidents also increase. Battery fires and explosions have become a regular sight in the news and on social media. Three events that caught worldwide attention:

- In 2019, a cell failure in a battery system at an APS facility in McMicken, Arizona led to a thermal runaway and ultimately caused an explosion that injured several first responders.
- Between April 2021 and May 2022,



Credit: Volkswagen.

Automaker Volkswagen's factory Germany will have annual production capacity equivalent to 2013's total global demand for lithium-ion batteries.

over 80 electric buses and 4 bus depots burned down across France, Germany, and the UK.

- Since 2020 thousands of electric scooters have caught fire around the world – some in private homes, some in warehouses.

While everyone in the industry agrees that battery safety should be the top priority, the reality is that the expectations and pressures relating to growth create conflicting priorities, in addition to the pressures to commercialise new, innovative technologies. Higher energy densities, for example, inevitably mean more energy that can fuel the fire during a failure. So, what are our options to prevent critical failures and make batteries—and clean energy—as safe as possible?

Three options for safer batteries

There are three main areas that engineers can work on to improve battery safety. These are:

1. Production quality
2. System design
3. Cloud analytics

In this article, we will take a quick look at production quality and system designs but take a deeper dive into cloud analytics because of the immediate results they deliver for battery safety. Their ability to go beyond the limitations of system design, the preventative advantages during battery operation, and the ease with which cloud analytics can be implemented means the benefits are highly accessible to battery operators and system integrators today. We will cover what a cloud-based battery analytics solution does, how it can be implemented and where it's used in real-world applications.

1 Production quality

To operate safely, batteries need to be produced with the utmost care and precision, from processing active materials to manufacturing the cells to assembling the pack. Any production defect can lead to unexpected (and sometimes critical) behavior years later.

The only solution to control manufacturing defects is rigorous quality management – so tighten your six-sigma black belt and dive into everything from incoming goods control to end of line testing. But there are two major challenges: For one, most mid-stream companies in the energy storage space have neither the full information about, nor the ability to impact the quality of the cells and packs they buy. On the contrary, in today's market, the sheer ability to buy batteries from a supplier weighs heavier than any quality management (QM) certification.

On top of that, even the most rigorous quality management will never catch 100% of the failures. And at giga-scale, even the tiniest slips become real problems. To reiterate on the recently announced Volkswagen Gigafactory: a failure that only happens once in a million will happen at least five times every month in this factory.

2 System design

Battery systems are equipped with several layers of protection. These protective measures are meant to keep the battery in its intended window of operation, shield it from external harm, and minimise the impact of a single-cell failure.

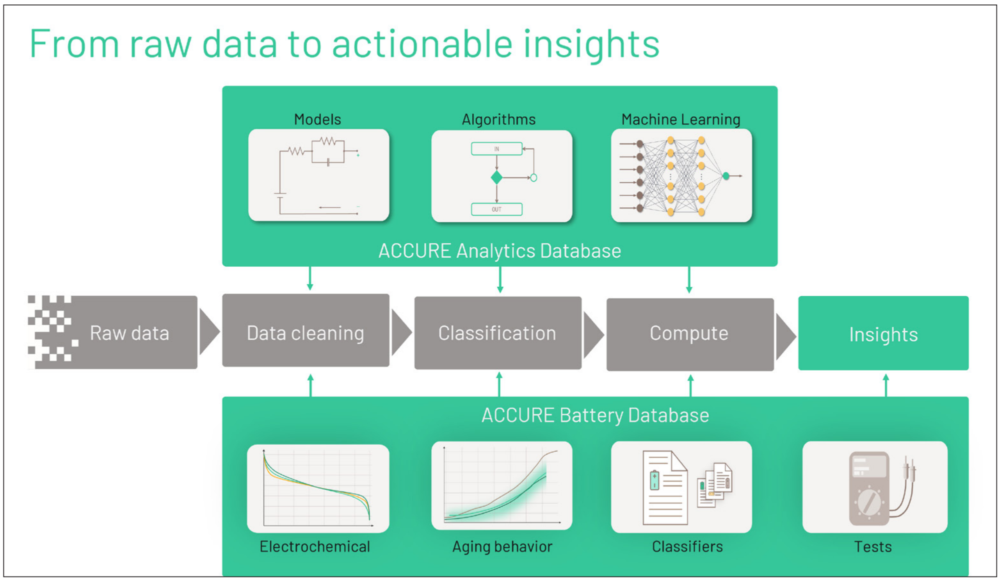
Passive safety components: LIB systems usually contain several passive components to ensure the safety of the overall system. However, passive safety components are last resorts to minimise the damage from critical situations that are already happening. In many cases they cannot prevent safety incidents.

