Best practice site visit
Csillebérc
2024.12.09

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NAS Battery Energy Storage System – Csillebérc (HU)

- **Location:** HU-REN Centre for Energy Research, Csillebérc (HU) - Hungary's first Na-S type battery
- **Date:** 2024.12.09.
- **Installed Technology**: NAS battery energy storage system
- **Operator:** HU-REN Centre for Energy Research
- **Participants:**

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1. Introduction

1.1. Background and Project Context

The StoreMore project is an initiative funded by the Interreg Danube program, aiming to advance the development and deployment of innovative energy storage solutions in the Danube region. The project focuses on addressing the increasing demand for renewable energy integration and grid stability by exploring and promoting the use of various energy storage technologies, including battery systems.

This report documents a site visit to a location utilizing Sodium-Sulfur (NAS) battery technology. The purpose of the visit was to gain first-hand insights into the operational characteristics, performance, and potential applications of NAS batteries, specifically within the context of the StoreMore project.

Disclaimer:

It is important to note that this particular installation was selected due to its status as the first and longest-operating NAS battery system in Hungary. As such, it provides a valuable opportunity to gain insights into the long-term performance and operational characteristics of this technology in the Hungarian context.

1.2. About NGK Insulators, Ltd.

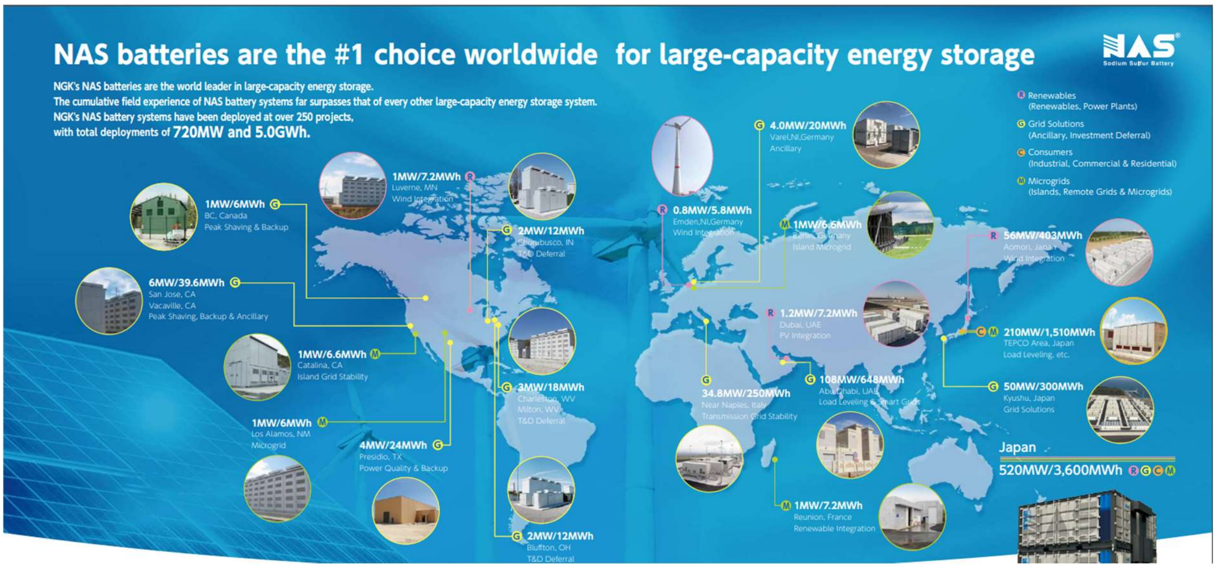
NGK Insulators, Ltd., headquartered in Nagoya, Japan, is a global leader in the manufacturing of advanced ceramics and insulators for various industries, including power transmission and distribution, electronics, and environmental protection. Founded in 1919, NGK has a long and rich history of innovation and technological excellence.

The company's core expertise lies in the development and production of high-performance ceramics, including alumina, silicon carbide, and zirconia. These materials exhibit exceptional properties such as high strength, excellent thermal conductivity, and superior resistance to corrosion and wear.

In recent years, NGK has diversified its business portfolio to include energy storage solutions, leveraging its expertise in materials science and engineering. The company has emerged as a prominent player in the global NAS battery market, with a strong focus on research and development, manufacturing, and system integration.

NGK's NAS batteries have been successfully deployed in various applications worldwide, demonstrating their reliability, durability, and suitability for large-scale energy storage projects. The company has established a strong reputation for providing innovative and high-quality energy storage solutions that meet the evolving needs of the global energy market.

NGK's NAS batteries over the World



Source: NGK Insulators Ltd leaflet

1.3. Sodium-Sulfur (NAS) Battery Technology: An Overview

Sodium-Sulfur (NAS) batteries are a type of high-temperature molten salt battery that employs sodium metal as the anode, sulfur as the cathode, and a solid ceramic electrolyte to separate the two. This unique combination of materials results in several distinct characteristics that differentiate NAS batteries from other energy storage technologies.

Operating Principle:

NAS batteries operate at high temperatures (around 300°C), which allows for the use of molten sodium and sulfur as active materials. During charging, sodium ions migrate from the anode to the cathode through the solid electrolyte, combining with sulfur to form sodium polysulfides. During discharge, the process is reversed, with sodium ions moving back to the anode, generating electrical energy.

The solid electrolyte, typically made of beta-alumina, is a key component of the NAS battery. It allows for the passage of sodium ions while preventing direct contact between the sodium and sulfur, which would cause a short circuit and damage the battery.

Key Characteristics:

NAS batteries exhibit several unique characteristics that differentiate them from other battery technologies:

- **High Energy Density:** NAS batteries offer a high energy density, allowing for compact and efficient storage of large amounts of energy.
- **Long Cycle Life:** With proper operation and maintenance, NAS batteries can achieve a long cycle life, typically exceeding 15 years or 4,500 cycles.
- **Fast Response:** NAS batteries can respond quickly to changes in grid demand, making them suitable for applications requiring fast frequency regulation and voltage support.
- **High Efficiency:** NAS batteries exhibit high round-trip efficiency, meaning a significant portion of the stored energy can be recovered during discharge.
- **Long Duration Storage:** NAS batteries are well-suited for long-duration energy storage applications, enabling the storage of energy over extended periods.
- **Environmental Benefits:** NAS batteries are environmentally friendly, with no harmful emissions during operation.

