UPPSALA UNIVERSITET

UPTEC ES 25005
Examensarbete 30 hp
Juni 2025

Data Acquisition Systems for Battery Energy Storages

An alternative DAS implementation for improved performance, security, and cost

Emelie Jin

Civilingenjörsprogrammet i energisystem

UPPSALA
UNIVERSITET

Data Acquisition Systems for Battery Energy Storages - An alternative DAS implementation for improved performance, security, and cost

Emelie Jin

Abstract

During recent years, battery energy storage systems (BESS) have become significantly essential as they help the energy transition. Not only do they reduce the dependence on fossil fuels, but they also play a vital role in the transition to electric vehicles and the use of energy during peak periods. Despite the many benefits of BESS, they also come with various challenges. To be able to manage parameters such as temperature, voltage or current, BESS is dependent on Supervisory Control and Data Acquisition (SCADA). This system is then often relying on Data Acquisition Systems (DAS) which handles the data collection as well as the data transfer to a storage system. This set-up often involves some operational and cybersecurity risks, along with some cost aspects.

The purpose of this thesis is therefore to analyze the separation of DAS from SCADA and the associated advantages and disadvantages. It will involve suppliers and their proposed DAS solutions by focusing on data extraction, compatibility to storage systems, security, costs and scalability. The goal is to determine whether the DAS solutions can retrieve large volumes of data from the BESS without affecting the operational part of the SCADA system. From the analyses, recommend the best solution for BESS.

The study contains a literature study including definitions of DAS and SCADA, DAS technologies as well as a description of the current set-up used by Vattenfall. The subsequent chapter describes the separation of DAS from SCADA. It includes an analysis about operational risks, cybersecurity and the cost. Three solutions along with their respective architecture are presented. A case study was also conducted. It explains the comparison of three file format, CSV, JSON and XML. The file formats were also compared using the bandwidth rate fiber (1000 Mbit/s), Ethernet (100 Mbit/s) and mobile broadband (50 Mbit/s).

The results present three different solutions: solutions 1, 2 and 3. While all three solutions have direct sensor input, are compatible with cloud storage and has fast sampling rate, only solution 2 and 3 have a high scalability. This means that new units can be added when needed. Solution 3 offers per-channel pricing, while solution 2 includes a built-in storage and the centralized setup is the most economical. Therefore, solution 2 and 3 are best suited for the purpose.

When it comes to determining the bandwidth of the battery park, the case study shows that if fiber connection is available, then the choice of file format does not matter. However, as all solutions use Ethernet to transmit data, CSV is the most suitable file format. This is as CSV does not occupy as much of the bandwidth as the other two format when transmitting data to the storage.

Teknisk-naturvetenskapliga fakulteten

Uppsala universitet, Utgivningsort Uppsala

Handledare: Fredrik Dillner Ämnesgranskare: Göran Ericsson

Examinator: Carla Puglia

Populärvetenskaplig sammanfattning

Batterilagring har tagit energimarknaden med storm. Dessa system kan erbjuda flexibilitet inom energiförsörjningen genom att lagra överskottsenergi från sol- och vindproduktion för att sedan användas när energikonsumtionen är som störst. Batterilager har även en stor roll när det kommer till omställningen till en mer grön transportsektor genom att bidra till batterier i elbilar. Däremot finns det inte endast fördelar med batterilager. För att kunna styra viktiga parametrar inom ett batteri såsom ström, spänning samt temperatur är det viktigt att kunna ha ett övervaknings- samt kontrollsystem i realtid. Detta system brukar oftast kallas Supervisory Control and Data Acquisition (SCADA). SCADA fungerar oftast tillsammans med ett Data Acquisition Systems (DAS) och är, precis som det låter, ett system som samlar in och hanterar data. I DAS uppgiften ingår även att föra den samlade datan vidare till ett lagringssystem. Denna typ av systemuppbyggnad brukar oftast involvera ett flertal risker, däribland operativa samt cybersäkerhetsrisker. Även kostnad är en viktig parameter att ta hänsyn till. Därför kommer denna rapport undersöka olika lösningar till att separera DAS från SCADA med målet hitta en uppbyggnad av ett system som kan fungera utan att DAS påverkar den operativa delen av SCADA vid datainsamling i en batteripark.

