White Paper

PowerUp

The true cost of BESS anomalies

The true value of battery analytics



2. Impacts of anomalies on uptime and safety

Introduction

Using live commercial data, PowerUp carried out a detailed analysis of battery anomalies occurring in battery assets and extrapolated this historical battery intelligence to corresponding commercial sales data. The result is a comprehensive study that not only identifies the key issues affecting BESS efficiency, but the real cost of anomalies in financial terms, a cost that can be prevented thanks to PowerUp's battery analytics platform, Battery Insight®.

Make your BESS work harder, and more profitably.
This white paper is the second in a series of three, which all analyse different battery anomalies and their impact not only on BESS efficiency but energy and revenue loss.

Anomalies relating to locked tradeable capacity.
Part one: Impacts of anomalies on useable energy

Anomalies that relate to service interruption and availability.
Part two: Impacts of anomalies on uptime and safety

Understanding the impact of these two different anomaly types over time.
Part three: The "big picture": How Battery Insight® Transforms BESS Anomaly Detection



Background

Fossil fuels represent the sword of Damocles in ecological terms – and our addiction to hydrocarbons has already done untold damage to the planet. In technological terms we have looked to nature, for alternative solutions and energies to replace these hydrocarbons that have pushed our planet, in environmental terms, to breaking point.

With these new solutions came new problems. The intermittent nature of alternative energies such as photovoltaic, wind and thermal power required new battery storage systems to stock and distribute the electricity produced from natural sources. This was an essential step. Because mother nature, fickle as she is, does not give us the opportunity to turn these energy sources on and off at will.

The consequential rise in Battery Energy Storage Systems (BESS) has spurred the emergence of battery analytics software (sometimes referred to as battery intelligence software).

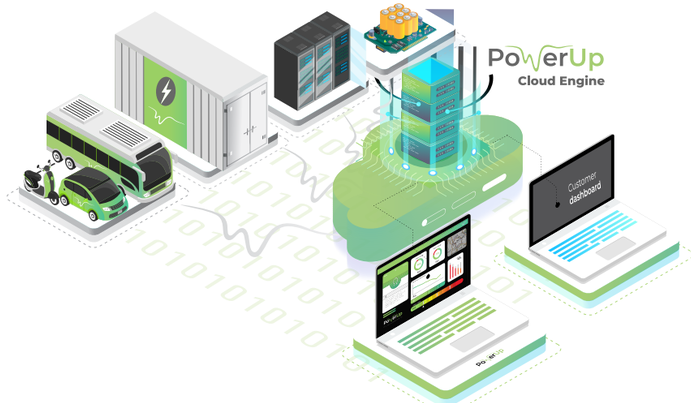
But how much financial value do Battery Analytics really add? What do they add over and above the Battery Management System?

PowerUp has prepared this white paper using case studies, based on historical (real life) data, from a variety of clients based in South America to demonstrate in factual terms how its Battery Analytics software platform, Battery Insight®, can not only identify important operational BESS anomalies, but also illustrate the commercial cost of these anomalies.

By analysing the different anomalies across different levels of the BESS, PowerUp was able to demonstrate how through precise, systematic monitoring, financial gains upwards of 9.6 % of revenues can be increased annually for battery energy storage systems.

Identifying and rectifying energy leakage with Battery Insight®. A holistic approach to BESS optimization and management.

So, by means of an analogy, if the BMS is the aircraft cockpit, the battery analytics platform can be seen as an air traffic control center enabling the monitoring of a myriad of battery key performance indicators such as SOC (State of Charge), SOH (State of Health), SOS (State of Safety) and much, much more. A vendor agnostic platform like Battery Insight® is not restricted in its scope; it can monitor vast, complex BESS infrastructure with a far greater range and accuracy, than the BMS, which is limited to analysing one individual section of the BESS. It cannot exploit the holistic, 360° birds-eye view offered by Battery Analytics platforms like Battery Insight®.



BESS, by nature are complicated systems
made up of different interconnecting components: the modules, racks, banks and containers, the system's "engine" but also important monitoring equipment such as the BMS, EMS as well as power conversion systems and thermal management (HVAC) systems. These energy storage systems have grown in scale rapidly to meet industrial demands, further complicating BESS asset managers' ability to monitor and manage them effectively.

The 360° vision awarded by PowerUp's battery analytics platform enables an ability to drill down not just deeper, but more extensively, across the different transverse levels of the system. This holistic approach: an ability to monitor from module to rack to container and even cooling systems has a profound effect on the optimisation of the BESS and subsequent revenue generation capabilities.

