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volytica diagnostics

BESSential

Modernizing Traditional BESS Factory Acceptance Testing with Advanced Battery Diagnostics

A Sinovoltaics and volytica diagnostics white paper

by

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EXECUTIVE SUMMARY

This white paper outlines a transformative approach to quality assurance for Battery Energy Storage Systems (BESS). As the demand for reliable and efficient energy storage solutions grows, ensuring the highest standards in BESS manufacturing is critical. Traditional Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT) have served as primary methods for quality control, but they often fall short in identifying deep-seated issues that can lead to significant operational and financial losses.

BESSential, a collaboration between Sinovoltaics and volytica diagnostics, introduces a comprehensive solution that combines advanced battery diagnostics with traditional testing methods. This partnership addresses critical challenges by implementing thorough diagnostics and real-time monitoring during the FAT phase, enabling early detection of potential failures and reducing the risk of costly downtime and repairs.

Key benefits of the BESSential approach include:

Enhanced Quality Assurance: BESSential provides a rigorous end-to-end testing process, identifying issues that traditional FAT and SAT might miss. This leads to more reliable and safer energy storage systems.

Cost and Time Efficiency: By detecting defects early in the development phase, BESSential minimizes delays and costs associated with shipping faulty units. This ensures faster commissioning and maximizes the operational lifespan of the BESS.

Increased Return on Investment (ROI): With fewer operational disruptions and extended system reliability, project developers and investors can expect improved ROI. BESSential's detailed analysis and quick resolution of issues protect the project's financial health.

Sustainability and Compliance: By reducing waste and optimizing energy storage performance, BESSential contributes to a lower carbon footprint and helps meet environmental and regulatory standards.

The white paper includes a case study demonstrating the effectiveness of BESSential in a 50 MWh energy storage project in Europe, where the solution identified and resolved critical issues that traditional testing overlooked. The adoption of BESSential can significantly reduce industry-wide losses, which are projected to reach over 2 billion dollars by 2030 if current testing practices remain unchanged.

INTRODUCTION

What is BESSential?

As the energy storage industry continues to grow, the demand for reliable and efficient Battery Energy Storage Systems (BESS) has never been higher. On the other hand, competition between BESS integrators is bringing battery costs down, sometimes at the expense of comprehensive quality assurance processes.

The partnership between Sinovoltaics and volytica diagnostics addresses key challenges in this sector by providing comprehensive quality assurance through the BESSential solution. By integrating Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT) procedures with advanced battery diagnostics, we are setting a new standard for reliability and performance in energy storage projects from production to commissioning.

BESSential combines Sinovoltaics' comprehensive FAT and SAT with volytica's advanced battery diagnostics, offering an unparalleled end-to-end quality assurance solution for the energy storage industry.

This collaboration ensures

→ Early failure detection,

→ Reduced replacement time for failed BESS components,

→ Avoidance of stressful claims management processes,

→ Increased probability of SAT success,

→ Secured BESS revenue generation milestone,

→ Significantly improved reliability and performance of BESS over its entire lifecycle.

Who is Sinovoltaics?

Since 2009, Sinovoltaics has been a pioneering Dutch-German firm specializing in technical compliance and quality assurance for Battery Energy Storage (BESS) and solar photovoltaic (PV) systems. Experienced in technical compliance and quality assurance for BESS and solar photovoltaic systems, we have established ourselves as a trusted partner in the industry.

Our innovative BESSential and SELMA solutions and with our Zero Risk Solar & BESS® guarantee aim to eliminate product defects, minimizing investment risks. We offer comprehensive services, including quality assurance inspections, factory audits, ESG reports, and traceability audits for utility BESS developers and investors. With a global presence and strategically located inspection teams, Sinovoltaics ensures the success and reliability of large-scale BESS and PV projects, striving to maintain high performance and traceability of 20GWh BESS and 100GW solar projects by 2030.

At Sinovoltaics, our work isn't complete until every piece of your equipment is rigorously quality tested.

Who is volytica?

volytica diagnostics, based in Dresden, Germany, is a pioneer in battery diagnostics.

As an independent software provider, we offer battery monitoring solutions that empower our customers to make informed decisions for the safe, sustainable, and efficient use of any battery, from e-mobility to renewable energy storage.

Our vision is "every battery must be used to its true potential".

Using advanced analytics and algorithms from daily field data, our software provides insights into battery degradation, health status, anomalies, and safety risks.

Additionally, our new **vdx sentry** focuses on relevant battery notifications and consolidates information, alerts, and health metrics into three essential risk categories: safety, performance, and lifetime. This first-level service provides diagnostics and actionable recommendations for maintenance and operations teams.

The volytica software solution for continuous battery monitoring integrates seamlessly into any SCADA system, thanks to its interoperability, compatibility with third-party platforms, ease of installation, and scalable architecture.

For Pre-COD we provide advanced battery diagnostics with 100% test coverage on cell, rack, module, or container level, ensuring optimal functionality and safety of battery systems during both FAT and SAT phases.

Confidentiality Note

This white paper contains information regarding a project where certain details have been intentionally modified for confidentiality purposes. Additionally, images and visuals included may originate from other projects and are used solely for illustrative purposes.

LIST OF ACRONYMS

As	Ampere-second
AQL	Acceptance Quality Limits
BESS	Battery Energy Storage System
BMS	Battery Management System
BOM	Bill of Materials
BU	Battery Unit
CDF	Constructional Data Form
DC	Direct Current
FAT	Factory Acceptance Testing
FCE	Full Cycle Equivalent
GW/GWh	Gigawatt / Gigawatt hour
Hz	Hertz
I	Current
ID	Identification
IE	Independent Engineering
MW/MWh	Megawatt / Megawatt hour
OCV	Open circuit voltage
O&M	Original Equipment Manufacturer
OEM	Operations and Maintenance
Pre-COD	Pre – Commercial Operations Date
QA/QC	Quality Assurance and Quality Control
ROI	Return on Investment
RTE	Round Trip Efficiency
s	Seconds
SAT	Site Acceptance Testing
SCADA	Supervisory Control And Data Acquisition
SoC	State of Charge
SoH	State of Health
UTC	Coordinated Universal Time
V	Volt

BESS QUALITY CONTROL TODAY

FAT vs SAT vs Site Monitoring

Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT) are the most popular steps in ensuring the reliability and performance of your BESS, but not the only ones. Let's have an overview:

Factory Audit – Qualifying Suppliers

BESS Factory Audit (Source: Sinovoltaics)

A Pre-Production Factory Audit ensures your Battery Energy Storage System (BESS) is built to high standards from the start. This audit thoroughly examines the manufacturer's facilities and processes before production begins, identifying potential issues early and resolving these before the production of the BESS. By confirming the manufacturer's capabilities, you reduce the risk of defects or delays later on. This audit sets a solid foundation for a reliable BESS, giving you confidence in the production process.

BESS FAT – Factory Acceptance Testing Before Shipment

BESS Factory Acceptance Testing (FAT) Electrical Test (Source: Sinovoltaics)

FAT is the first line of defense against potential issues. Conducted at the manufacturer's facility, it ensures that the BESS meets all design specifications before it leaves the factory. By catching defects or performance issues early, FAT helps prevent costly delays and fixes at the installation site before shipping the BESS. This testing phase verifies that each component works as intended, providing peace of mind that your BESS is built to perform reliably.

