

Improve the safety, availability & performance of energy storage systems with battery analytics



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Introduction

Battery energy storage systems (known as BESS or ESS) are essential for accelerating the shift towards green energy. As renewable energy generation depends on weather conditions, it can be unpredictable and unaligned with timing of energy usage. Battery energy storage systems address this challenge as they store surplus energy when abundant and discharge it when needed, thus equalizing supply with demand, ensuring grid stability. In addition, ESS provide ancillary services like frequency response to maintain electric grid reliability and operations within specified parameters.

Battery energy storage systems are now an integral part of the electricity grid across the globe, meaning that their availability and safety are more important than ever. Considerable numbers of BESS have been deployed in recent years¹, and this is forecast to grow significant amounts in the next years, as shown in Figure 1. Furthermore, global investment in battery storage exceeded 20 billion USD in 2022 and is expected to exceed 35 billion USD in 2023², a 75% increase. The increased investment and deployment of energy storage systems means that serious and professional treatment is required to gauge how well they are operating to ensure they are fulfilling their requirements to the grid as well as achieving their ROI objectives.

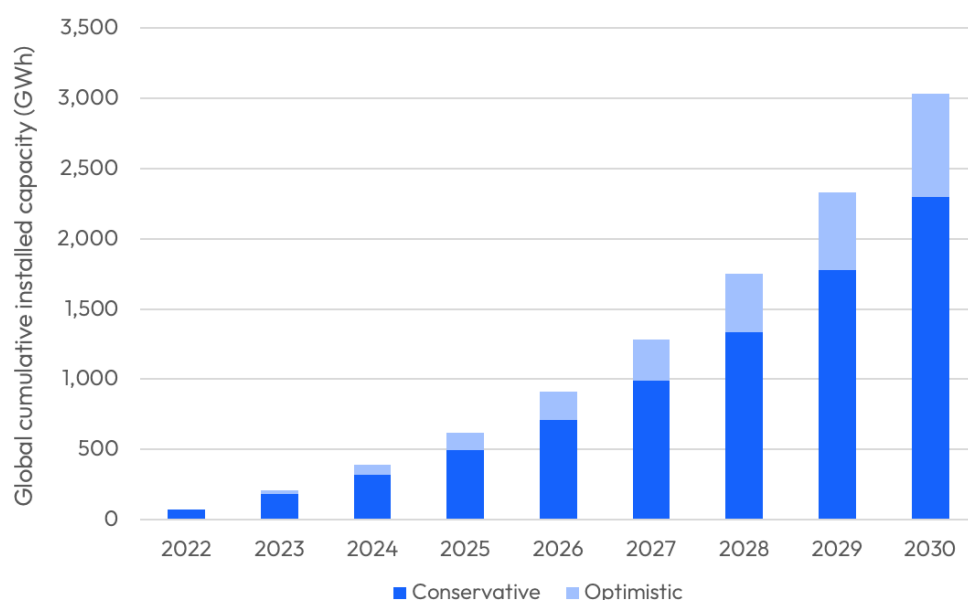


Figure 1: Global cumulative installed battery capacity (GWh) (Source: McKinsey, BNEF, Ark Invest)

¹ IEA, Annual grid-scale battery storage additions, 2017-2022, IEA, Paris <https://www.iea.org/data-and-statistics/charts/annual-grid-scale-battery-storage-additions-2017-2022>, IEA. Licence: CC BY 4.0

² IEA, 2023, Grid-scale storage, <https://www.iea.org/energy-system/electricity/grid-scale-storage>

The increasing numbers of BESS that are supplying electricity to the grid come with risks, which is why the North American Electric Reliability Corp (NERC) continues to develop new reliability standards for inverter-based resources (IBR) – including battery storage, wind and solar³. Batteries are such complex systems that a lot can go wrong, such as risky increases in temperatures which can cause the system to trip offline, or cell imbalances, which over time decrease the amount of energy that can be discharged. Battery energy storage systems as well as other renewable energy assets must be able to reliably provide the amount of electricity to the grid that they have agreed to. If they are not able to do this, they are liable for penalties and in the future, will risk non-compliance with regulations.