Resultaten för examensarbetet redogör för tre olika lösningar: lösning 1, 2 samt 3. Lösning 1 består av en centraliserad uppbyggnad och lösning 2 är valbar mellan centraliserad eller decentraliserad. Båda lösningarna är presenterade av Yokogawa. Lösning 3 är en fullt distribuerad och modulärlösning från Dewesoft.

Samtliga lösningar har direkt sensorinmatning, men lösning 1 är den mest kostsamma av de tre. Lösningar 2 och 3 kan skalas bättre gentemot den första lösningen. Detta innebär att det är enkelt att addera flera enheter till dessa två lösningar om man skulle vilja expandera batteriparken utan att påverka själva systemuppbyggnaden. Den centraliserade uppbyggnaden av lösning 2 är den billigaste samt har en inbyggd förvaring. Lösning 3 är skalbar redan från start och har en kostnad som beror av mängden kanaler som ska mätas, vilket gör kostnaden flexibel. Därför visar resultatet att lösningar 2 samt 3 är de som är bäst anpassade efter detta syfte.

En fallstudie utfördes i samband med rapporten. Detta gjordes i syfte att vägleda beslut när det kommer till vilka krav det nya DAS ska ställas inför, samt för att uppskatta den nödvändiga bandbredden för batteriparken. Detta genomfördes genom att jämföra tre olika format: Comma-Separated Value (CSV), JavaScript Object Notation (JSON) samt Extensible

Markup Language (XML). CSV är en filtyp som lagrar information i avgränsade komman och är en filtyp som enkelt går att skapas eller redigeras i både Excel och andra program. JSON är ett textbaserat format som används för att utbyta data. Det är skapat för att enkelt kommunicera samt fungera med Javascript, men idag kan nästan alla typer av programspråk läsa JSON-filer. XML har en hierarkisk trädstruktur och brukar därför oftast kallas XML-träd. Formatet används för att exempelvis strukturera samt klassificera information.

I fallstudien utfördes även en jämförelse kring bandbreddshastigheten för fiber (1000 Mbit/s), Ethernet (100 Mbit/s) och ett vanligt mobilt bredband (50 Mbit/s). Denna typ av analys är viktig då överförandet av data kommer att ockupera hela bandbredden i parken. Detta innebär att under detta tidsfönster kan det tillkomma tillfälliga nätverksavbrott eller påverka kommunikation inom parken.

Resultatet visade att när fiber finns tillgängligt, spelade inte filformatet någon större roll. När endast Ethernet eller ett mobilt bredband var befintligt var dock CSV formatet det mest passande. Detta för att det formatet ockuperade bandbredden i parken under kortast tid. Då alla lösningar använde Ethernet för att överföra filerna så blir det mer väsentligt att välja CSV som format för det nya DAS för att undvika nätverksavbrott eller bristande kommunikation i batteriparken.

De övriga övergripande delarna i rapporten inkluderar en litteraturstudie där definitionen av DAS samt SCADA fastställs, samt där olika DAS teknologier presenteras. I den beskrivningen tas för- och nackdelar upp. Det efterföljande kapitlet presenterar dagens uppbyggnad av batteriparken, SCADA- samt DAS-systemet. Detta följt av en redogörelse kring separationen av DAS från SCADA och dess medföljande fördelar samt nackdelar. Till exempel tas det upp kring den operativa risken, cybersäkerhetsrisken och avslutar med att diskutera vilka kostnader som skulle kunna höjas samt sänkas om DAS var separerat från SCADA systemet.

Executive summary

The result of this thesis presents three different DAS solutions, each proposed for integration with the battery energy storage system. All solutions are separated from the operational part of SCADA as they have a direct sensor input. From this report, the most suitable solution for the purpose is either solution 2 by Yokogawa or solution 3 by Dewesoft. While both solutions have high scalability, solution 3 is fully modular and distributed from the start. For solution 2, users need to keep in mind that the setup needs four additional devices in each of the battery containers to be able to expand. However, solution 2 provides its own built-in storage and the centralized setup of solution 2 is the most inexpensive. Solution 3 offers a per-channel pricing, which makes it easier to scale the system while keeping track of the costs. Although solution 1 meets many requirements, it falls short when compared with the key benefits of solution 2 and 3, due to its higher cost and limited scalability.