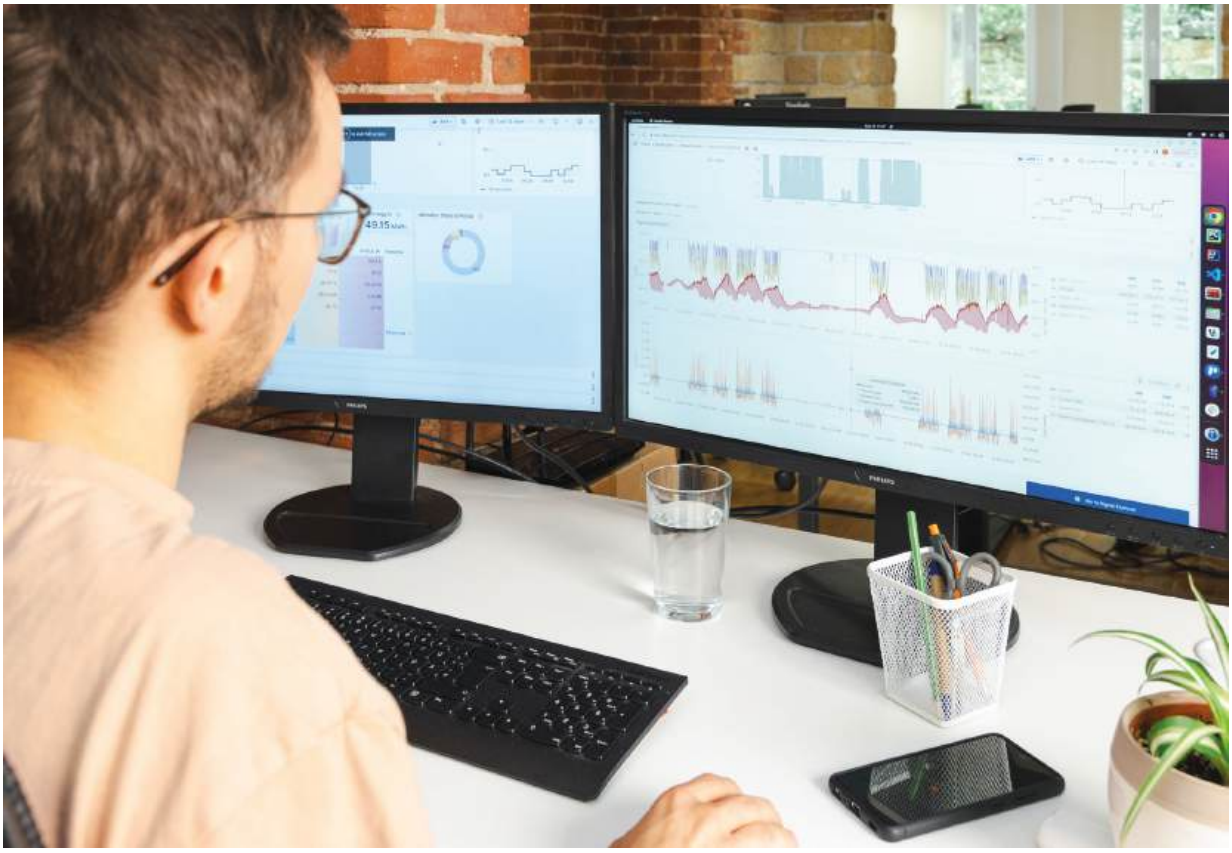
BESS SAT – Site Acceptance Testing During Commissioning

Commissioning team at the site of a battery energy storage system

SAT, on the other hand, takes place after the BESS is installed at its final location. It ensures that the system functions correctly within the specific conditions of your site. SAT helps to identify any problems that may have arisen during transportation or installation, as well as how the system interacts with other site infrastructure. By performing SAT, you confirm that the BESS not only works but works optimally in its real-world environment.

Together, traditional FAT and SAT provide a comprehensive testing strategy that ensures your BESS is ready for reliable, long-term operation, minimizing risks and safeguarding your investment.

Battery Monitoring for Operations and Safety of BESS



Insight for Battery Monitoring on our vdx dashboard (source: volytica)

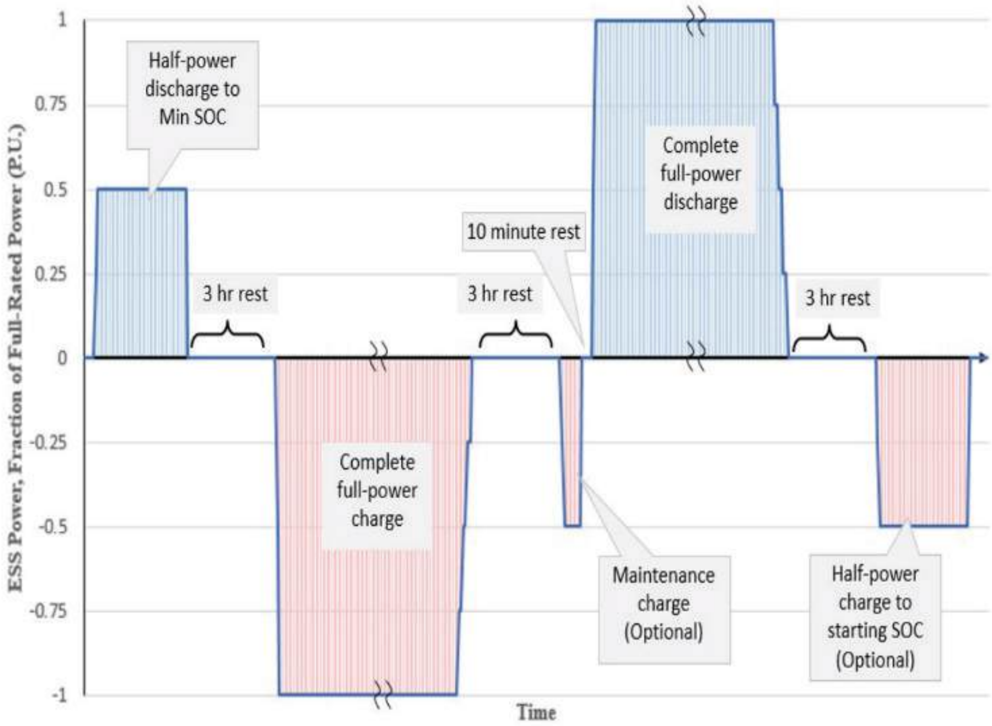
Continuous Battery Monitoring is crucial for maintaining the performance, lifetime and safety of your BESS during usage. By continuously tracking the BESS's operation, you can detect and address potential issues early, such as performance deviations or safety problems that can lead to personal injuries or environmental impacts. Active monitoring helps keep the system running efficiently and extends its lifespan, ensuring your BESS remains a reliable and profitable energy storage solution over time.

BESS manufacturer shortcuts

Traditional BESS Factory Acceptance Testing has several critical oversights that can lead to higher risks for the project developer, owner, and to a delay in site commissioning:

1. **No FAT Performed:** If your manufacturer skips the Factory Acceptance Testing (FAT), it's a clear indication that it's not prioritizing quality. Without a FAT, your project will be vulnerable to undetected issues that could compromise the entire project and its expected revenue.

2. **No Performance Testing:** Skipping performance testing may lead to risks that complicate site commissioning. Without performance testing, you're left in the dark about whether any issues stem from site integration, transportation, or inherent manufacturing defects. The absence of performance testing could lead to significant challenges after full deployment.