Construction and Design:

NAS batteries typically consist of several key components:

- **Battery Cells:** Individual battery cells contain the sodium anode, sulfur cathode, and solid electrolyte.
- **Battery Modules:** Multiple battery cells are connected in series and parallel to form battery modules, increasing the overall capacity and voltage of the system.

- **Battery Container:** Battery modules are typically housed in insulated containers to maintain the operating temperature and ensure safety.
- **Power Conversion System (PCS):** The PCS converts the DC output of the battery system to AC power for grid connection and controls the charging and discharging processes.
- **Thermal Management System:** A thermal management system is essential to maintain the optimal operating temperature of the battery cells.

Applications:

NAS batteries have a wide range of applications in the energy sector, including:

- **Grid Stabilization:** Balancing supply and demand, providing frequency regulation, and maintaining grid stability.
- **Renewable Energy Integration:** Storing excess energy from renewable sources such as wind and solar power to ensure a consistent and reliable power supply.
- **Peak Shaving:** Reducing peak demand by discharging energy during peak hours and charging during off-peak hours.
- **Microgrid Applications:** Providing reliable power supply and grid support for isolated communities and microgrids.
- **Backup Power:** Serving as a backup power source for critical loads during grid outages.

Advantages of NAS Batteries:

- High energy density and long cycle life
- Fast response and high efficiency
- Suitable for long-duration energy storage
- Environmentally friendly with no emissions
- Modular design allows for flexible system scaling

Challenges and Considerations:

- **High Operating Temperature:** Maintaining the high operating temperature requires careful thermal management.
- **Safety Considerations:** Handling molten sodium requires careful safety precautions.
- **Capital Cost:** The initial capital cost of NAS battery systems can be significant.

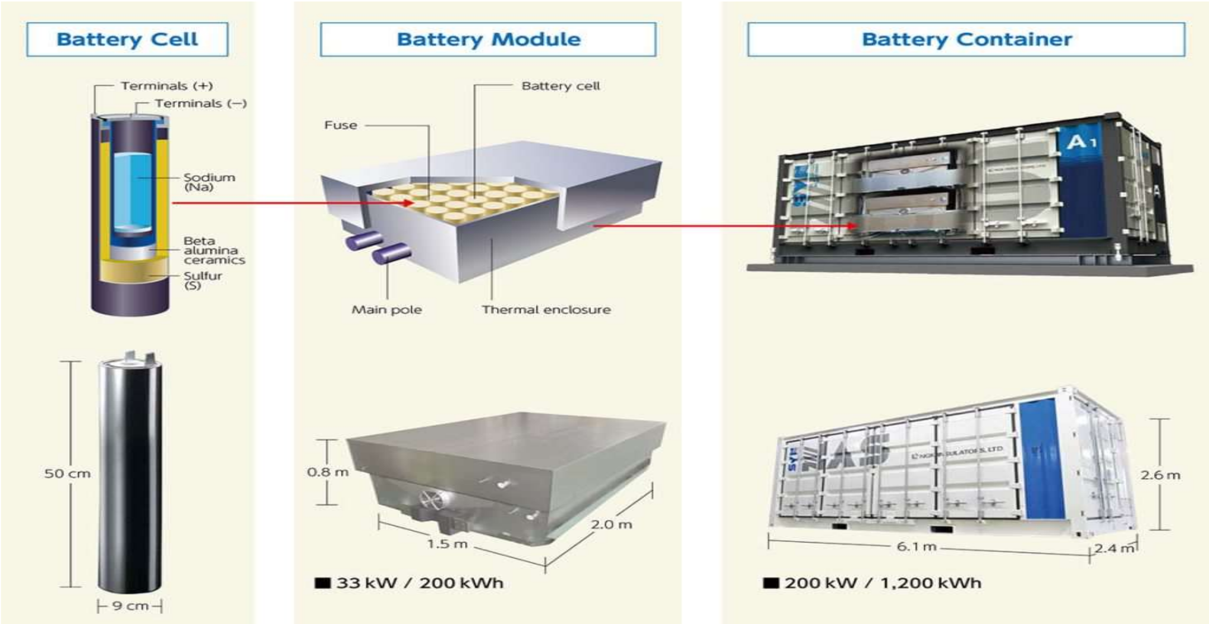
Despite these challenges, NAS batteries offer a promising solution for addressing the growing demand for energy storage and grid modernization. Continued research and development efforts are focused on improving the cost-effectiveness, safety, and overall performance of NAS battery technology.

2. Observations and findings

2.1 System Setup

The site at Csillebérc HUN-REN Research Facility has a standard 20 feet container battery module with DC250kW power and DC1,450kWh (BOL) capacity.