BESS availability is just as important for owners and operators who are not providing grid services but are engaging in energy trading. To take advantage of price fluctuations to purchase, store and release energy on-demand, the energy storage system must be reliable. It must be available when required and perform to its optimal potential, otherwise trades could be interrupted or rendered unviable. Also, extreme price spikes in the market mean that energy storage systems can earn a large portion of their planned income in just a couple of events – for example during extreme windy weather. If these rare events happen, the system must be up and running and performing at its optimal level, otherwise asset owners and operators leave money on the table.

Companies need to ensure there are measures in place to ensure high availability and safety of energy storage systems. However, this isn't easy. Asset owners and operators are juggling many different tasks and often lack transparency into what is going on with their ESS, making it practically impossible to identify what problems might occur and how they can be avoided. While there are many different root causes of poor availability or downtime, cell imbalances are one of the main ones. Identifying and solving problems with cell imbalances can go a long way in ensuring BESS safety and availability. In this whitepaper, we discuss the challenge of cell imbalances and how battery analytics can help to overcome it.

³ Utility Dive, 2023. FERC directs NERC to draft reliability standards for wind, solar and storage: <https://www.utilitydive.com/news/ferc-nerc-ibr-reliability-standards-inverter-based-wind-solar-storage/697287/>

Risks of imbalanced cells

Imbalanced modules and cells lead to inverter faults and can cause wasted energy. This can be hugely problematic and lead to losses of billions of dollars/euros over the lifetime of an asset. An internal analysis carried out by TWAICE showed that if a 100 MWh system experiences a State of Charge (SoC) imbalance of 15% within half of all strings, this could lead to a revenue loss of 10 million EUR over the entire lifetime of the asset.

Cell imbalances can occur because battery energy storage systems comprise of hundreds of thousands of individual battery cells, and while these cells are part of the same system, they vary in quality and aging. The weakest cell among them dictates the performance. Thus, when the BESS is charged, not every cell will charge to the same targeted value (e.g., 100% SoC). At the same time, when discharged, not every cell will be discharged to the same planned value (e.g., 0% SoC).

This has profound implications for the BESS. On the one hand, this can cause considerable stress for the battery and drive systems out of the pre-defined and safe operation windows, leading to safety issues, downtime and shorter lifetime. Additionally, this leads to wasted energy, meaning that BESS are less likely to be able to fulfil their market obligations.

Figure 2 below indicates the amount of wasted energy (red) that can occur due to imbalances. On the left, you see the SoC of various cells that should be fully discharged. However, they do not have an equal amount of charge. Therefore, when they are charging, the cell (second to the left) reaches 100% charge before the others, meaning the other cells do not reach 100%, causing considerable wasted energy.