Operation Performance Test Charging & Discharging Profile (Source: EPRI[1])

3. **Sampling FAT:** Traditional FAT uses the sampling methodology that conducts the FAT on only a few select units rather than each container. Sampling is a dangerous shortcut when it is now possible to efficiently test each container. Given the highly manual nature of BESS manufacturing, the sampling approach increases the risk of overlooking critical flaws. Every unit should undergo rigorous testing to ensure consistency and reliability. As an example, Sinovoltaics finds that the fire suppression system is not working in at least 1 container in 25% of the projects we inspect. Performing sampling would have never allowed us to find such manufacturing defects.

SAMPLE SIZE COMPARISON			
LOT SIZE	General Inspection Levels		
	I	II	III
2 to 8	2	2	3
9 to 15	2	3	5
16 to 25	3	5	8
26 to 50	5	8	13
51 to 90	5	13	20
91 to 150	8	20	32
151 to 280	13	32	50
281 to 500	20	50	80

Sample Size according to ISO 2859 (Source: Sinovoltaics[2])

4. **Limited Testing:** When testing is limited to just 10%, 25%, or 50% of the BESS's maximum performance, the performance tests results are skewed. This reduction in testing scope prolongs the process and prevents the system from being adequately stressed. By not testing the BESS under full load, manufacturers make it easier for the system to pass without truly proving its capability to handle real-world demands.

In short, a comprehensive FAT includes:

- Testing all BESS containers
- A detailed performance test, performed at full specifications
- A detailed report from your BESS manufacturer. Reports that only list PASS/FAIL results are not acceptable.

We've now discussed the essential traditional methods for FATs and SATs, but there is still an even higher level that we call "BESSential."

BESSential EXPLAINED

Case Study: 50 MWh Energy Storage Project in Europe

The BESSential solution was implemented for a 50 MWh energy storage project in Europe, where our combined efforts ensured the highest standards of quality and reliability from factory to field.

After **reviewing and improving the FAT process** with the BESS integrator and the client, we first performed a comprehensive FAT at the OEM factory on each of the 23 containers of the client's 50 MWh BESS project. Because the BESS manufacturing process requires skilled manual labor, it is important to thoroughly test each container. Our BESSential enhanced FAT inspection revealed several defects, which included a design issue with the air duct.

Traditional FAT

As with any traditional FAT, our inspector started by inspecting:

Visual Inspection performed during a FAT (Source: Sinovoltaics[3])

→ **Visual Inspection of key components: container, battery rack,...**

Example of Electrical Measurements done during a FAT (Source: Sinovoltaics[4])

→ **Electrical Testing: Verifying electrical parameters and safety.**

Data Collection BESS FAT Performance Test (Source: Sinovoltaics[5])

→ **Performance Testing: At least one full charge and discharge cycle is necessary. Performance Testing is also called a Dynamic Load Test.**

Example of Fire Suppression System Testing Performed During a FAT (Source: Sinovoltaics)

→ **Safety Testing: Confirming that systems operate safely under various conditions.**

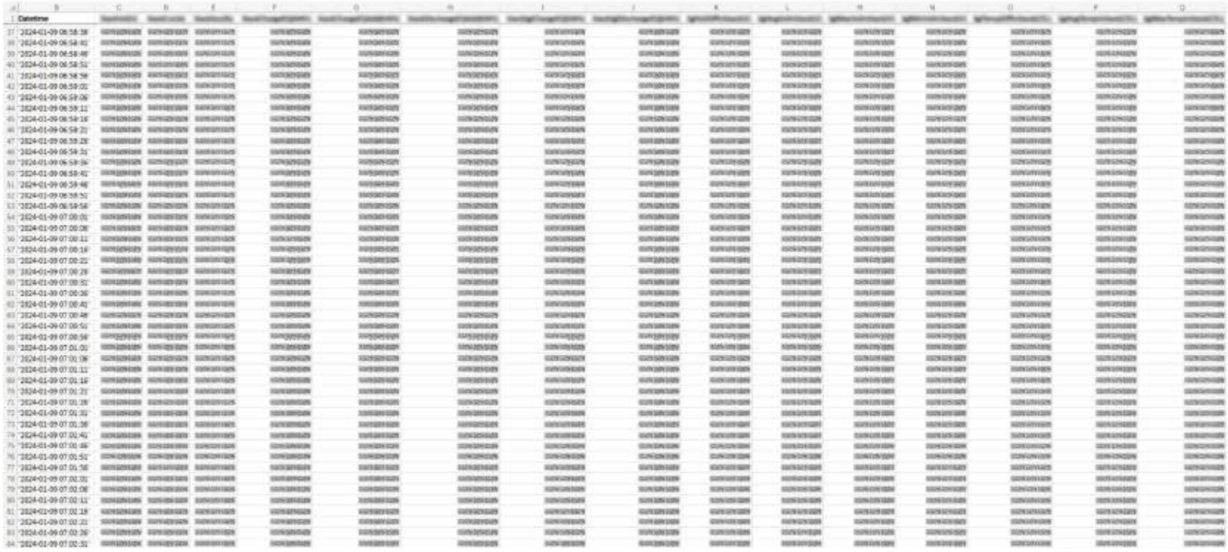
The BESSential FAT

A traditional BESS FAT typically concludes with a detailed report illustrating what Sinovoltaics found regarding the sections listed above. With the implementation of our BESSential FAT, the next step was to monitor the performance testing of each container and collect raw data for each of the 23 containers.

From PASS/FAIL criteria defined at the container level, the containers appeared to be within the manufacturer's specifications for Round Trip Efficiency, minimum capacity, and other standard testing parameters.

As soon as we collected each container's data, we worked with volytica to establish a smooth and fast analysis, ensuring that our analysis would not impact the containers' shipment date. **This critical step takes only two days or less to receive the full data analysis of the containers from volytica**.

As the data template has been already communicated by the manufacturer before the start of the manufacturing, the BESSential diagnostic software was ready to start the analysis. **Prior to the start of the first FAT test, BESSential's diagnostic software is established with the support of the factory and guaranteed to be completed within 3 weeks, but normally takes less time**.



Raw data extract from one container performance test (Source: Sinovoltaics)

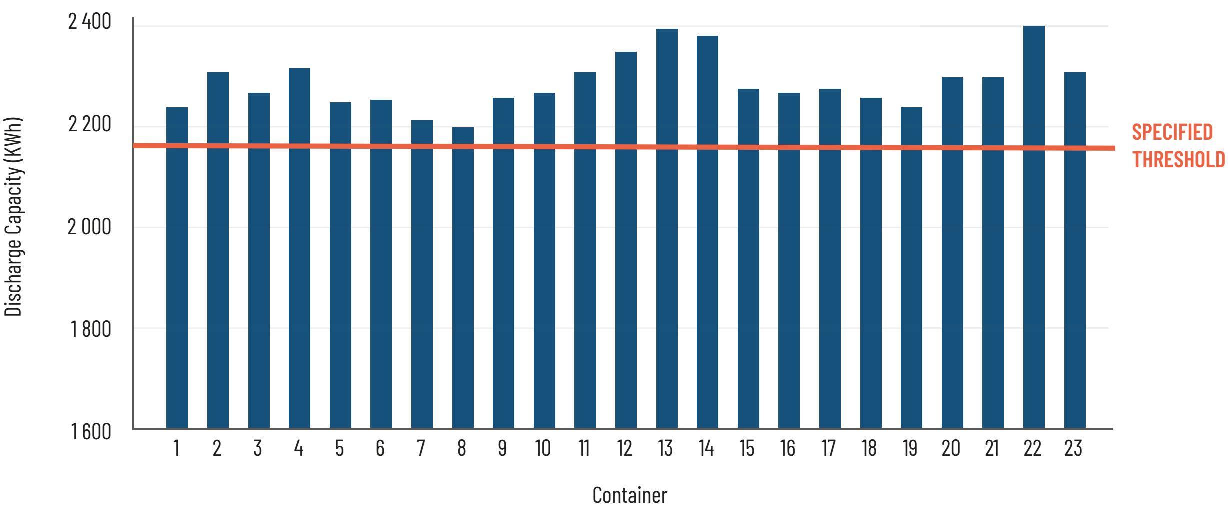
As mentioned above, the standard test parameters of the plant were aligned with the manufacturer's specifications. With a traditional FAT, the containers would have received a PASS grade. **However, the BESSential diagnostic analysis revealed interesting facts about the system and a serious defect that needed to be addressed**.