Standard NAS Battery System of NGK

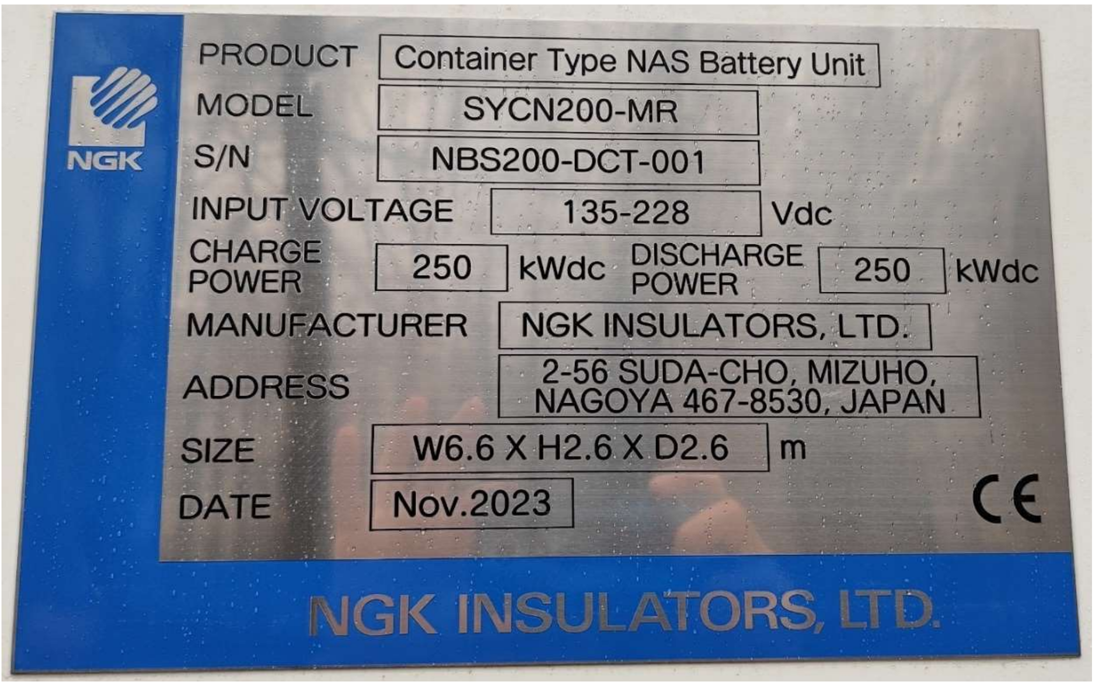


Source: https://www.ngk-insulators.com/en/product/nas-configurations.html

Battery and BMS containers

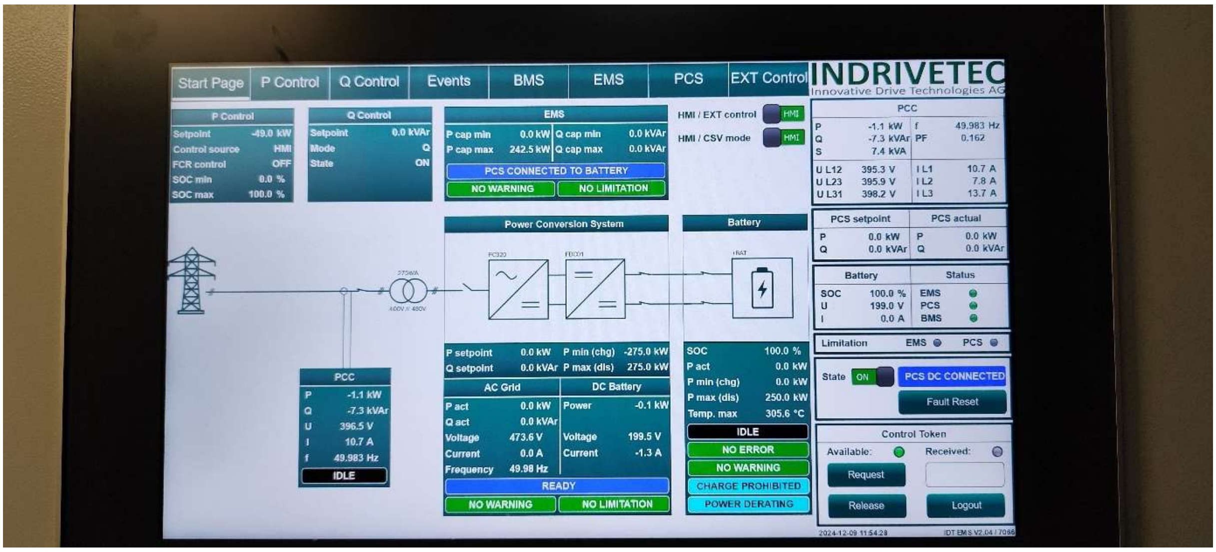
Container setup: battery container to the left, converter and BMS on the right

System parameters



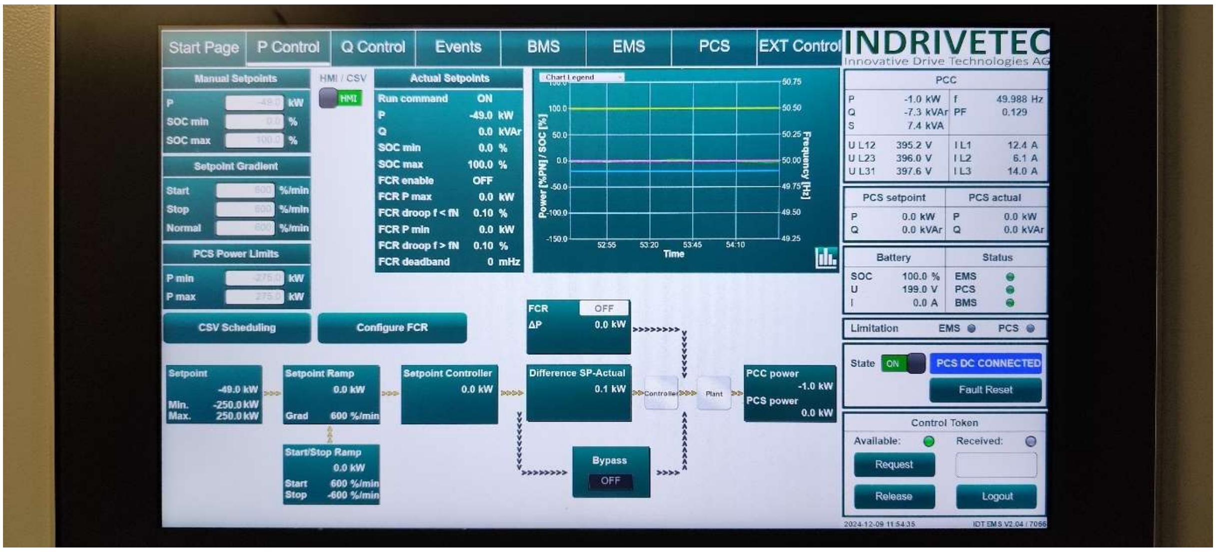
BMS system screens

BMS Start page



Operational interface of a Battery Management System (BMS) connected to a NAS battery. Key metrics visible include the state of charge (SoC) at 100%, indicating the battery is fully charged. The battery voltage is measured at 199.5V, and the system is in an "IDLE" state, with no active power output or input (P act = 0.0 kW). The Power Conversion System (PCS) is connected and ready, with no errors or warnings flagged. The system highlights essential statuses for the Energy Management System (EMS), PCS, and BMS, all showing as operational (green indicators). The interface also includes controls for setpoints, system limitations, and fault resets, displaying a robust real-time monitoring and management setup for grid-connected operations.

Power Conversion System



Detailed overview of the Power Conversion System (PCS) control and configuration for the NAS battery. Key parameters include the setpoint for power (P) at -49.0 kW, with manual limits for the PCS power defined as -275.0 kW to 275.0 kW. The battery state of charge (SoC) remains at 100%, and the system is operating within its nominal voltage range (199.0V). A graphical plot indicates grid frequency stability over time, centred around 50 Hz, as the system is monitoring grid interactions.