In this thesis, a case study was conducted. The purpose of this study was to determine the bandwidth of the battery park by comparing three different file formats: CSV, JSON and XML. This was then used to compare different bandwidth rates: fiber (1000 Mbit/s), Ethernet (100 Mbit/s) and a mobile broadband (50 Mbit/s). The results show that when fiber is available, the file format was insignificant. However, when using Ethernet or a mobile broadband the file format became more important. The reason is that JSON and XML are twice and four times larger than CSV. As a result, the data transmission occupies the full bandwidth of the park for a longer duration. Because all of the solutions use Ethernet to forward the data to a storage system, CSV would be the most suited format to select for the new DAS.

From this thesis, the conclusion is to choose solution 2 or solution 3 as the new DAS setup, together with the CSV format when transferring data to a cloud storage using Ethernet. The choice between the two solutions is based on the user's budget, but also how much scalability and a built-in storage matter as a whole.

Acknowledgments

Bringing this thesis to completion has been a milestone in my academic journey and I could not have done this without the participation of so many people. I would like to express my sincere gratitude to all my family and friends who supported me throughout the process of writing this thesis. Your constant encouragement, patience and belief have meant everything to me. I also want to reach out a big thanks to Vattenfall, more specifically the R&D department for giving me this incredible opportunity. Thank you for believing in my potential and entrusting me with this meaningful and challenging project.

A very special thanks to my supervisor Fredrik Dillner at Vattenfall who has provided me with valuable insights, guidance, and essential tools during the work. Your mentorship played a key role in deepening my understanding and has helped me grow both technically and professionally.

I also want to extend my appreciation to my supervisor Göran Ericsson at Uppsala University for the support and academic guidance you have provided me during my thesis work. Your expertise has been essential in shaping the direction and quality of this project.

Finally, I am proud of what this thesis represents and the journey it reflects, and I am so very thankful to everyone who has helped me make it possible.

List of Abbreviations

AI	Artificial Intelligence
BESS	Battery Energy Storage Systems
BMS	Battery Management System
CSV	Comma-Separated Value
DAS	Data Acquisition System
EtherCAT	Ethernet for Control Automation Technology
HMI	Human-Machine Interface
IED	Intelligent Electronic Devices
JSON	JavaScript Object Notation
ML	Machine Learning
RTUs	Remote Terminal Units
SCADA	Supervisory Control and Data Acquisition
SoBa	Solar and Batteries
UI	User Interface
XML	Extensible Markup Language

Contents

1 Introduction

The global energy landscape is undergoing a profound transformation driven by the increasing integration of renewable energy sources, growing concerns over climate change, and the urgent need to achieve sustainable energy systems. Among the critical technologies facilitating this energy transition, Battery Energy Storage Systems (BESS) play an essential role. These systems offer a reliable solution to bridge the gap between energy supply and demand, integration of renewable resources, improved grid stability, and operational efficiency in modern power systems (Saldarini et al., 2023).

BESS have gained significant attention as they serve as a key system for maximizing the use of renewable energy sources while reducing dependence on fossil fuels. They have the ability to capture the energy produced from renewable sources during periods of high production, store it, and then deliver it during peak demand. In doing so, they help balance the intermittency of renewable energy sources, such as wind and solar, contributing to a more stable and reliable energy supply (Li & Deusen, 2025).

Furthermore, BESS are essential for achieving de-carbonization goals in the transportation sector by facilitating the transition to electric vehicles powered by renewable energy resources. Beyond that, BESS has expanded their scope into areas such as microgrids and industrial management, emphasizing their flexibility and increasingly important role across a wide range of uses (Saldarini et al., 2023).

Despite their potential, the implementation of large-scale BESS involves numerous challenges. These include failure in thermal management or voltage imbalance, limitation in system scalability, and the need for advances monitoring and control systems. Moreover, ensuring the safety, lifespan and cost-effectiveness of BESS is crucial for continuing their widespread adoption (U.S. Department of Energy, 2024).

In this context, BESS is dependent on Data Acquisition Systems (DAS), which collect and transfer data to various storage systems (Park & Mackay, 2003). This system is traditionally integrated into the Supervisory Control and Data Acquisition (SCADA), but this setup often involves measures such as security and cost (Thomas & McDonald, 2015).