Specifically, we found:

→ **Higher capacity and Round-Trip efficiency**

All containers had higher capacity and Round-Trip Efficiency than nominally specified, which was a positive outcome. The extra capacity could be utilized once the system is properly balanced. **The figure below shows that the discharge capacity for all containers exceeded the nominal value of 2180 kWh (red line).**

DISCHARGE CAPACITY OF CONTAINERS VS. GUARANTEED CAPACITY (2180 KWH)

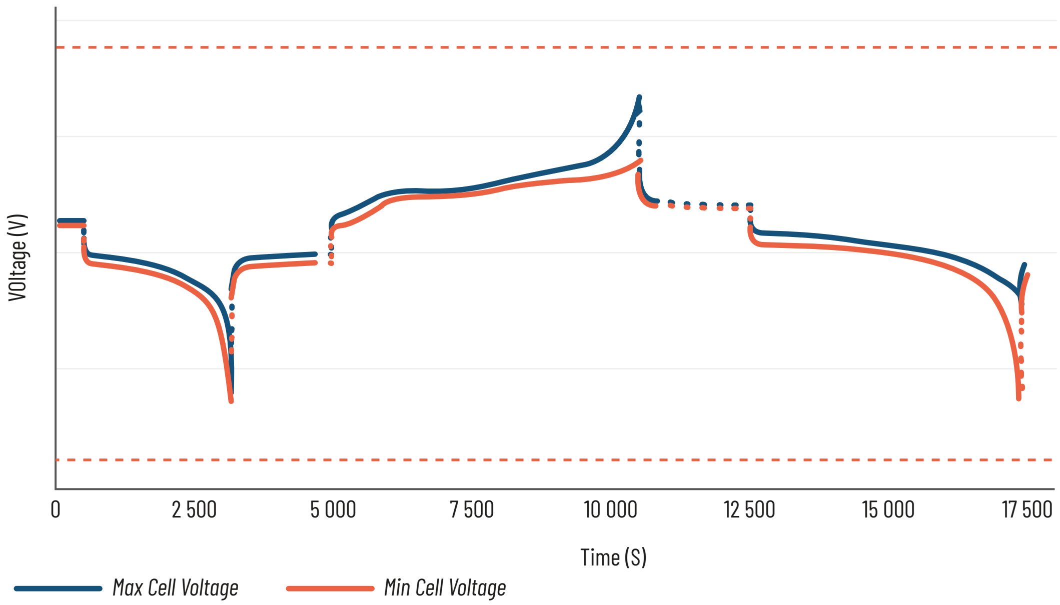


Discharge capacity of containers from 50 MWh system case study (source: volytica)

→ Noticeable voltage variations between cells

In addition, all the containers had noticeable voltage variations between cells. The first cell to reach its voltage limit caused the BMS to stop further operation. Most of the remaining cells still had around 20 minutes of available charge or discharge time. **This led to a portion of the capacity being 'trapped' and left unused, reducing potential profit**. These findings were within specification thresholds and not critical, but they indicated possible variations in even brand-new systems and the importance of data-driven assessment.

MINIMUM AND MAXIMUM CELL VOLTAGE OF A CONTAINER

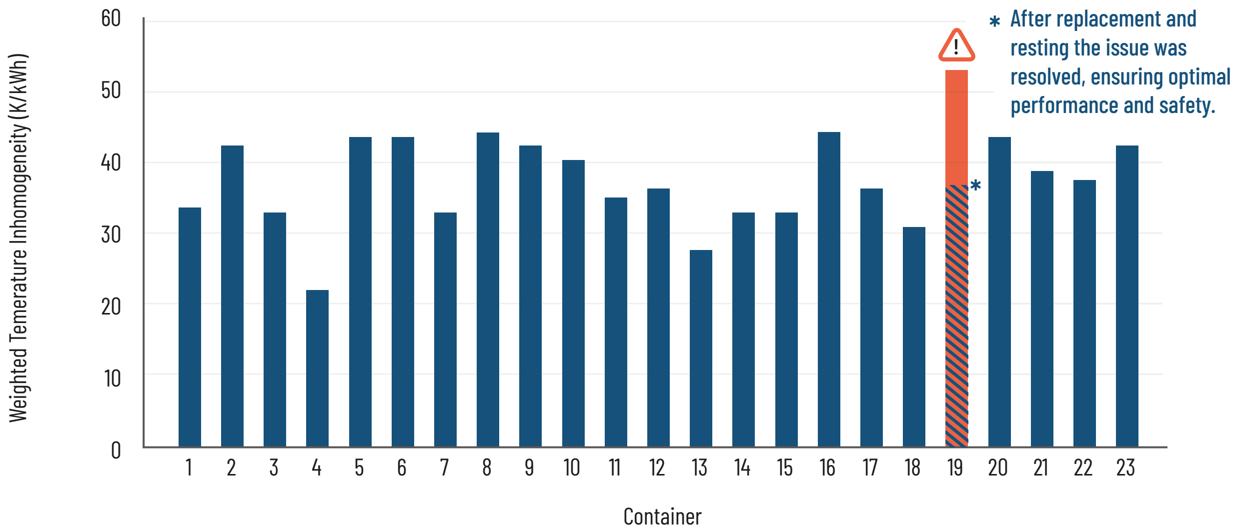


Minimum and Maximum Cell Voltage of a container (Source: volytica)

→ Temperature inhomogeneity

The figure below shows exemplary FAT results where a significant temperature inhomogeneity in BESS container unit No. 19 was identified. The maximum temperature difference with respect to the consumed energy during the FAT exceeded a threshold. At the same time, **this battery unit showed outstanding higher temperature inhomogeneity (+25%)** than its peers subjected to the same testing procedure. This higher temperature reading indicates that the battery unit has either problems with its thermal management (e.g. HVAC issues lead to inhomogeneous cooling) or has at least one defective or damaged cell (e.g. cabling issues lead to locally increased heat generation).

THERMAL CHARACTERISTICS TEMPERATURE DISTRIBUTION IN BATTERY UNITS OF A 50 MWh BESS



Temperature distribution of containers from 50 MWh system case study (source: volytica)

These problems found in this 23-container BESS evaluation posed a performance or safety risk that would prohibit proper system commissioning. Without addressing these issues, the long term performance would be have been severely impacted, as the difference in temperature would lead to inhomogeneous aging.