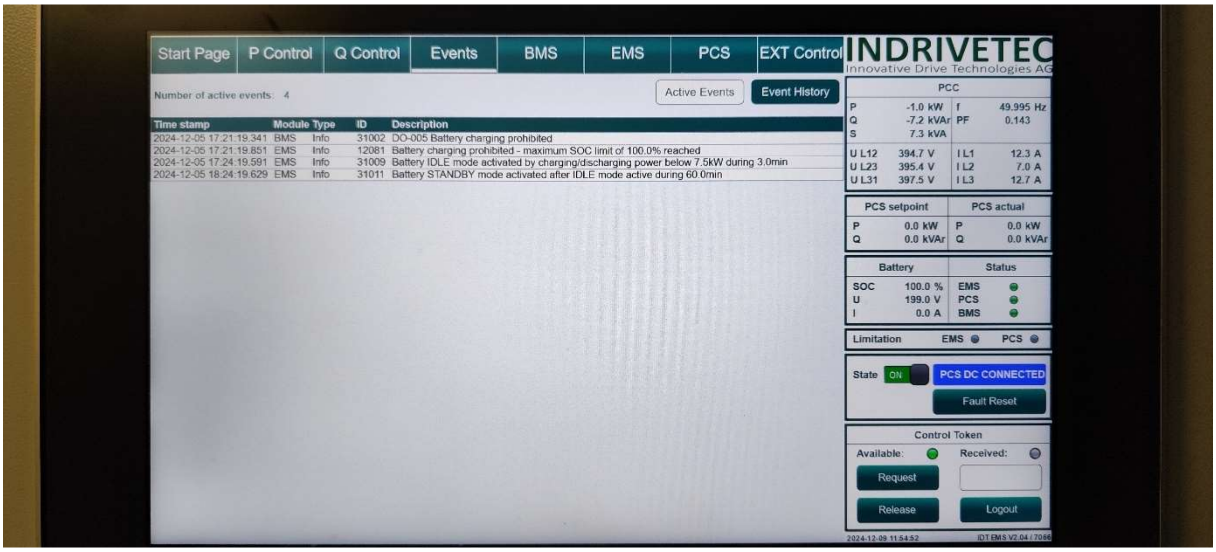
The "FCR" (Frequency Containment Reserve) mode is turned off, but its configuration options are available for dynamic grid support. The system allows for ramp gradients of up to 600% per minute for operational adjustments, ensuring rapid response to grid or storage requirements. Both the PCS and EMS statuses are operational (green indicators), with no errors or warnings. The screen also provides tools for fault resets and the ability to toggle bypass functionality, further enhancing operational flexibility and control.

Q Control – power flow management

Q Control screen, which manages reactive power flow in the system. The mode is activated, and the Q Controller is set to "ON," allowing for reactive power regulation. The system indicates a setpoint of 0.0 kVAr, with the current power output at -7.3 kVAr, signifying an underexcited state. The maximum allowable limits for reactive power are set between -250.0 kVAr (underexcited) and +250.0 kVAr (overexcited).

A live chart displays reactive power and voltage trends over time, providing real-time monitoring of grid dynamics. The interface also outlines the flow from the setpoint to the actual output, highlighting the difference (-7.3 kVAr). The bypass function remains off, suggesting direct control over reactive power is actively engaged. The system's battery remains fully charged (SoC: 100%), with all critical components (EMS, PCS, BMS) functioning correctly (green indicators). The interface reflects a stable operation designed to balance grid voltage and improve power quality.

Recent Events

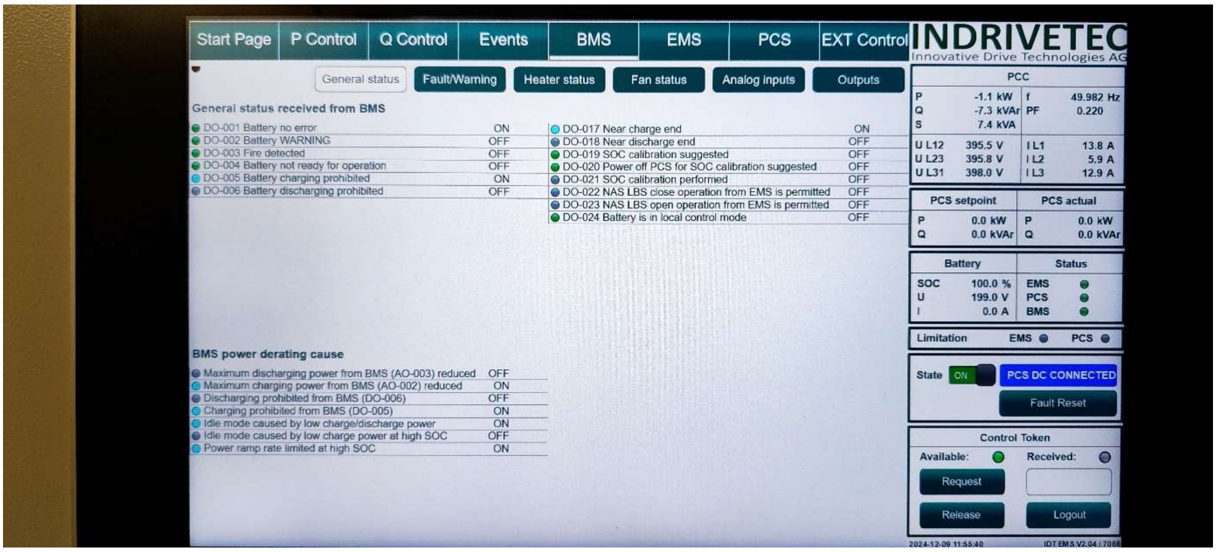


"Event History" for the NAS battery system, listing four active events. Key details include timestamps, module types, event IDs, and descriptions. Notably:

- Two events indicate "Battery charging prohibited" due to the maximum State of Charge (SoC) limit of 100% being reached.
- Another event records "Battery IDLE mode activated" as the charging or discharging power dropped below 7.5 kW for 3.0 minutes.
- A final event notes the activation of "Battery STANDBY mode" after IDLE mode was active for 60.0 minutes.

These events demonstrate automated system behaviour designed to maintain operational safety and efficiency, particularly regarding SoC management and transitioning between operational states. The system status (EMS, PCS, BMS) shows no errors or warnings, confirming stable conditions despite the logged events.