Battery management systems (BMS) are electronic circuits containing sensors, logical units, actors, and a communication interface. BMS make sure that a battery is operated within its specifications. A basic BMS constantly monitors the status of voltage, current and temperature of the battery system via sensor measurements, calculates and monitors the states of the system such as SOC and SOH and performs cell balancing by selectively discharging cells over resistors. The BMS is also responsible to bring the system to a safe state when boundary conditions of temperature, voltage, current, etc. are exceeded.

While BMS are crucial to the safety of LIB, they also have noticeable shortcomings: They only see the cells within the corresponding battery pack, have little to no access to historic data or data from other battery systems and, importantly: they are limited in their computing power. Due to these limitations, BMS capabilities to detect edge-case anomalies, run deep analytics, and predict long-term trends are slim to none.

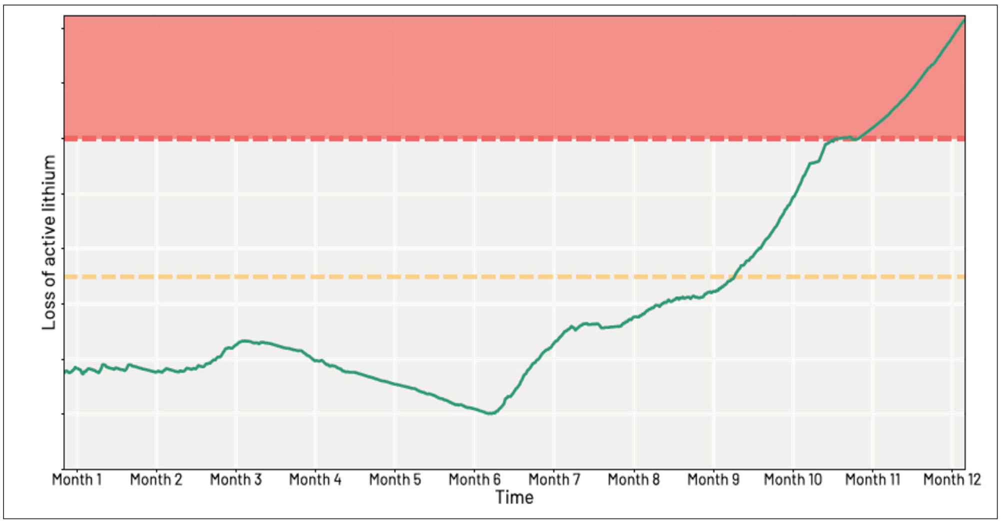
3 Cloud-based analytics

A proven strategy to improve battery safety is the use of cloud-based analytics. By detecting critical faults at an early stage using more sophisticated and modern analytical methods, battery operators can act before any damage is done. Diagnostics based on existing field data streams can be applied to any LIB system without the need for any product modification.



Credit: ACCURE.

Figure 1: Schematic workflow of ACCURE's predictive diagnostics.



Credit: ACCURE.

Figure 2: Model-based safety diagnostics track the loss of active lithium over time and give automated warnings if thresholds are reached.

The concept of cloud-based analytics is presented in Figure 1 and summarised in the following.

Step 1: Data acquisition

The starting point for all cloud analytics is the continuous stream of measurements from the BMS ("raw data"). This raw data is passed to the communication bus and then pushed to the cloud where it can be stored, consolidated, and analysed by the battery operator or a third-party service provider.

Step 2: Data pre-processing

To leverage the raw data, extensive data cleaning needs to be performed. For one, outliers and systematic measurement errors in the raw data need to be detected and flagged as such, to avoid false interpretations. But, more generally speaking, every BMS has its own (systematic and statistical) errors and idiosyncrasies that need to be understood to make sense of the data. If you plan to evaluate a cloud-based analytics solution, then make sure it works with any kind of input data and is able draw the right conclusions from every new data point. This pays off in terms of scalability for diverse BMS's.