The cells that exhibited temperatures as high as 45°C would likely degrade up to four times faster than the ones operated at 25°C. As these cells were connected in one battery unit, **the weakest cell would have limited the overall performance**.

Sinovoltaics' BESS inspectors were immediately notified and worked with the BESS manufacturer to find the root cause of this thermal imbalance. **Our investigation concluded that one battery pack was showing an overheating behavior**.

The defective pack was replaced immediately by another battery pack that had already been preliminary tested.

A second run of the BESSential service ensured that the thermal inhomogeneity and **subsequent overheating of parts of the module were resolved**, ensuring optimal performance and safety.

Our 23 Container/50 MWh Case Study Findings

As demonstrated by this 50 MWh energy storage project in Europe, BESSential's combined approach:

→ **Analyzed 23 containers** during FAT, ensuring compliance with specified discharge capacity and round-trip efficiency.

→ **Identified and resolved** thermal anomalies and voltage imbalances, enhancing overall system reliability.

→ **Prevented potential failures** due to faulty battery pack, improving the longevity and performance of the energy storage system.

Financial and Operational Benefits of a BESSential FAT

BESSential offers numerous financial and operational advantages to BESS asset owners.

Comprehensive Quality Assurance by Sinovoltaics:

BESSential Factory Acceptance Testing (FAT) provides state-of-the-art quality control of your BESS. It includes:

- → **Visual Inspection:** Ensuring every component is free from defects and assembled correctly.
- → **Electrical Testing:** Verifying electrical parameters and safety.
- → **Mechanical Testing:** Checking the physical integrity and durability of the system.
- → **Performance Testing:** Assessing overall efficiency and functionality.
- → **Safety Testing:** Confirming that systems operate safely under various conditions.
- → **100% Battery Pack analysis:** ensuring deep analysis of each battery unit.

Saving Money and Time:

By resolving issues at the source, we eliminate the significant costs associated with shipping defective units, as well as the inconvenience of negotiating a warranty claim and replacement of defective components with BESS manufacturers. Container shipping **from Asia to Europe or North America** can take several weeks, delaying project timelines and increasing costs. Early detection and resolution mean systems can be operational from day one, avoiding delays and enabling immediate revenue generation through energy sales and trading. In addition, by ensuring the highest performance of each battery pack, we ensure the highest possible BESS performance throughout its lifecycle.

Operational Readiness:

Ensuring that systems are fully functional and compliant with specifications before they leave the factory and during on-site commissioning means that they are ready for operation as soon as the SAT is completed. Performing BESSential during FAT can also help shorten the SAT lead-time. This maximizes uptime and ensures the fastest investment returns.

Sustainability Impact - Avoiding Waste and decreasing CO_2-footprint:

Early defect detection through BESSential significantly reduces waste and the carbon footprint associated with faulty systems.

Testing battery modules, racks, or containers in the factory (e.g., in Europe, North America or Asia) ensures that any defects are identified and rectified before shipping. BESSential can prevent costly and time-consuming returns and replacements once the containers are shipped from Asia, for example, to the customer.

BESSential impact on Project's Return on Investment

Financial Impact at the Project Level

How much time and money can be saved with BESSential services?

Here is our calculation:

We considered a project size of 50 MW/100 MWh, made of 25 containers, each with a capacity of 4 MWh.

Each container contains 120 battery packs, with every pack capable of storing 33.3 kWh of energy.

For this example, the following is a classic scenario for discovering and fixing the issues:

1. A battery pack with predictable overheating potential was not detected during the FAT or the SAT due to limited capabilities (in other words: not using BESSential service)
2. This defective battery pack degraded faster during 5 years of operation.
3. After 5 years, an alarm rings, and the associated BESS is down due to the overheating.
4. Because the O&M team doesn't know what is happening, the whole site is put on hold for several days until they figure out what is wrong with the BESS. We considered that the project is typically down for 15 days.
5. The issue is finally isolated to only one container. The other containers can start operating again.
6. However, many conversations are happening between the BESS integrator and the manufacturer, who are trying to understand the root cause in order to claim that the issue is under warranty.
7. Finally, the supplier agrees to replace the defective components. It took 100 days.
8. A new site commissioning happens with the new components
9. The BESS starts operating again.

Regarding BESS revenue per MW, we used the average value of Gore Street portfolio, one the biggest BESS asset owner in the world, with BESS portfolio in multiple markets (Great Britain, Germany, United States...). It's a reasonable proxy for Western markets:

Market	FY 2024 $ per MW/year	FY 2023 $ per MW/year
Great Britain	$ 96 250	$ 172 500
Ireland	$ 227 500	$ 163 750
Germany	$ 100 000	$ 187 500
Texas	$ 250 000	$ 160 000
Portfolio weighted average	*$ 166 250*	*$ 168 250*

Gore Street Portfolio average BESS revenue per MW (Source: Gore Street[6])

From the above scenario, here are the financial losses we calculated for the project owner:

Losses from accelerated degradation of the defective battery pack for 5 years

Section	Parameter	Value	Unit	Source
From accelerated degradation during 5 years *(this is applied to only one container)*	Accelerated aging of module due to temperature	3	%	Arrhenius equation
	Number of years until issue is found	5	years	Authors' decision
	Number of cycles per year	329	cycles	90% availability
	Total number of cycles for 5 years	1 645	cycles	
	Loss energy discharge per cycle for one container	0,12	MWh	
	Average BESS revenue / MW per year	166 250	USD/MW	Gore Street
	Revenue loss per year due to overtemperature	9 975	USD	
	Project revenue loss for due to overtemperature	**49 875**	**USD**	

Losses from accelerated degradation - hypothesis and calculation

In our example, the cost of the overheating would have generated missed revenues of around $50,000 in 5 years.

Losses from unscheduled downtime

Section	Parameter	Value	Unit	Source
From unplanned BESS downtime *(this is applied to the whole project)*	Downtime for the whole project to check for safety issue	15	days	Authors' experience
	Average BESS revenue/MW per year	166 250	USD/MW	Gore Street
	Average BESS revenue/MW per day	455	USD/MW	
	Revenue loss on energy market during downtime	341 610	USD	
	Third party IE company costs per day per downtime	1 500	USD	Interviews
	Total third party IE or QA company costs per day per downtime	22 500	USD	
	Total money loss during project downtime	**364 110**	**USD**	

Losses from unscheduled downtime - hypothesis and calculation

In this example, the sudden downtime of the BESS, leading to stopping the site for a few days to understand the cause of the thermal alarm, costs the asset manager approximately $364,000.

Losses from claim management process with the BESS manufacturer

Section	Parameter	Value	Unit	Source
From claim management with the BESS integrator *(this is applied to only one container)*	Claim management duration	100	days	Authors' experience
	IE cost per day for claim management	250	USD	
	Total IE cost per day for claim management	25 000	USD	
	Manufacturing + Transportation (1 way)	45	days	Authors' experience
	New component installation + SAT	15	days	Authors' experience
	Third party IE costs per day for new SAT	1 500	USD	Interviews
	Total Third party IE costs for new SAT	22 500	USD	
	Total time loss on full claim management cycle	160	days	
	Average BESS revnenue/MW per day	455	USD/MW	Interviews
	Revenue loss per day	911	USD	
	Revenue loss due to claim management cycle	145 753	USD	
	Total money loss for the whole claim management process	**193 253**	**USD**	

Losses from claim management process - hypothesis and calculation

Now that the issue is identified and limited to one container, a long claim management process is started to get new battery modules. This process will add approximately $193,000 in additional losses.