2 Aim and research questions

The aim of this research is to investigate different DAS-systems and suppliers, as well as the potential benefits and challenges of separating DAS from SCADA in BESS. It will focus on evaluating different DAS architectures, their implications for data extraction, and their ability to operate independently while complementing SCADA systems in large-scale BESS. By exploring this separation, the goal is to assess whether the DAS can efficiently retrieve large volumes of data from the BESS without affecting the operational control of the SCADA system. Additionally, this analysis will consider the operational risks, cybersecurity risks, and the cost.

To fulfill this, the following research questions have been composed:

- What alternative ways exist to separate DAS and SCADA systems and what are the associated advantages and disadvantages?
- How will the various solutions offered by suppliers impact security, scalability, and the total cost?
- What are the requirements for the new DAS when considering data transmission and the needed bandwidth?
- Based on all previous analyses, what are the recommended solutions for BESS?

3 Thesis outline

The following sections of this thesis are organized based on literature studies and a case study. Chapter 4 provides a good background on the subject, including information about a battery, definition of SCADA and DAS and the current setup. Chapter 5 displays a comprehensive review of the advantages and disadvantages of separating DAS from SCADA. This includes operational risks, cybersecurity risks, and cost aspects. The same chapter also delves into the new separated DAS system and displays the different suppliers and their proposal on a DAS solution. Section 5.4.2 compares the different solutions considering parameters like sensor input, scalability, and cost.

The required size of the bandwidth of the battery park, as well as the data format are detailed in the case study which can be seen in Chapter 6. This is then followed by the discussion in Chapter 7 including potential areas for future research. Finally, Chapter 8 concludes the thesis by summarizing the key findings.

4 Background

In this section, the background of the thesis is presented. It displays relevant information about battery energy storages, including components of a battery, followed by the definition of DAS and SCADA. Finally, it explains the current setup of the system and how to extract data from the battery site.

4.1 Battery Energy Storage systems

Batteries consist of stacked cells and facilitate the conversion of chemical energy into electrical energy and vice versa. The desired voltage and current levels are achieved by connecting these cells, either in series or parallel configurations. Batteries are typically rated based on their energy and power capacities, which, for most battery types, are interdependent and fixed during the design phase (Divya & Østergaard, 2009).

Some of the key characteristics of a battery include efficiency, lifespan, operating temperature range, energy density, and depth of discharge. The last mentioned indicates the extent to which a battery is discharged, as batteries are generally not fully discharged during operation. It also includes self-discharge, which represents the rate at which a battery loses charge when not in use (Divya & Østergaard, 2009).

A typical BESS consists of an inverter, a transformer, switchgear, a control system, a battery management system (BMS), and protection mechanisms. Batteries constitute the core component and are responsible for storing energy in chemical form and converting it into electrical energy when needed. The inverter plays a critical role in transforming the DC energy stored in the batteries into AC energy, making it suitable for grid integration or other applications. To align voltage levels with grid requirements, a transformer steps the voltage up or down as needed (Fernandez et al., 2024).

The switchgear provides essential switching and protection functions, ensuring safe management of electricity flow within the system. The control system manages the overall operation of the BESS, optimizing performance and allowing seamless integration with the grid (Fernandez et al., 2024).

The BMS is responsible for monitoring and regulating the battery's state of charge, state of health, and safety parameters, ensuring efficient and reliable operation. Finally, protection mechanisms, including various relays and fault management systems, are used to protect the

BESS components from electrical and operational faults, improving system reliability and safety (Fernandez et al., 2024).

4.2 Supervisory Control and Data Acquisition systems

Supervisory Control and Data Acquisition systems (SCADA) is a type of technology that is used to control and monitor distributed processes. Such can be found in factories, transportation system, and in battery energy storage systems. SCADA systems collect real-time data from instruments and field sensors, process it, and allow operators to make informed decisions, take control actions, and respond to faults immediately (Fernandez et al., 2024).