So, if the BESS is the "sum of its individual parts", effective battery analytics monitoring strategies can help BESS asset managers via a "marginal gains approach". By working systematically through the system, they can identify those impossible to find anomalies, the needles in this vast technological haystack, and identify tangible, actionable insights to resolve them quickly and efficiently.

The analysis illustrated in this white paper describes this strategy. It illustrates how a holistic, systematic approach to battery analytics monitoring can not only safeguard the system, but drive revenue generation and protect BESS infrastructure, optimizing investors' ROI.

Part 2: Impacts of anomalies on uptime and safety

Part two: Overview

In the second part of this paper, we will look at anomalies which lead to loss of service through rack or container shutdowns. Although safeguarding BESS security will always be, and should always be, paramount for Battery Asset Managers, the financial aspect of these anomalies on the long-term cannot be discounted. While it is clear and evident that battery assets must be shut down to avoid the risk of any eventual incident, these shutdowns come at a financial cost to the Battery Asset Manager.



Anomaly - electrical defect causes increased resistance and temperature resulting in rack shutdown

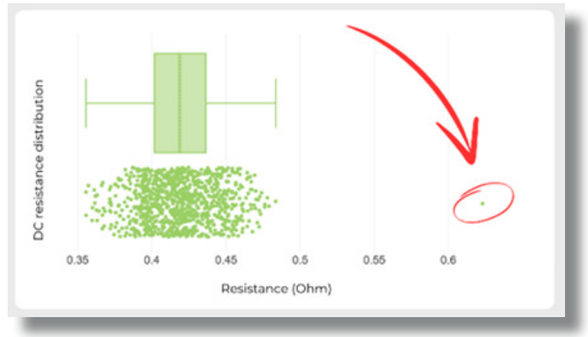
Case Study#1:
Bad connections create hotspots*

While monitoring resistance values helps identify loose electrical connections, it can sometimes uncover significantly more severe problems, as demonstrated in this case.

The majority of racks monitored by Battery Insight® indicated resistance metrics clustered tightly around the mean. However, one specific rack displayed an entirely steady but abnormally high resistance value, falling far outside the usual 3-sigma range of a normal distribution – In short: a clear outlier (Figure 1).

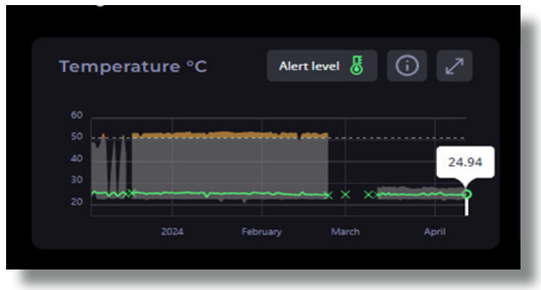
* Hotspots: space-limited metallic zones of high temperature

Figure 1: High resistance outlier



Safety alarms: Battery Insight® also flagged the same rack, as it exhibited excessively high temperature metrics, reaching over 50°C during operation (Figure 2 below).

Figure 2: Overtemperature alarm is present until the rack is shutdown at the end of February.



What lies behind these extremely high temperature and resistance values? A closer look when overlaying current and temperature metrics (Figure 3) helps to better understand the origin of these issues.

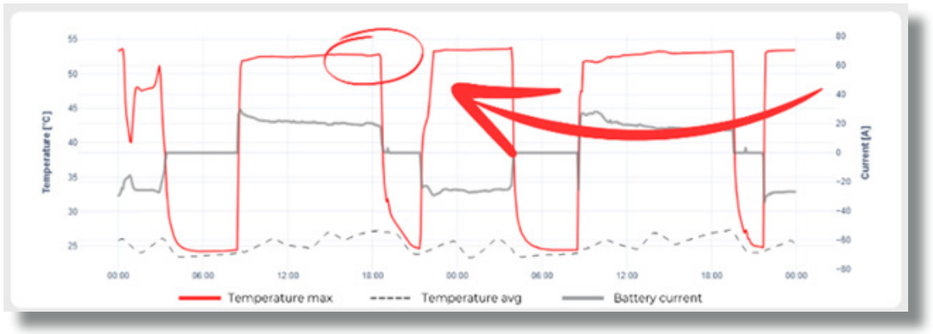


Figure 3: Data overlay of current and temperature timeseries

Zooming on a few charging/discharging cycles shows that the maximum temperature timeseries (i.e. the highest temperature measurement from all rack sensors) exhibits a jagged pattern which follows the rack's usage. When no current is applied, the maximum temperature is normal, but as soon as current is applied (whether charging or discharging), the maximum temperature abruptly deviates to 53°C.