Total losses for our container overheating issue

From accelerated degradation during 5 years	$ 49 875
From unplanned BESS downtime	$ 364 110
From claim management with the BESS integrator	$ 193 253
TOTAL LOSSES	**$ 607 238**

Total losses from the defective battery pack

Overall, the whole process will cost more than $600,000 in losses to the BESS asset owner.

Other non-financial losses to be considered:

In addition to the financial losses, other non-monetary costs will have a huge impact on the project success:

- → 175 days between downtime and claim management processes
- → Time wasted on numerous international emails that are rarely read immediately.
- → Unhappy asset owner and O&M management team

If BESSential had been used directly at the factory, it would have paid for itself several times in financial costs and would have prevented many frustrating issues for every stakeholder in that project.

Quality defect as a share of battery cost

Another way to look at losses is through calculating as a share of the batteries' costs.

In 2024, the cost of battery enclosures (i.e. battery rack together within enclosures plus cooling, fire detection and suppression systems) was estimated at $130/kWh[7] by Clean Horizon. For a 100 MWh project, this amount is around $13 million. Consequently, **our $607,000 case study loss corresponds to around 5% of the project's total battery cost**, which will likely jeopardize the entire project's Return on Investment.

Potential criticism of our estimated financial losses

There are a few limitations and global variables in the above calculations. The losses could have been much higher, but we calculated them for an average scenario. The above limitations include:

- BESS revenue per MW is a complicated value to calculate, and is relying heavily on the electricity market and often seasonality. See this article[8] for a simple explanation. **Had the BESS outage occurred during a period of high market prices, losses could have been 100 times higher**. On the other hand, if the downtime had happened during a period of low arbitrage, the losses could have been lower than in our example.
- To balance this, we considered that 100% of component replacement and transportation falls under the supplier warranty. Unfortunately, this is not always the case.
- Our defect is a major one, but not a critical one, and it is still localized to one battery pack. However, because most asset owners use the traditional sampling method rather than checking every container, an issue could have happened to an entire BESS, or even several BESS during a few years, jeopardizing the whole project ROI in a few weeks.
- Obviously, all lead-times used (SAT, downtime, claim management, transportation) are all project specific and are highly volatile. We did our best to have a real-life scenario based on our experiences. To be clear, **this example did not use the worst-case scenarios** we have experienced in our careers. Catastrophic failures happen, but they are not typical, so we did not use one as an example.
- Service fees vary and will depend on the end market.

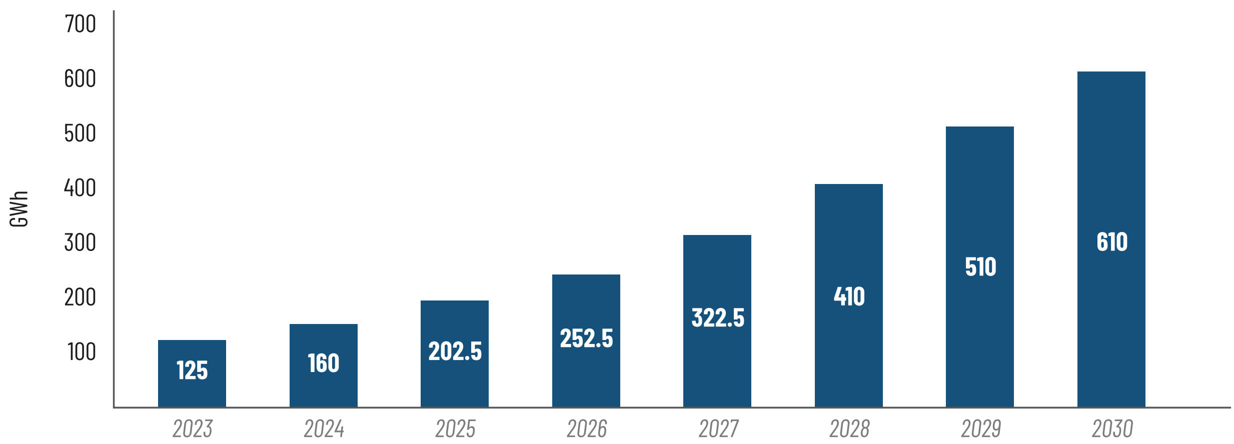
Financial Impact at the Industry Level

While traditional FAT and SAT have certainly protected BESS customers, our findings have broader implications for existing and future BESS projects.

If we extrapolate our example based on all global BESS deployments, the culminative financial cost of traditional BESS quality control protocols have already cost developers and investors billions of dollars.

To calculate the impact, we first need to estimate the number of BESS that have already been deployed. Our BESS deployments estimates are based on this August 2023 McKinsey study of current and future BESS projects:

BESS DEPLOYMENTS ACROSS THE WORLD *(source: McKinsey[8])*



In 2023 and 2024, the BESS deployments have been as follows:

Year	2023	2024
Utility-scale BESS deployed	125 GWh	160 GWh

Estimating an average BESS container size of 3 MWh for those 2 years, we can estimate that a total of 70,000 BESS containers will be deployed within those two years.

Based on volytica diagnostics and Sinovoltaics inspection data, it can be assumed that around 1% of BESS deployed globally are subject to experience on-site issues. As a result, **700 defective BESS containers are projected to be deployed worldwide in 2023 and 2024.**

Based on the average loss estimation from our 100 MWh project case, **the total BESS losses for the projects deployed over the two-year period will total $421 million.**

Even worse, anticipating McKinsey's estimates of BESS deployments until 2030, we can estimate the following GWh of deployments:

Year	2025	2026	2027	2028	2029	2030
Utility-scale BESS deployed	202.5 GWh	252.5 GWh	322.5 GWh	410 GWh	510 GWh	610 GWh

As the average size of BESS containers will continue to grow, we have assumed a container size of 6 MWh for this part of the study.

Using the same assumptions from our 100 MWh project case study, the total estimated BESS losses for projects deployed from 2025 to 2030 could reach almost $2 billion.

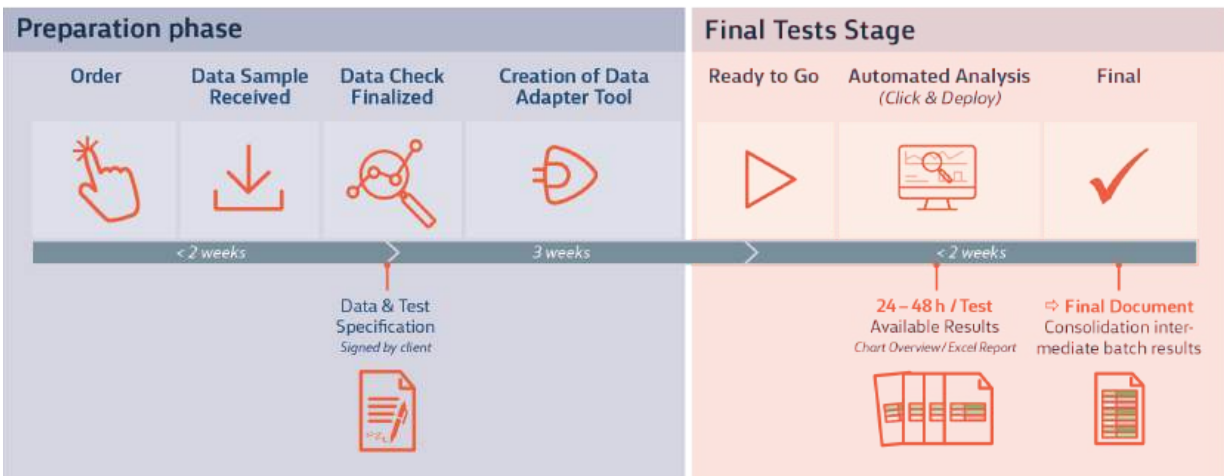
Overall, if we consider all projects deployed between 2023 and 2030, we project that the impact of defective BESS containers will amount to almost $2.3 billion of preventable losses.