Battery Management System (BMS) screen General status



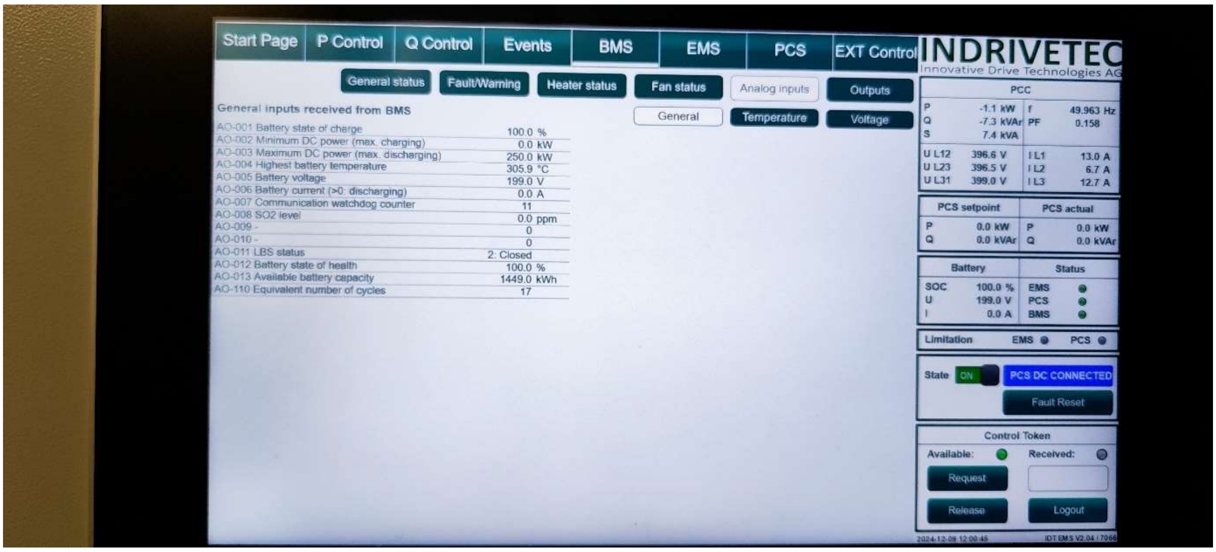
The screen provides a general status overview of the Battery Management System (BMS). Key indicators show that the battery has no errors (DO-001 is ON), but charging is currently prohibited (DO-005 is ON) due to the 100% State of Charge (SoC). Other critical statuses, such as fire detection and discharging prohibition, are OFF, indicating no active safety concerns.

The "BMS power derating cause" section highlights factors impacting power operations. Active causes include:

- Charging prohibition (DO-005 ON),
- Idle mode due to low charge/discharge power, and
- Power ramp rate limitation at high SoC.

Additional statuses, such as "Near charge end" (DO-017 ON), further confirm the system's operational focus on preventing overcharging while maintaining safety and performance. The system remains stable and operationally responsive, with no indications of critical faults or emergencies.

Battery Management System (BMS) screen – General analog inputs

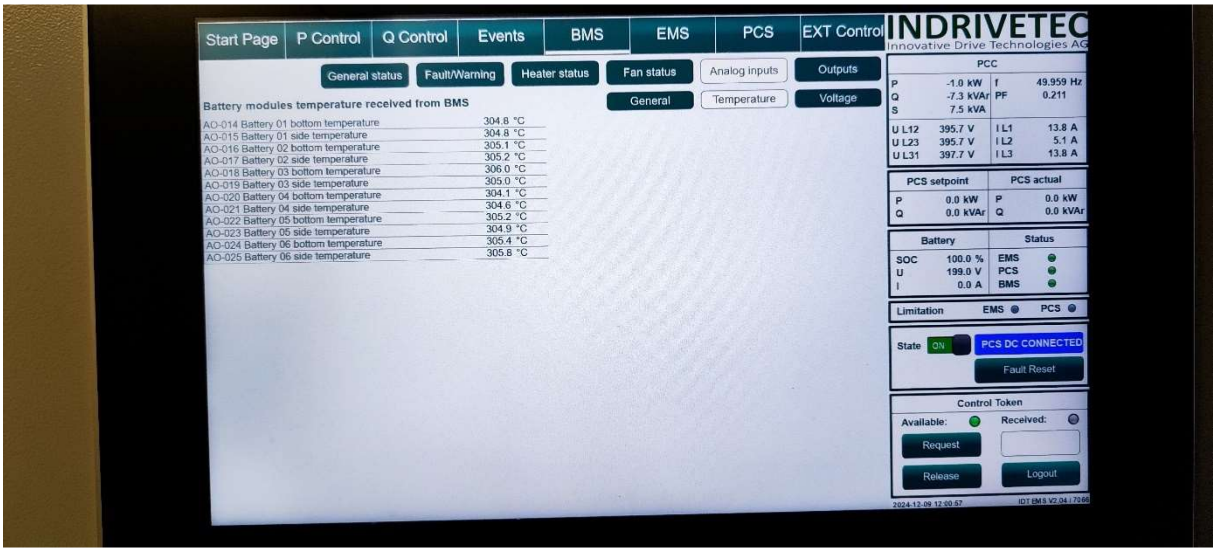


This screen provides a detailed overview of general inputs received from the Battery Management System (BMS). Key parameters include:

- **Battery state of charge (SOC)**: 100.0%, indicating the battery is fully charged.
- **Battery voltage**: 199.0V, which aligns with the nominal voltage for stable operation.
- **Battery state of health**: 100.0%, suggesting no degradation or wear, with the system performing at optimal capacity.
- **Available battery capacity**: 1449.0 kWh, reflecting the current energy storage availability.
- **Equivalent number of cycles**: 17, indicating the battery has undergone relatively few full charge/discharge cycles.
- **Highest battery temperature**: 305.9°C, highlighting the thermal state, which is expected given the sodium-sulfur chemistry's high operating temperature range.

Additional entries like communication watchdog counter and SO2 level (0.0 ppm) confirm operational safety and connectivity. The LBS (Load Break Switch) status is "Closed," indicating the battery is connected to the grid. These parameters collectively suggest that the system is in excellent condition, with no significant anomalies or performance issues.