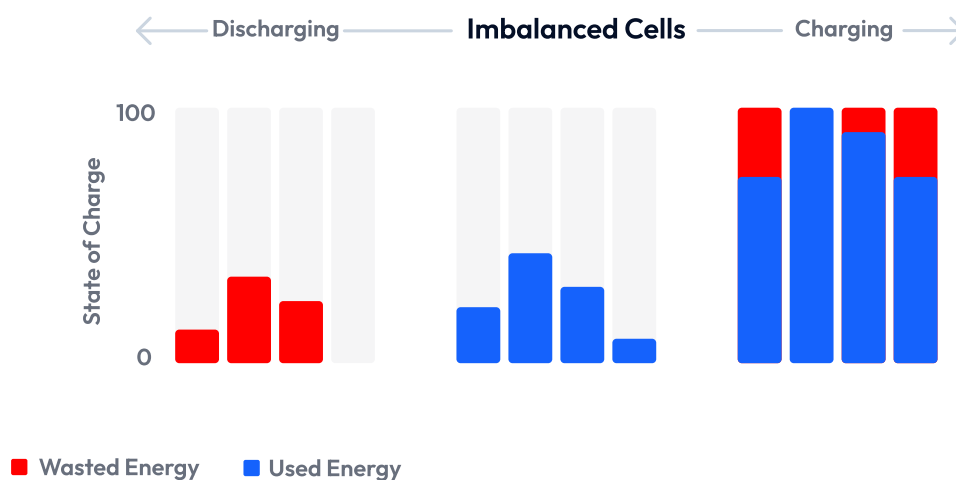


Figure 2: Portrayal of wasted energy that can occur due to cell imbalances

While SoC imbalances can occur naturally due to quality differences among the individual battery cells, they can also occur due to the way in which the battery management system (BMS) calculates state of charge. The BMS usually calculates the state of charge based on the Coulomb Counting method or voltage. The Coulomb Counting Method measures the current of the battery, but errors accumulate when the battery is used for a long time without being fully charged or discharged, making it difficult to accurately estimate SoC. The limitation of using the voltage method to calculate the SoC is that the open circuit voltage (OCV) changes with temperature and aging. This is particularly problematic for LFP storage systems because these have a flat OCV, therefore small errors in voltage cause huge distortions for the SoC estimation. ([This whitepaper](#) explains about the different methods of calculating battery State of Charge in more detail).

When several cells or modules are aggregated, the inaccurate SoC provided by the BMS means that some cells are overcharged and some cells are undercharged, leading to even stronger SoC imbalances – thus more wasted energy, and higher safety risks.

Summary

Cell imbalances are a key indicator that can lead to low availability, revenue loss, safety risks and shorter battery lifetimes. Cell imbalances cause low availability as they lead to wasted energy and over time, lead to increased stress on the battery.

While it is helpful to know when and where cell imbalances are occurring, it is even more helpful to understand the root cause of the problem. This could be a problem that occurred during manufacturing or construction, it might have to do with HVAC components such as the cooling system, or it might result directly from the way that the storage system is operated.

Pinpointing weak cells with battery analytics

Battery analytics provides granular insights and transparency about the entire battery energy storage system, making it easier to pinpoint the exact components that are not working as they should. While a battery management system is in place to ensure the safe operation of the battery, it provides limited information – temperature, current, and voltage as well as calculations of State of Charge and State of Health. As discussed in the previous section, cell imbalances are a key concern, and these are not identified or shown by a battery management system.

Continuous insights into subsystem levels

With battery analytics, asset owners and operators can easily identify which inverters and strings contain high imbalances – displayed using the SoC and voltage dimension. This helps to define measures for predictive maintenance, as maintenance teams know where to investigate on site, and can replace modules or external components such as cooling systems where required. With these granular insights, asset owners and operators can predict which modules might cause downtime and replace them before it happens.

Example: Inverter 2.1 Performance Analysis

This example shows how cell imbalances can be pinpointed with battery analytics. In this case, shown in Figure 3, Inverter 2.1 exhibited the highest voltage and TWAICE State of Charge variance in the entire system. This is mainly driven by two strings out of the entire group, which can be clearly seen due the color distribution. These strings are constraining the performance of all strings within that inverter.