This staggering figure highlights the critical importance of addressing defects. While the exact numbers require scrutiny, we firmly believe that **the cost of BESS container defects in the field represents a billion-dollar loss to project owners across the industry**.

HOW DOES BESSential WORK?

In this section, we will review the timeline for our BESSential process:

1. Order Placement:	Customer initiates the diagnostic assessment by placing an order.
2. Data Quality Assessment (Data Check):	Customer provides existing battery load test data (CSV, TXT format) and BESS specifications. This is done before a few weeks before the start of the FAT. Our team reviews the data and tailors a customized evaluation plan.
3. Creation of Data Adapter Tool	Based on the results of the data check and on the agreed test specifications our team is creating a so called data adapter tool top make sure that it's simply a click to run our analysis software and to make sure that everything is in place and works as expected whenever testing will start.
4. Automated Analysis	The diagnostic analysis is performed using automated algorithms on a scalable cloud platform. This is an internal process – no additional physical tests are conducted.
5. Final Report	A comprehensive report is delivered with key findings and actionable recommendations.



Prerequisite: Defining the Optimal Battery Unit of BESS in FAT

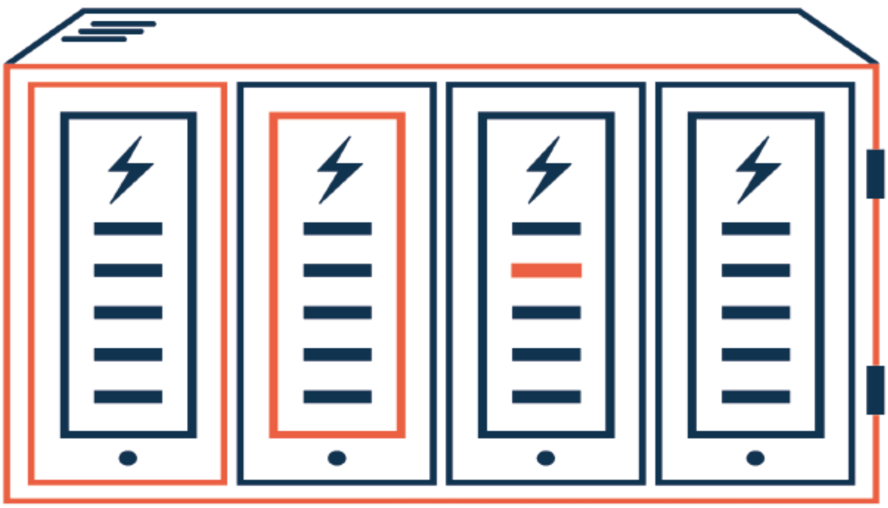
In the dynamic and rapidly evolving field of Battery Energy Storage Systems (BESS), terminology surrounding key components is as varied as the technologies themselves.

Terms like *cell*, *module*, *rack*, *pack*, *container*, and *cube* are often used interchangeably, depending on the system's configuration and the specific context. This lack of standardization can lead to confusion, especially when it comes to system design, diagnostics, and performance analytics.

To streamline communication, we propose adopting the term **battery unit** as a universal descriptor, serving as a consistent reference point regardless of OEM-specific terminology.

- → **Unit Definition:** A "Unit" refers to the device being analyzed, typically at the rack level or similar granularity.
- → **Optimal size:** A battery unit size of 10-200 kWh provides reasonable and reliable results while balancing cost effectiveness.
- → **Recommended size:** For the highest precision and maximum diagnostic value, we recommend a unit size of 10-50 kWh, typically referred to as "modules or pack".

Battery Units



Different meanings for Battery Unit (source: volytica)

Lack of standardization for terms such as cell, module, rack, pack, container, and cube can lead to confusion. We use the term battery unit.

Data Quality Assessment

First and foremost, we need to set up the BESS and battery unit data in our algorithms. We call this the "Data Quality Assessment".

To ensure optimal performance of the BESSential analysis, we will require the following information to set up the analysis:

- Battery Unit datasheets (including topology, capacity, voltage, temperature, and current limits).
- Cell datasheets (including Open circuit voltage (OCV) curve, capacity, voltage, temperature, and current limits).
- Specified minimum capacity, efficiency, and other relevant/warranted parameters.

Crucially, **no additional tests or time are needed**, as we leverage data from existing battery performance test* already conducted during FAT.

By analyzing this data through our algorithms, we can precisely diagnose battery performance without adding any extra testing effort. The evaluation is done using our highly scalable cloud environment. Only through this high level of automation the low time and cost-wise effort is reachable.

** Performance Test, sometimes called Dynamic Load Tests for Batteries are commonly used in BESS to evaluate a battery's performance and health under controlled load conditions. These tests measure the battery's ability to deliver power and maintain voltage levels, assessing its capacity and identifying potential issues or degradation.*

Technical & Procedure Requirements

→ Technical Requirements for BESSential

Format:	Data should be in text files (CSV, TXT) with English column headers.
File Sharing:	Use secure data sharing platforms or email.
File Organization:	Separate files per unit per test (no mixed data).

Required Signals per Unit:

Signal (per each Battery Unit)	Resolution	Frequency
Time Signal	UTC time	1 s
Current of Unit *(Alternative: Unit Power)*	ca. 0.1 A	1 Hz
SoC of Unit	<1.0%	1 Hz
Voltage *of Unit, total*	=<0.1 V	1 Hz
Voltage *of Highest/Lowest/average cell within Unit*	1 mV	1 Hz
Temperature *of Highest/Lowest/average cell within Unit*	<1.0°C	1 Hz

→ Testing procedure

Test procedure:	Must follow specified guidelines per unit.
Adaptations:	Deviations possible upon request.
Batch size:	Minimum 10 units per test to enable relative/cross-comparison.

By clearly defining the battery unit, streamlining the process, and specifying technical requirements, this approach ensures FAT is both efficient and aligned with industry best practices. Utilizing existing load test data for our diagnostics allows us to maintain a quick turnaround without compromising accuracy or requiring additional resources.

Initial analysis and planning

The volytica team will analyze the shared data, provide feedback, and finalize the setup. **This process of setting up the BESSential diagnostic software is guaranteed to be done within 3 weeks, but normally it takes less, and is done prior to the start of the first test.**

BESSential test during FAT

We are now starting the FAT. It might be a few weeks after the data sample analysis. Once we begin our BESSential service, our combined volytica diagnostics and Sinovoltaics engineers and inspection team will manage and monitor the entire process. If there are any critical issues or updates that would delay shipping, we will share that information as soon as it is communicated by our inspection team at the factory.

Result Review and Reporting

Once the FAT is completed and containers have been authorized to ship by our combined teams, we will prepare a final report for you to review.

This report not only helps gain investor confidence by demonstrating a commitment to quality and reliability but also becomes a valuable asset when selling the project to a new owner in 1-2 years. By showcasing that your project has been maintained with high standards through BESSential, you can better highlight the quality and integrity of the system, directly supporting your project's value in the market.