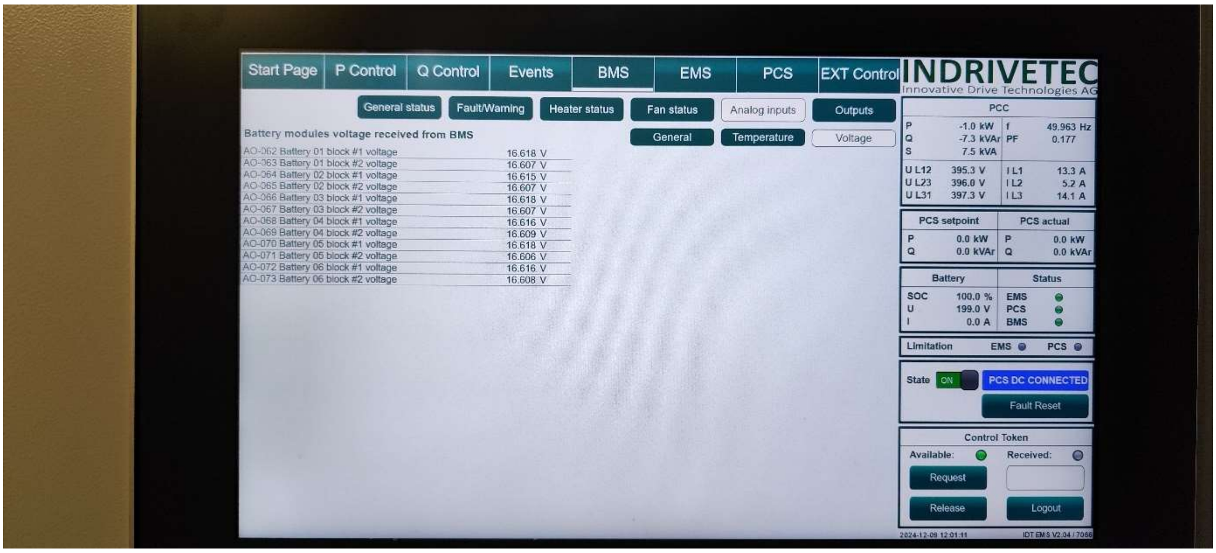
Battery Management System (BMS) screen – Temperature analog inputs



This screen focuses on the temperature monitoring of individual battery modules within the NAS battery system. Key data points show the bottom and side temperatures for six modules, with values ranging from **304.1°C to 305.8°C**. These temperatures are within the expected operating range for NAS batteries, which require high temperatures to maintain the molten state of the sodium and sulfur electrodes.

The uniformity in temperature readings indicates stable thermal management across the modules, ensuring consistent operation and efficiency. The slight variation between modules (less than 2°C) suggests effective heat distribution and minimal thermal imbalance. Maintaining such precise temperature control is critical for the performance, safety, and longevity of the NAS battery system.

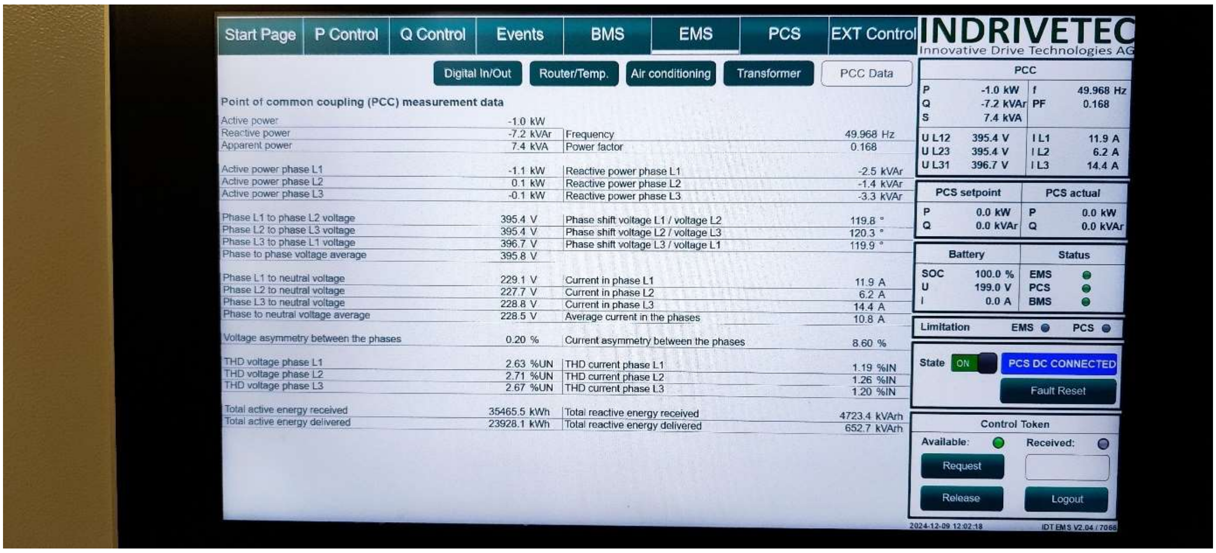
Battery Management System (BMS) screen – Voltage analog inputs



The screen provides the voltage readings for individual blocks within the battery modules, as received from the Battery Management System (BMS). Each block voltage is consistent, ranging from **16.607V to 16.618V**, indicating a high level of uniformity across the system.

This minimal variation in block voltages highlights the effective balancing of cells within the battery, which is critical for maintaining overall system health and efficiency. Uniform voltages also ensure that no individual block is overcharged or undercharged, which could otherwise lead to capacity loss or potential safety risks. These readings affirm that the NAS battery system's voltage management and cell balancing mechanisms are functioning as intended.

Energy Management System Point of Common Coupling (PCC) screen



This screen presents detailed Point of Common Coupling (PCC) measurement data, illustrating the interaction between the NAS battery system and the grid. Key parameters include:

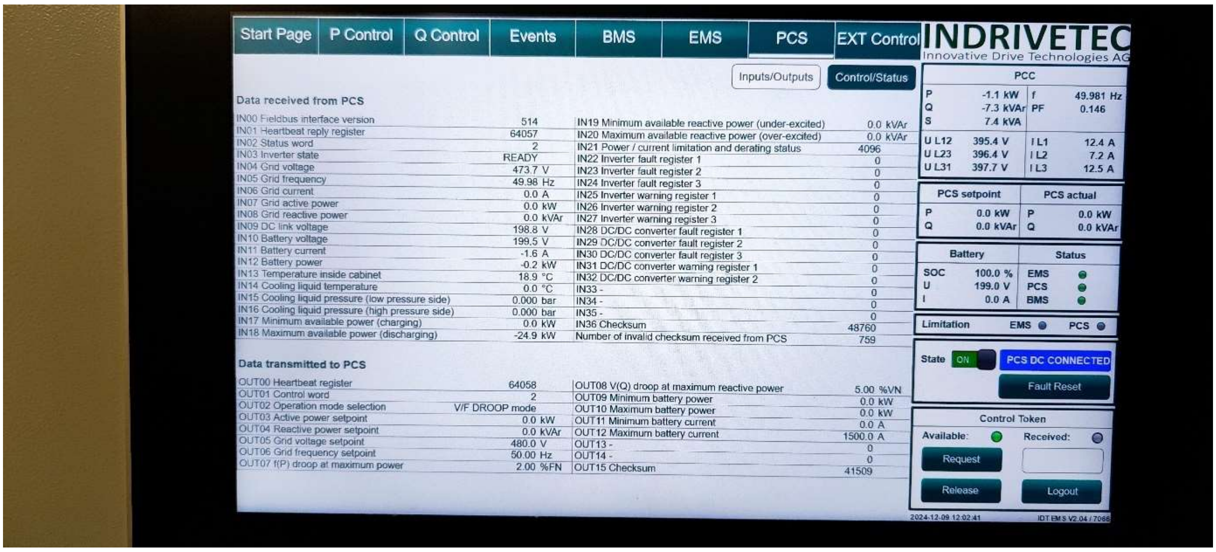
- **Active power**: -1.0 kW (exporting a small amount of power to the grid).
- **Reactive power (Q)**: -7.2 kVAr, indicating the system is providing reactive power to support voltage stability.
- **Apparent power (S)**: 7.4 kVA.
- **Frequency**: 49.968 Hz, which is within the expected range for grid stability.
- **Power factor (PF)**: 0.168, suggesting significant reactive power relative to active power.

Voltage measurements across phases L1, L2, and L3 are consistent (395.4V to 396.7V), with a minimal phase-to-phase voltage asymmetry of 0.20%. Current levels vary across phases, with L3 carrying the highest load at 14.4A, followed by L1 (11.9A) and L2 (6.2A).

Total Harmonic Distortion (THD) for voltage is low across all phases (2.63–2.71% UN), indicating good power quality. Current THD is also minimal (1.19–1.26% IN), reflecting stable and efficient operation.

Energy metrics highlight **total active energy received** (35,465.5 kWh) and **delivered** (23,928.1 kWh), as well as reactive energy exchange. These values confirm the system's active role in balancing energy demands and supporting grid operations. Overall, the PCC data indicates the NAS battery is effectively managing power flow and maintaining grid stability.

Power Conversion System (PCS)



This screen displays detailed data exchanged between the Power Conversion System (PCS) and other components, divided into "Data received from PCS" and "Data transmitted to PCS."

Key data received from PCS:

- **Grid voltage**: 473.7 V, indicating stable grid conditions.
- **Grid frequency**: 49.98 Hz, within the acceptable range for grid synchronisation.
- **Battery voltage**: 199.5 V, consistent with operational norms.
- **Battery current**: -1.6 A (charging), indicating a small inflow of current to the battery.
- **Battery power**: -0.2 kW, reflecting minimal power transfer during current conditions.
- **Temperature inside cabinet**: 18.9°C, which is well within the safe operating range.

- **Available power**: -24.9 kW (discharging), indicating readiness for a controlled energy release if needed.

Key data transmitted to PCS:

- **Grid voltage setpoint**: 480.0 V, used for grid interaction control.
- **Grid frequency setpoint**: 50.0 Hz, aligning with the nominal grid frequency.
- **Droop settings**: Configured at 5.00% for voltage and 2.00% for power frequency, enabling dynamic control to stabilise grid power.

No faults or warnings from the inverter, DC/DC converter, or related components are logged, confirming stable performance across subsystems. This data reflects precise monitoring and control for both battery and grid interactions, ensuring reliability and safety.

Electrical panel and control hardware for the NAS battery system

2.2 Operational Performance

Efficiency and Output

The NAS battery system at the Csillebérc facility demonstrates high efficiency and output capacity, designed to optimise grid operations and renewable energy integration. With a round-trip efficiency typically ranging between 85–90%, the system minimises energy losses during charge and discharge cycles. The battery operates at a nominal voltage of 199.5V (per battery module) and achieves consistent performance due to its unique sodium-sulfur chemistry, which is ideal for long-duration energy storage. The ability to provide a continuous discharge for up to six hours at rated output makes it a reliable solution for peak shaving, load levelling, and voltage support. Additionally, its reactive power management capabilities, evident in the data showing -7.2 kVAr of reactive power supplied to the grid, highlight its effectiveness in stabilising grid voltage during fluctuations.

The system's ability to balance active and reactive power seamlessly supports grid demands in real-time. Voltage uniformity across all battery modules (16.607V to 16.618V per block) ensures optimal energy utilisation and reduces the risk of performance degradation. Furthermore, the system’s capacity to handle large-scale energy flows—evidenced by the total energy delivered (23,928.1 kWh) and received (35,465.5 kWh)—positions it as a key asset for grid-connected renewable energy projects. These metrics underline the system’s operational reliability and its capability to contribute to energy resilience in demanding applications.

Maintenance Requirements and Procedures

The NAS battery system at Csillebérc is designed for minimal and infrequent maintenance, a key feature that enhances operational efficiency and reduces downtime. Preventative maintenance can be scheduled outside of peak operational seasons to ensure seamless grid support during critical periods. One of the standout advantages of the system is its modular design, allowing maintenance to be conducted on partial sections of the battery while the rest of the system remains operational. This feature ensures uninterrupted energy storage and delivery, making it an ideal solution for applications requiring high reliability and availability.

The maintenance tasks include routine checks for abnormalities, cleaning components, and inspecting subsystems such as heaters, cooling systems, and power distribution. Periodic replacement of consumable parts and functional tests, recommended every four years, help maintain the system's 20-year lifespan and over 7,000 charge-discharge cycles. The thermal management system, critical for operating at the high temperatures required by sodium-sulfur chemistry (above 300°C), also receives special attention during maintenance to ensure uniform temperatures across modules. By combining these maintenance practices with remote monitoring capabilities, the system balances long-term durability with ease of operation, further solidifying its reputation for reliability.

Monitoring and Control Systems

The NAS battery system at Csillebérc is equipped with a sophisticated monitoring and control system that ensures seamless operation and efficient management of energy storage. The system integrates multiple layers of oversight, including the Battery Management System (BMS), Power Conversion System (PCS), and Energy Management System (EMS). These components work together to provide real-time data on key operational parameters such as State of Charge (SOC), battery voltage, current, and temperature. For instance, the BMS consistently tracks uniformity across modules, with SOC maintained at 100% and voltage readings between 16.607V and 16.618V per block, ensuring optimal energy utilisation and preventing imbalance. The PCS adds another layer of control by managing power flows, reactive power output, and grid synchronisation, as evidenced by its ability to provide -7.2 kVAr of reactive power for voltage stabilisation.