This observation, correlated with the very high resistance value found for this rack, indicates an electrical connection fault that leads to significant overheating at one point in the rack (a local hotspot) as soon as current is applied.

This type of problem clearly falls under the kind of electrical faults responsible for intense overheating or electrical short-circuits, inducing a true risk of thermal runaway in the BESS.

Battery Insight® flagged the anomaly and PowerUp informed the site operator immediately. For safety reasons the operator made the wise decision to immediately shut down the rack to prevent a thermal runaway. The operator then requested a replacement from the supplier.

Because of this shutdown on February 24th, the rack stopped producing any energy from that date onwards. This energy output was already significantly lower than that of a nominal rack in the days leading up to the shutdown, due to its excessively high resistance. This can be observed in the period between January and April, which was selected for the loss calculation (Figure 4).

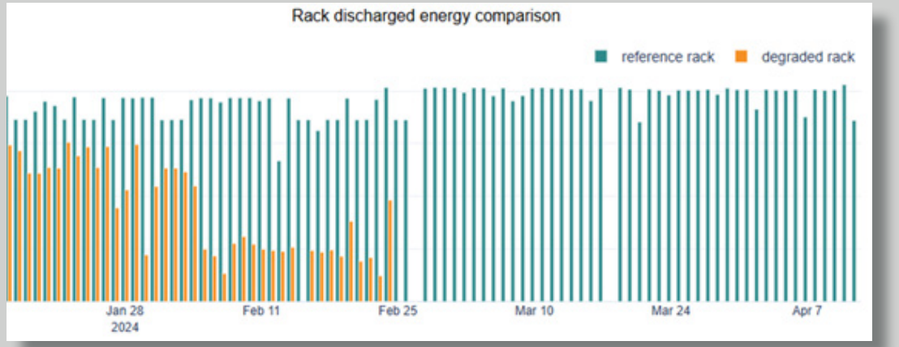
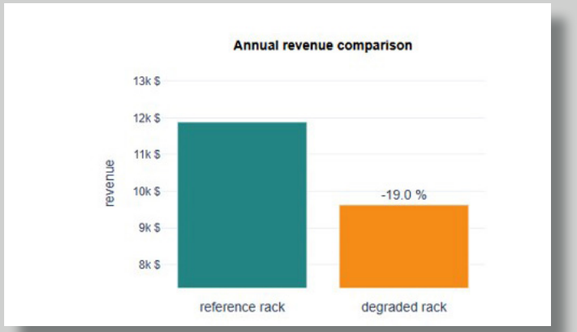


Figure 4: Comparative analysis of discharged energy for healthy and degraded racks



	period loss (value)	period loss (%)	annual loss (value)	annual loss (%)
energy	- 26 MWh	- 78.5%	- 26 MWh	- 19.1%
revenue	- 2 259 $	- 77.9%	- 2 259 $	- 19.0%

Figure 5: Comparative analysis of revenue loss (annually and by period) for healthy and degraded racks.

Over this four-month period, this rack has produced roughly 78% less energy/revenue than expected for a healthy rack.

As seen in Figure 5, the impact of this defective electrical connection represents 19% less energy/revenue per annum, when this data is extrapolated from the four-month period to the course of a year's BESS activity



The true cost of BESS anomalies

The true value of battery analytics

Anomaly - Undervoltage event leading to service interruption

Case Study#2: Rack off! Cell imbalance causes 40 day service interruption

This case highlights a critical operational issue where severe cell imbalance within battery racks led to undervoltage conditions, ultimately causing a prolonged service interruption.

During routine operations, a battery rack was fully discharged and then remained in a depleted state for several days. Due to inherent cell imbalance, certain cells within the rack reached voltages significantly lower than others. Once the voltage of any cell dropped below a predefined minimum threshold, the Battery Management System (BMS) classified the rack as non-operational. This status prevented the rack from participating in normal charge-discharge cycles like the other racks, from that event onwards.