SCADA is a combination of hardware and software that helps users remotely manage and optimize these systems. The system consists of four primary components. The first one being Remote Terminal Units (RTUs). These provide data from field devices and send control commands. Modern systems often use Intelligent Electronic Devices (IEDs) instead of traditional RTUs. The second component is the communication system that transfers data between the field and the control center. The third component is the master station. This is a control center where operators can monitor and manage the system. The fourth and last component is the user interface (UI), also called the human-machine interface (HMI). This enables the interaction between the operator and the system. These components work together to carry out the monitoring and control of processes to contribute to effective performance of SCADA systems (Thomas & McDonald, 2015).

SCADA consists of two main functional parts: supervisory control and data acquisition. The operational control part is the interactive and operative segment of SCADA and uses collected data from sensors to monitor the BESS. Human operators can issue control commands in real time through this part. The data acquisition section is responsible for collecting data from field devices, such as sensors, and transfers it further for analysis. This is the non-interactive part of SCADA, and it primarily focuses on gathering and transmitting data for either analysis, visualization, or historical storage (McCrady, 2013).

SCADA system has different functions when it comes to BESS. It can be used for real-time data acquisition, where SCADA continuously collects essential parameters such as voltage, current, temperature, state of charge, state of health, and charge/discharge status. This data provides operators with valuable information on battery performance and overall system health. It also plays a crucial role in protection mechanisms, implementing safeguards against potential battery damage. They actively monitor conditions such as over- and under voltage, over temperature, and leakage currents. The system will then trigger protective responses when necessary. In addition, SCADA can provide alarm and notifications by analyzing the collected data and alert operators or subsystems of abnormal conditions, which can prevent damage (Kubiak et al., 2017).

4.3 Data Acquisition System

A Data Acquisition System (DAS) is a device which is used to convert real-world physical phenomena into electric signals and then into digital data, typically presented in a table format. This is often suitable for transmission to a computer, printer, or text display. The purpose of the data collected by DAS is to store it and also for later analysis (Park & Mackay, 2003).

The stored data offers valuable insights into the historical performance of the battery. By analyzing the stored data, it can reveal patterns of usage, identify abnormalities, and observe trends over a span of time. This type of information is valuable when assessing battery health, optimizing system performance, and when making decisions about upgrades, maintenance, or replacements (Reza et al., 2024).

4.4 Different DAS technologies

There are three relevant types of DAS technologies: edge, cloud, and hybrid. These are not distinct types of DAS systems themselves. Instead, they describe architectures or data handling approaches that a DAS system can use.

4.4.1 Edge DAS

Edge DAS uses local processing powers to analyze data before sending them to a central server or cloud. In this way, decisions can be made locally based on algorithms running on edge devices, which improves the response times (Bigelow, 2021).

An example of how edge DAS can be used is that if it detects a thermal runaway risk, the smart controllers can immediately start cooling actions without waiting for a cloud-based system to analyze and respond (Bigelow, 2021).

The advantages of edge DAS in BESS is the almost instant processing time, since data is analyzed closer to the devices. This means that data can be processed in real-time within the same environment in which it was created. This is critical for safety, especially for BESS installations. Instead of sending loads of raw sensor data further for analysis, only the most relevant data are transmitted. As a result, it minimizes data storage costs (Earney, 2022).

Edge DAS remains functional even with network disruptions, as edge devices can continue to operate and make decisions locally. Since edge DAS tend to hold minimal amounts of data, they are also less vulnerable to cyberattacks. This is because hackers will only access a small amount of data, rather than complete datasets. Furthermore, sensitive BESS data do not need to leave the local storage, further reducing the risk of exposure (Bigelow, 2021).

The disadvantage of edge DAS is the high hardware cost. The system requires edge computing devices at multiple points, increasing the cost. The system is also more complex, which means that more devices will require updates, security, and monitoring (Saini et al., 2022).

4.4.2 Cloud DAS

Cloud-based DAS uses cloud computing to store, process, and analyze data remotely. Unlike Edge DAS, where the data is processed locally, cloud DAS transmits sensor data to remote cloud servers for analysis (Earney, 2022).

The advantages of cloud DAS are that all BESS data are stored in a scalable cloud environment, making it accessible from any location. Operators can therefore monitor multiple BESS sites remotely, reducing on-site visits (Earney, 2022). Cloud-based DAS also minimize the need for expensive infrastructure as the cloud provides storage, computing power, and security. It is also easily scaled to adapt to the growing energy storage infrastructure (Microsoft, n.d.-a).