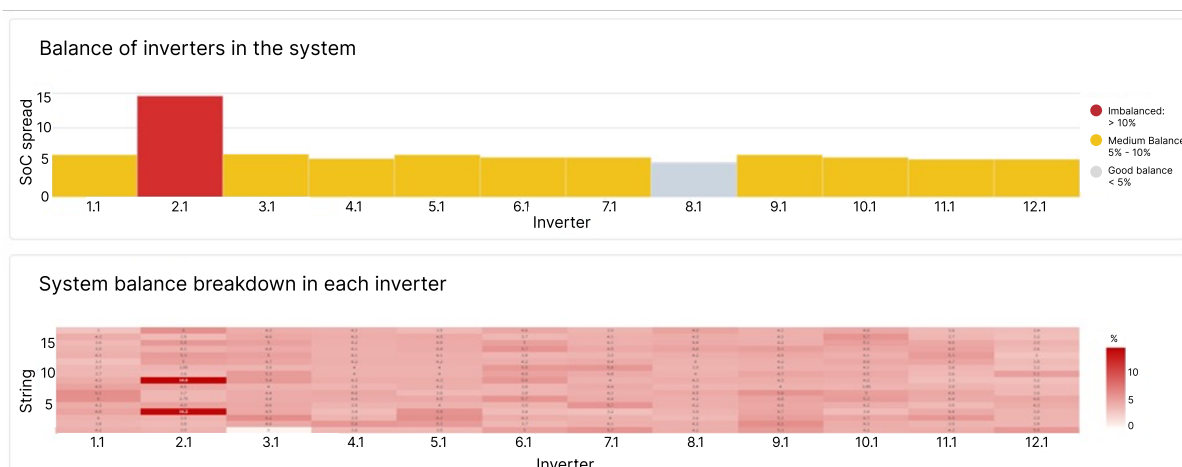


Figure 3: Example showing high State of Charge imbalances

This imbalance was ultimately fixed by carrying out system balancing. However, other inverters started to exhibit similar problems, but with an increasing trend. The following graphs shows the evolution of the TWAICE State of Charge spread over time. In February 2022, all inverters were balanced, which reduced the imbalances in most strings throughout the system. But especially in inverter 5, three strings (5.1.2 to 5.1.4) still showed an imbalance higher than the average, which remained constant throughout the next months and even slightly increased. The analysis can be used by operations and maintenance teams on-site when they are investigating. With this information, they know they should look directly into Strings 5.1.2 to 5.1.4 and check the balancing functionality.

The imbalances reduce the overall performance quite significantly, up to 10% in this example. Reduced performance means reduced revenue potential.

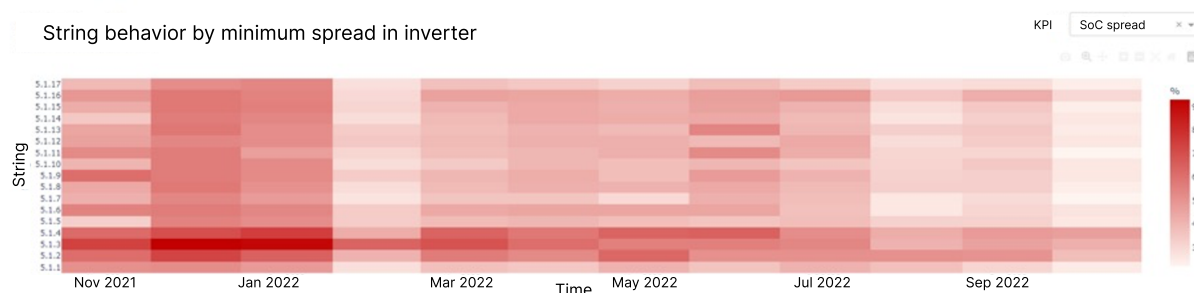


Figure 4: Example showing a trend of imbalance within a few strings

TWAICE analytics offers the ability to not only identify the limiting string but also pinpoint the individual modules responsible for String 5.1.2's to 5.1.4's diminished performance. Ultimately, single, weak cells exhibit a higher, abnormal self-discharge rate which leads to these issues.

Don't leave money on the table due to an incorrect SoC from the BMS

An additional major advantage of battery analytics is its ability to provide an SoC based on a data- and battery-model based approach that provides more accuracy than the SoC provided by the BMS. Firstly, this means that SoC imbalances can be calculated and displayed, helping asset owners and operators to pinpoint and fix imbalance issues. Secondly, it provides trust to storage system owners and operators as they can be confident that the battery will have enough charge to fulfil the performance requirements of a particular service.

Conclusion

Even minor imbalance issues can cause unnecessary downtime and revenue loss, especially if combined with other problems. The insights provided by battery analytics enable asset owners and operators to detect balancing issues, support the planning of countermeasures and identify and fix weak cells and modules before they limit performance, availability or lifetime. Pinpointing issues through analytics and addressing them proactively is vital to ensuring the financial viability of large-scale BESS assets.

Equipped with TWAICE analytics, asset owners can identify performance issues promptly. This empowers them to instruct the Operations and Maintenance (O&M) team to replace strings or modules containing weak cells and devise countermeasures to mitigate performance limitations until replacements are executed. These actions allow adjustments in system operations to minimize voltage and SoC spreads, thus safeguarding revenue.

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batteries
&
Outperform your
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About TWAICE

TWAICE provides predictive analytics software for companies working with batteries to eliminate risks and enable opportunities. Customers using TWAICE outperform their peers by saving time & costs while increasing battery performance & lifetime. Uniquely combining deep battery knowledge and artificial intelligence on a scalable analytics platform, TWAICE generates actionable insights at every step of the battery lifecycle. In addition to enabling TWAICE products, the analytics platform is a launchpad for customer and partner solutions, leveraging an entire ecosystem of market leaders. TWAICE is committed to increasing the lifetime, efficiency, safety, and sustainability of the products that power the economy of tomorrow.

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