Undervoltage (effect)

Cell imbalance (cause)



Figure 1: Significant cell imbalance leading to undervoltage flagged by Battery Insight®

Impact

- The undervoltage condition rendered the rack inactive for a period of 40 days (see Figure 1).
- During the shutdown period, the voltage of the weakest cell dropped so low that a decision was made to replace the module concerned, to avoid any risk of chemical component degradation.
- This downtime resulted in a substantial loss of revenue due to the unavailability of the rack for energy storage and delivery (See Figure 2).

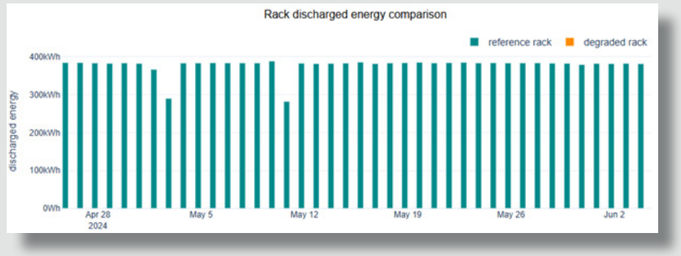
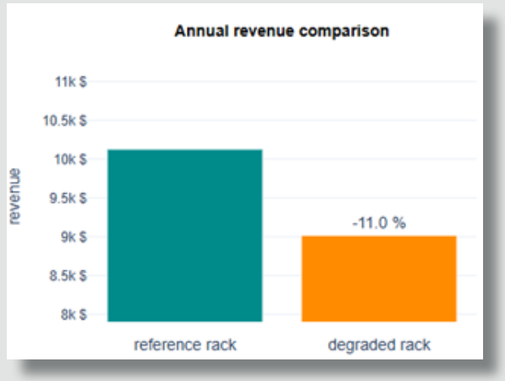


Figure 2: Energy discharged by healthy rack during the selected period of shutdown. The degraded rack has been turned off.



	period loss (value)	period loss (%)	annual loss (value)	annual loss (%)
energy	- 15 MWh	- 100.0%	- 15 MWh	- 11.0%
revenue	- 1 110 $	- 100.0%	- 1 110 $	- 11.0%

Figure 3: Comparative analysis of revenue loss (annually and by period) for healthy and degraded racks.

TAKEAWAY: Once again, we see the importance of managing cell imbalance, quickly and effectively. Failure to do so will come at a cost. In this case, the cell imbalance not only reduced the rack's operational performance but led to it being taken out of service, due to undervoltage. **The 15 MWh loss in energy (Figure 3) would cost the Battery Asset Manager 1110$, equating to an 11% annual loss in revenue for this rack.**

But this could be even more costly. Deep discharge beyond the manufacturer's cut-off voltage can potentially affect the electrochemical structure of cells leading to irreversible capacity loss.

Overdischarge may cause copper dendrite formation during subsequent charging, depending on the conditions. Copper dendrites can then create internal short circuits, posing a safety risk by potentially triggering a thermal runaway.

> **"Once again, we see the importance of managing cell imbalance, quickly and effectively.**



Anomaly - Service interruption of two months due to temperature alarm

Case Study#3
One faulty sensor. Two months lost revenue.

Service interruption may also be caused by temperature anomalies.

This is the case here, where an alarm was raised in the supervisory system used by the operators, due to a “temperature discrepancy” detection for one of the BESS racks.

This alarm appeared in the SCADA system on August 12th, and subsequently, the rack concerned was immediately shut down (Figure 1) and put on hold for investigation and repair by the supplier.

The service interruption for the rack lasted almost 2 months, until October 8th, primarily because the supplier had to return to the site from abroad.

Because the analysis was carried out after the event, PowerUp was unable to commence an investigation until some time after the start of the issue.

The investigation eventually concluded in October, that the temperature sensor of module #1 was faulty. After replacing the electronic board of this module, the rack was brought back online on October 8th.

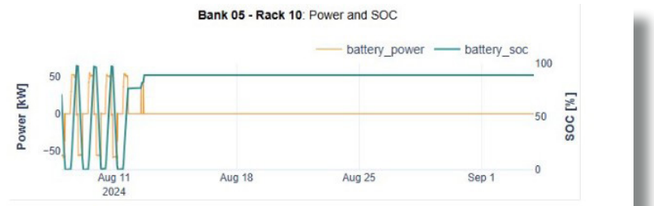


Figure 1: Illustration of rack shutdown from August 12th

Revenue opportunities missed: Be ready or pay the price...