The system's user interface further enhances operational control by offering detailed visualisations of performance metrics and system states. Screenshots from the Csillebérc NAS reveal dashboards displaying power flows, grid parameters, voltage uniformity, and thermal conditions in a clear and intuitive layout. Alerts and fault logs, such as charging prohibitions or maintenance triggers, are readily available, enabling operators to respond quickly to any issues. Moreover, advanced features like bypass functionality, live frequency plots, and control token systems allow for precise adjustments and operational flexibility. This robust monitoring infrastructure, combined with remote access capabilities, ensures that the system operates reliably and efficiently, even in complex grid environments.

Safety Protocols

The NAS battery system at Csillebérc is equipped with comprehensive safety protocols to ensure secure operation and mitigate risks associated with high-temperature sodium-sulfur chemistry. Key safety measures include continuous monitoring by the Battery Management System (BMS), which tracks critical parameters such as temperature, voltage, and current across all modules. The BMS immediately flags any deviations, such as overvoltage, undervoltage, or excessive temperature, to prevent thermal runaway or other hazardous conditions. Additionally, the system incorporates moulded case circuit breakers (MCCBs) for power isolation, allowing operators to disconnect specific sections of the system in the event of a fault. Fire detection systems are also integrated, with automatic triggers to shut down the battery and isolate it from the grid in case of emergencies.

Another critical safety feature is the system's thermal management. Operating temperatures are maintained uniformly across all modules (approximately 304–306°C) to prevent hotspots or thermal imbalances. The robust housing and insulation ensure that even under high thermal stress, the risk of external exposure to heat or chemical leakage is minimised. The modular design also enhances safety, as maintenance or troubleshooting can be performed on specific sections without shutting down the entire system. Furthermore, charging and discharging are tightly controlled, with the system automatically enforcing limits to avoid overcharging or deep discharging. These safety protocols, combined with clear fault logs and alerts, ensure the Csillebérc NAS battery operates reliably and securely, even under demanding conditions.

2.3 Environmental Considerations

Thermal Management and Energy Consumption

The thermal management system of the Csillebérc NAS battery is a critical component for maintaining the high operating temperatures (above 300°C) required for sodium-sulfur chemistry. While this system ensures optimal performance and longevity, it does consume energy, which contributes to the overall environmental footprint of the installation. Typically, the heaters and insulation work continuously to maintain the required temperature, with the energy consumption varying depending on ambient conditions and system size. For a NAS battery, thermal management can account for approximately 5–10% of the total energy input over its operational lifespan. This translates to about 1-2% of energy used for thermal management in the daily charge-discharge cycle of the battery. However, the environmental impact is mitigated by the system's high energy density, long operational lifespan (20+ years), and reduced need for frequent maintenance or replacement. By minimizing energy losses during storage and retrieval (85–90% round-trip efficiency) and offering high cycle stability, the thermal management system balances its energy demands with the broader environmental benefits of enabling renewable energy integration and grid stabilization.

Emissions, Recycling, and Disposal

The NAS battery system at Csillebérc is designed to have minimal environmental impact during operation, as the cells are hermetically sealed, preventing any emissions or leakage of chemicals into the environment. This sealed design ensures that no gases or by-products are released during charging, discharging, or thermal management processes, making it an environmentally friendly choice for large-scale energy storage. The lack of operational emissions aligns the system with stringent environmental standards, further supporting its role in renewable energy integration and sustainable grid operations.

Regarding end-of-life management, the materials used in NAS batteries, such as sodium, sulfur, and beta-alumina ceramics, are recyclable to a significant extent. Sodium and sulfur can be recovered and reused, reducing the environmental footprint of battery disposal. However, the recycling process requires specialised facilities due to the unique chemistry and high-temperature requirements of the battery. The ceramic electrolytes and thermal enclosures are also recyclable but may require additional energy and resources for processing. Proper disposal practices and adherence to recycling protocols are crucial to minimising the environmental impact at the end of the battery's lifecycle, ensuring that NAS batteries remain a sustainable option from production to disposal.

3. Potentials in StoreMore

The inclusion of sodium-sulfur (NAS) battery technology in the Analysis and Cataloguing of Energy Storage Solutions activity within the StoreMore project offers significant potential. The A1.3 Energy Storage Outlook has already recognised NAS technology as a viable long-duration energy storage solution, highlighting its technical feasibility, high energy density, and long operational lifespan. Given these strengths, the Csillebérc NAS battery installation provides an excellent real-world case study to enrich the project's catalogue of sustainable energy storage solutions.

NAS batteries stand out for their unique combination of sustainability and performance. Their hermetically sealed design eliminates emissions during operation, ensuring minimal environmental impact. Furthermore, their recyclability, with recoverable sodium and sulfur components, aligns well with StoreMore's emphasis on environmental assessment. The robust thermal management system, while energy-intensive, is integrated into the overall high round-trip efficiency (85–90%) of the technology, making it competitive with other advanced storage solutions. Evaluating NAS batteries in-depth as part of A1.5 would also allow the consortium to explore their CAPEX implications, particularly in scenarios where long-duration storage and grid stabilisation are prioritised.

By incorporating NAS technology into the StoreMore analysis, the consortium could provide a well-rounded view of its capabilities, limitations, and potential environmental and economic benefits. This would enhance the value of the Catalogue of Sustainable Energy Storage Solutions by offering decision-makers a proven, scalable, and durable alternative to conventional lithium-ion systems. Including NAS technology could also bolster the modelling and optimisation tools developed in subsequent activities, ensuring that the StoreMore project addresses a broader spectrum of real-world storage needs.

4. Conclusions

The Csillebérc NAS battery site visit demonstrated the remarkable capabilities and potential of sodium-sulfur technology in addressing modern energy storage challenges. Its high efficiency, long-duration capacity, and environmentally friendly design underscore its suitability for renewable energy integration and grid stabilisation. The system's robust monitoring, control, and safety protocols, combined with its modular and low-maintenance nature, make it a prime candidate for broader adoption in energy storage projects across the Danube region and beyond.

As the StoreMore project continues to evaluate and catalogue sustainable energy storage solutions, incorporating insights from this site visit into its activities will provide valuable real-world context. The NAS battery's proven durability, emission-free operation, and recyclability align seamlessly with StoreMore's goals of fostering sustainability and innovation in energy storage.