IMPLEMENTING BESSential IN YOUR PROCUREMENT CONTRACT

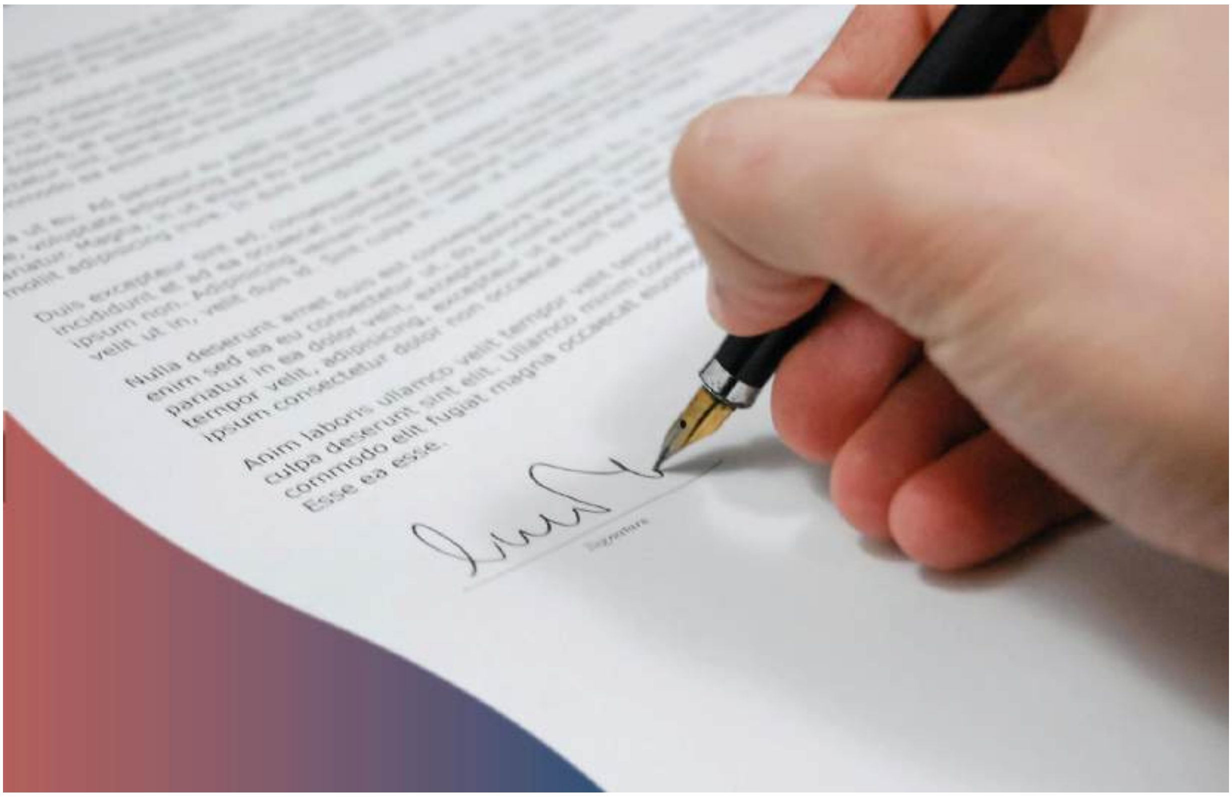
Your BESS integrator or manufacturer might not see extra quality control favorably. As such, it is important that your procurement contract covers the critical quality control steps you would like to implement with your manufacturer.

The permission process is the same for any QA/QC work Sinovoltaics performs for BESS, PV modules, inverters, transformers, mounting structures or cables. **In all cases, the manufacturer has the right to refuse what is not included in the contract. As such, it is critical that you contact Sinovoltaics or volytica diagnostics to obtain contract language that will ensure we can perform a BESSential inspection**.

Additional content specific to BESSential procurement contract language can be downloaded from this page:

https://sinovoltaics.com/bessential-white-paper/

If your contract is already signed, but you still would like to perform the BESSential service, please do not hesitate to reach out to Sinovoltaics or volytica diagnostics so we can find a solution.



CONCLUSION

With Sinovoltaics and volytica diagnostics' BESSential service, we're taking a giant step forward in ensuring the quality of battery energy storage systems . By combining Sinovoltaics' in-depth Factory Acceptance Testing and Site Acceptance Testing with volytica's state-of-the-art battery diagnostics, we're making energy storage systems more reliable, efficient, and sustainable from start to finish.

Consider our recent 50 MWh project. The factory standard FAT passed the system based on discharge capacity and efficiency standards. **However, after BESSential was implemented, we identified and resolved critical thermal issues and voltage imbalances that the standard testing missed**. Without BESSential, these defects could have posed financial and operational risks to the project's success. Instead, the system is now operating smoothly, is predicted to last longer, and is delivering superior performance.

And here's why traditional FAT and SAT protocols are no longer acceptable: Poor BESS quality can cost a fortune. In our 100 MWh case study project, we found that **quality issues could lead to losses as high as $650,000. Looking at the bigger picture, the entire energy storage industry could face losses of up to $2.3 billion by 2030 deployments if we don't address these challenges**.

Sinovoltaics and volytica diagnostics are here to help you avoid those pitfalls. When you partner with us, you're partnering with a team that's deeply committed to quality and reliability. Make your next BESS project a success. Reach out to us today.

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ABOUT THE AUTHORS

Arthur Claire
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With over 12 years of experience, I have decided to dedicate my career to the energy transition and specifically energy storage for the past five years. After Graduating from an engineering background with a master thesis, my journey began as a project manager for international semiconductors projects, where I quickly recognized the complexities of international supply chain and critical aspects of quality control.

Recognizing the pivotal role of energy storage in the future of energy, I supported AMPD Energy to develop its innovative BESS solution. Afterward, I returned to Europe as a consultant, assisting clients in successfully sourcing BESS from China and ensuring optimal project returns.

For the past two years, I have been serving as the Director of Technology at Sinovoltaics, where I lead our BESS practice. My focus is on maintaining the highest standards of quality in the BESS solutions we deliver to our clients, driving the energy transition forward with reliable and efficient technologies.

Lutz Morawietz
Head of Algorithm Development, volytica diagnostics

After graduating in electrical engineering, Lutz spent years developing algorithms and conducting experiments, deeply exploring the intricacies of battery data. With over two decades of experience in battery testing, algorithm development, and R&D, Lutz has dedicated his career to understanding the most expensive and relevant part of the energy transition, the battery.

Four years ago, Lutz joined volytica diagnostics as Head of Algorithm Development. This role focuses on unlocking the full potential of battery data, turning insights into actionable improvements for performance and efficiency. Driven by a passion for energy transition, he strives to ensure that every battery is used to its true potential, contributing to a more sustainable and efficient energy landscape.

NOTES

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[3] Sinovoltaics, "BESS Factory Acceptance Testing (FAT) Monitoring," accessed August 22, 2024, **https://sinovoltaics.com/energy-storage-fat/**

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[8] Avery Dekshenieks, "ERCOT: Battery energy storage revenue breakdown - Jan/Feb 2024," *Modoenergy*, accessed August 22, 2024, **https://modoenergy.com/research/ercot-bess-index-january-february-2024-battery-energy-storage-systems-revenues-ancillary-services-energy-arbitrage-eolian-key-capture-energy-jupiter-power-triple-butte.**

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