The two-month service interruption coincided with periods of exceptionally high energy prices (Figure 2). Notably, the highest prices for energy occurred on September 1st and 2nd. During this critical period, the degraded rack was offline, unavailable to the market, and could not generate revenue (Figure 3). **This resulted in significant lost revenue for the BESS operator.**

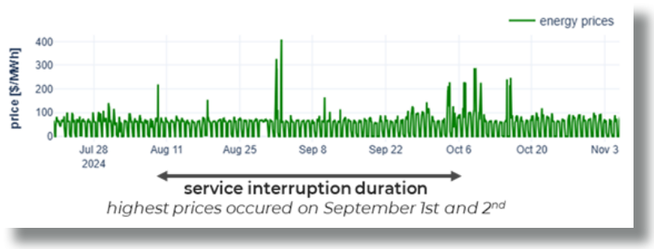


Figure 2: Energy prices during service interruption

The service interruption occurred at the very worst possible time for the Battery Asset Manager with outages coinciding with dates where energy prices were at their highest. In this case, it resulted in a 93% loss of energy during this period equating to a similar percentage in lost revenue, equating to 1637$ in real terms (see Figure 4). **The real loss, however, is the lost opportunity – with energy prices spiking from an average 100$/MWh to 400$/MWh.**

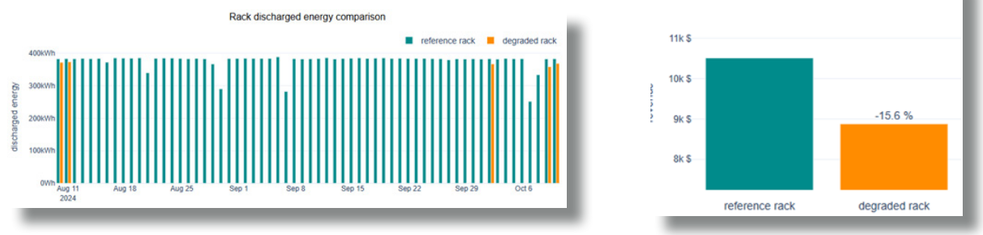


Figure 3: Comparative analysis of discharged energy (reference and degraded rack)

	period loss (value)	period loss (%)	annual loss (value)	annual loss (%)
energy	- 22 MWh	- 93.5%	- 22 MWh	- 15.6%
revenue	- 1 637 $	- 93.2%	- 1 637 $	- 15.6%

Figure 4: Comparative analysis of revenue loss (annually and by period) for healthy and degraded racks.

Identifying the needle in the haystack. How could Battery Insight® help to mitigate this case of service interruption?

By automatically analyzing the temperature spread within each rack, PowerUp’s Battery Insight® was not only able to detect from the very beginning of the dataset (see Figure 5a, July 18th) that one of the module’s temperatures was inconsistent with the others, but also pinpointed the fault by identifying that it was module #1’s temperature displaying deviant behavior.

Identifying the problem and its exact location several weeks before the SCADA alarm was triggered could very likely have enabled a solution to be identified well before the two-month service interruption. This would have saved valuable time and, more importantly, generated much more revenue if the interruption could have been shortened or even completely avoided.

Early detection of anomalies through Battery Insight® in this case is more than just best practice. It is a critical profitability imperative. Had the abnormal temperature trend been identified and addressed in mid-July, the issue could have been resolved much faster, potentially avoiding the two-month service interruption and allowing the BESS to operate during the highest price days.

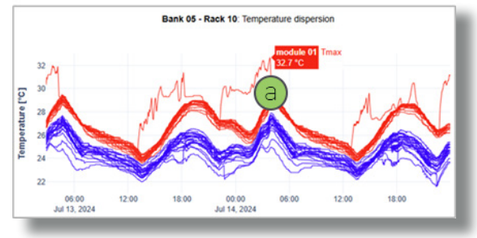


Figure 5: Faulty temperature sensor for module 01 leading to eventual shutdown”

“The service interruption occurred at the very worst possible time for the Battery Asset Manager

Case Study#4
HVAC failure and the importance of staying cool

Anomaly - Service interruption due to cooling failure

This case details a service interruption caused by a cooling failure in a container, leading to significant temperature increases and subsequent shutdowns.

As we can see in Figure 1, the thermal management system responsible for cooling the container stopped functioning abruptly on May 4th, leading to a gradual temperature increase that spanned 8 days until May 11th without triggering a shutdown of the racks.

When the temperature exceeded 55°C, all racks within the container abruptly stopped and even battery data monitoring was turned off for the following 11 days (May 12-23).