Step 3: Fault detection

Fault detection algorithms scrutinise the battery data to check for potential faults. A fault can be identified through changes in primary parameters such as voltage, temperature, and current or in secondary parameters such as impedance, a shift in the open circuit voltage curve, or the amount of active lithium in each cell. To track secondary parameters, model-based algorithms, which consider reduced order physical-/chemical processes through mathematical equations are used. Identifying and tracking specific patterns in these parameters for the millions of similar cells, which are in operation, enables these algorithms to find anomalies before they become dangerous.

Credit: Metropolitan Transportation Authority of New York via Flickr.

Electric buses present an opportunity to decarbonise and reduce air pollution, but are assets that need to be managed safely.

Step 4: Reporting

If a battery is identified as dangerous by the cloud analytics, automated warning notifications are generated to allow the operator to act – by bringing the system into a safe state and arranging for maintenance or replacement.

A technical example of one of 20 safety indicators

There are many ways field data can reveal safety-critical battery behavior. In fact, there are at least 20 safety indicators a robust cloud analytics solution should track multiple times per day. They are based on electrical, thermal and mechanistic models empowered by machine learning. The algorithms mirror electrochemical relationships and processes, revealing insights about the internal states of the battery. In Figure 3, an analysis of the loss of lithium inventory, a process closely linked to lithium plating, is presented.

Lithium plating, where metallic lithium gathers on the outside of the anode, has been a major headache in the LIB world for decades. It mainly occurs when a battery is charged with high current rates at low temperatures but can also happen under "normal" operating conditions. Not only does it quickly degrade a battery's capacity, but it can also become a safety threat by forming metallic dendrites and triggering side reactions such as gassing. It manifests itself in a decrease of the lithium inventory which is no longer available for the main reaction.

Cloud-based safety algorithms, among other things, must closely track the loss of active lithium to accurately predict safety critical events.

Two real-world cases of cloud-based safety monitoring

At ACCURE Battery Intelligence a team of 70 battery experts applies cloud analytics to optimise the safety, reliability, and lifetime of currently 1.6GWh of battery assets. Among our customers are companies that have experienced battery fires and other safety incidents, which are not often publicised, before coming to us.

One public example, however, is Senec, a residential PV+Storage provider with over 65,000 installations across Europe and Australia. In March 2022, Senec experienced three battery fires within two weeks. After contracting ACCURE and transferring its historic operation data to our cloud, we were able to show that our cloud-based safety monitoring would have predicted all three incidents and together implemented a powerful new safety solution, the "Senec Safeguard 2.0." This combination of BMS and cloud-based algorithms now performs daily check-ups to ensure maximum safety.

Another example is the Berlin Transport Authority (BVG) who will transition their entire fleet to electric vehicles by 2030 – a total of 1,600 buses. After several battery fires in e-buses across Europe, BVG decided to be proactive about safety and started to use ACCURE's cloud-based safety monitoring on a part of their fleet.

Take control of battery safety

Battery safety is a complex topic spanning many stakeholders. With novel technology variants launched every month and new suppliers entering the market, it becomes increasingly difficult for battery system integrators and operators to manage their risks and optimise their upside.

The main levers to improve battery safety are production quality, system design and cloud analytics. As many companies do not have full insights into or even impact on the production quality and system design, cloud analytics are oftentimes the best way to manage risks today. While even the most advanced analytics cannot replace high production quality and a robust system design, they are proven to prevent critical failures and drastically improve the agency of battery owners and operators. Implementing advanced cloud analytics is a no-regret solution for companies – whether using their own resources or by partnering with a trusted analytics software provider. ■

Author

Dr. Kai-Philipp Kairies is a scientist and entrepreneur focusing on innovative battery energy storage solutions. He worked as a battery researcher and consultant in Germany, Singapore, and California. Since 2020, he is CEO of ACCURE Battery Intelligence, a battery analytics solution provider that supports companies in understanding and improving their batteries' safety and longevity to reduce risk and increase value and sustainability.