Figure 1: Battery Insight® metrics illustrating HVAC malfunction

Restarting racks that were shut down for protection and their cooling systems can take a significant amount of time. In this example, the total service interruption was 11 days, up until May 23rd, after the BMS protective shutdown.

This type of service interruption, which affects all racks in a bank (23 racks per bank) for several days, inevitably has a considerable effect on lost production (See Figure 2).

The system returned to normal operation after the 11 days of interrupted service mentioned above. This extended interruption could have been avoided if the cooling system had been restored before the service interruption eventually triggered by the BMS.

> **This extended interruption could have been avoided if the cooling system had been restored before the BMS triggered a shutdown.**



What was the financial impact of this temperature drift?

The 11-day service interruption for the bank affected by the cooling system failure induced a loss in dispatchable energy of 84 MWh (Figure 3) which represents a difference of 3% in annual revenue compared to a bank without service interruption.

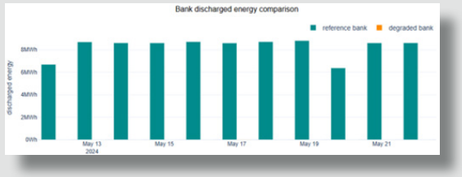
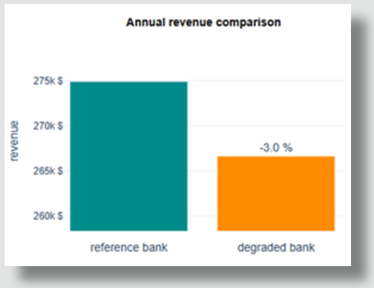


Figure 2: Energy discharged by healthy bank during the selected period of shutdown. Degraded bank has been turned off due to cooling failure.



	period loss (value)	period loss (%)	annual loss (value)	annual loss (%)
energy	- 84 MWh	- 100.0%	- 84 MWh	- 3.0%
revenue	- 8 284 $	- 100.0%	- 8 284 $	- 3.0%

Figure 3: Comparative analysis of revenue loss (annually and by period) for healthy and degraded racks.

What could the Battery Asset Manager have done to resolve this quickly?

This issue could have easily been resolved (or mitigated) if Battery Insight® monitoring had been put in place. An Orange alert was picked up by Battery Insight® at the start of the temperature drift on May 4th. This still left 8 days to react and enable the BESS battery asset management team to start implementing measures to control the temperature drift in this rack and avoid the later BMS shutdown.



Annex: The environmental & commercial context

The data used for this analysis originates from a mixture of different battery assets all located in Chile, a country that has embraced whole-heartedly the benefits of renewable energy and energy storage.

A lack of fossil fuels in the region is offset by the significant availability of alternative energy sources – namely solar and hydroelectric power. The huge progress made by Chile in establishing an alternative energy network is evident in the fact that in January 2025, solar's share reached a record 29%* of Chile's electrical output.

Chile has positioned itself as an early adopter in renewable energy, putting in place plans to develop infrastructure as early as 2008.

This policy effectively moved up several gears in 2015 with the "Roadmap to 2050" and an ambitious plan to convert 70% of its total electrical generation to renewables by 2030 and carbon neutrality by 2050. This important strategic plan, deemed by some to be the blueprint for other South American countries, was put in place to combat global warming, but also because the country lacks fossil fuels (Chile was ranked 64th worldwide in 2022 for its oil production)*.

Chile's heavy industry, located in the low-density North of the country, is particularly reliant on PV-shifting BESS energy to feed the huge energy demands of heavy industry. The ability of PV+BESS to provide rapid dispatchable power has helped significantly improve both grid stability and reliability as well as curtailment. Exceptional Chilean solar irradiance (amongst the best in the world) means a PV+BESS approach will help manage excessive energy supplies that could be damaging to the grid.

Similarly, a PV+BESS model is highly suited to energy arbitrage revenue streams enabling Battery Asset Managers to exploit commercial hot spots, where energy can be discharged to the grid during periods of high demand (and higher price).

* Source: Ember/IAE.org



Additional reading

The following articles in PowerUp's battery knowledgebase may be of interest to you:

White Papers In this series:

WP1: Impact of anomalies on useable energy

WP3: The "big picture": How Battery Insight® Transforms BESS Anomaly Detection

In Battery Knowledge

BESS Rack Imbalance: The "rotten apple effect"

Safeguarding Battery Storage: AI-Driven HVAC Anomaly Detection

Resistance: a key – yet underestimated – parameter of BESS energy efficiency