The disadvantages are that data must be sent to the cloud and processed before decisions are made, causing delays in critical operations, unlike edge DAS. As cloud-based systems are dependent on connectivity and the internet, the cloud-based DAS will be temporarily useless if the system fails. This can cause delays in critical BESS insights (Fazeldehkordi & Grønli, 2022).

Cloud DAS also operate on pay-as-you-go pricing (Fazeldehkordi & Grønli, 2022). This can both be an advantage and a disadvantage. With that pricing, users are able to access remote resources and services, and they will only be charged for the number of resources they use. On the other hand, these types of pricing will lead to recurring costs for data storage, analytics, and bandwidth. This means that long-term expenses may exceed initial costs (Fazeldehkordi & Grønli, 2022).

Lastly, cloud-based DAS raises cybersecurity concerns. For example, there is a risk of cyber-attacks and limited security controls on data, loss of connection, security standardization, and sufficient authentication. This is a result of an open environment that makes data more accessible and creates security vulnerabilities which potential attackers can exploit. It can allow attackers to, for example, inject malware, modify control data, or block data transfer (Wali & Alshehry, 2024).

4.4.3 Hybrid DAS

A hybrid DAS combines edge and cloud DAS infrastructure. It enables real-time data acquisition and control at the edge while using cloud resources for large-scale storage and analytics (Parmar, 2024).

By integrating these two technologies together, several key benefits can be achieved. Edge DAS could offload certain tasks from the cloud DAS, enhancing overall efficiency and performance. Once processed, the data can be sent to a cloud system, either for further analytics, or for long-term storage. This hybrid approach allows for more critical data to be processed and stored locally while less sensitive data can be handled by the cloud. For added security, data can be encrypted at the edge before being sent to the cloud. Additionally, in the event of temporarily cloud interruptions, the edge DAS would still be able to operate independently, ensuring continuous data collection and maintaining system functionality (Parmar, 2024).

The disadvantages are that the system is exposed to multiple entry points, increasing the risk of cyberattacks. Moreover, data breaches and vulnerabilities can occur during the communication between edge and cloud DAS. Therefore, it requires robust data synchronization and network security mechanisms (Alwakeel, 2021). Another disadvantage is the high costs. As a hybrid DAS requires both edge devices and cloud infrastructure, it will require higher overall costs. This is due to the involvement of multiple devices, which results in increased maintenance demands, including the need for regular updates and scalable system management (Hewlett Packard Enterprise, n.d.).

4.5 Current battery trustee and data extraction

This chapter is divided into two different sections. The first section introduces the trustee of the battery parks, followed by the second which describes the current setup and how the data are extracted from the BESS.

4.5.1 Solar and Batteries

The business unit Solar and Batteries (SoBa) is the current trustee of several battery parks. SoBa operates within Vattenfall's business area wind which is responsible over Vattenfall's renewable activities within wind, solar photovoltaic and battery energy storage. Solar and Batteries is in charge of developing large-scale solar and battery technologies with the goal of achieving fossil-free energy efficiency through profitable solar and battery assets (Vattenfall, n.d.).

4.5.2 Extracting the data

A simplified visualization of the current setup is presented down below:

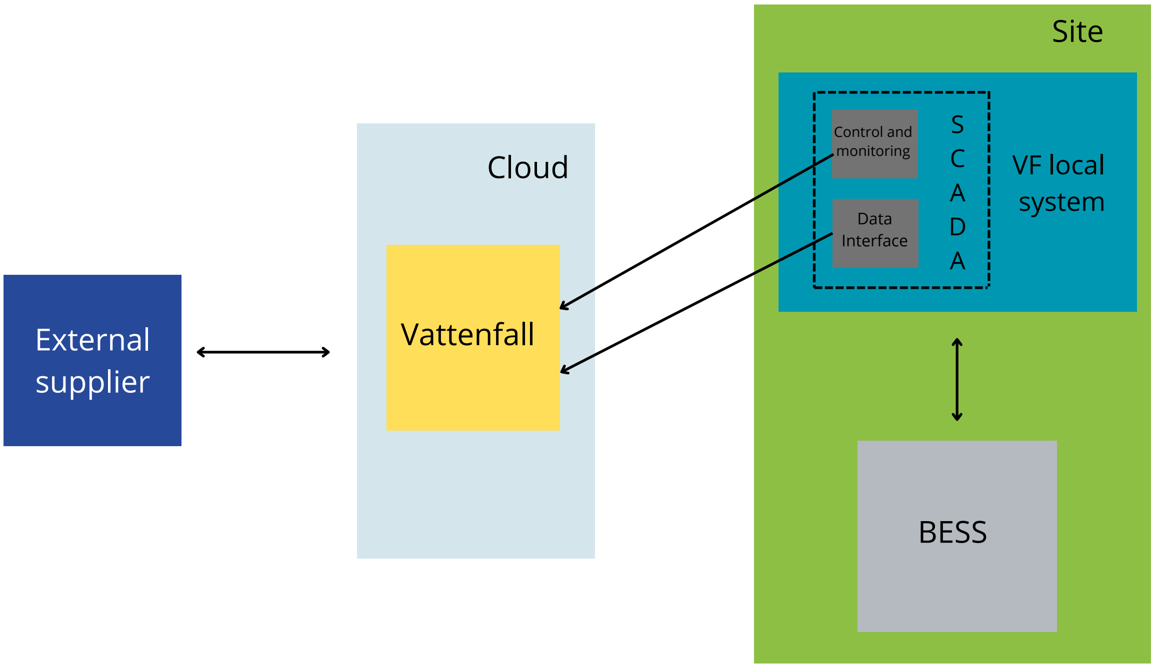

Figure 1: Current setup of the system used by SoBa.

As seen in Figure 1, the BESS is managed locally by Vattenfall's local system that includes SCADA and real-time data are collected through sensors. This data is then processed and transmitted to Vattenfall's cloud storage system. From there, the collected data can be used by operators for analysis or comparison between the BESS. Today, this process is performed by both the SCADA control and monitoring part as well as the data interface layer (see Figure 1). The data interface layer performs functions typically associated with a DAS. As this interface is embedded within the SCADA, the system are considered integrated.

SoBa also uses an edge system that functions as an interface between the data collection and the cloud storage. The technology used for this setup is therefore a hybrid solution (see Chapter 4.4.3).

5 Separation of DAS and SCADA

The DAS is today integrated with the operational part of SCADA (see Figure 1). When integrated, SCADA has the responsibility for both the monitoring and data logging. The advantage of this integration is the optimized industrial automation and the reduced amount of components in the system. However, the downside is that the operational part of the SCADA system will carry a larger load, making it an operational risk.

In the new case, these two systems are separated. A new DAS device is introduced and continues to extract data, but now by having a direct sensor input from the BESS. This differs from the earlier setup where the DAS layer used the same input sensor as SCADA. The operative part of SCADA will then only need to focus on real-time monitoring, while DAS manages the data collection and the transmission of the data to storage systems.

The risks presented in the following section, include system overload and cybersecurity vulnerabilities, which are applied directly to the Vattenfall's existing architecture. The analysis highlights how these risks can be mitigated through an implementation of a separate DAS system. A cost aspect is also introduced, outlining both the potential savings and added expenses associated with this new setup.

5.1 Operational risks

Having DAS and SCADA integrated introduces operational risks. Some key challenges include system overload and performance bottleneck, where large volumes of historical and real-time data can lead to potential system failures (Smart Vatten, n.d.).

5.1.1 System Overload and Performance Bottlenecks

SCADA primarily handles real-time control and monitoring, while DAS focuses on detailed data logging and analysis. When integrated, they could overload the system, causing latency in control actions and delayed data retrieval (Smart Vatten, n.d.).

By separating the two systems, SCADA can remain focused on real-time monitoring and controlling the various parameters without risking overload or performance delays. It reduces the additional burden of data logging and analytic tasks (Renewable energy integration group, 2024). The DAS can continue operate independently which ensures that data processing does not interfere with the operational control managed by the SCADA systems. It allows for data analysis without compromising the responsiveness of control operations (Renewable energy integration group, 2024).

The separation can also simplify troubleshooting and maintenance, as issues can be more easily identified and contained within their respective systems. This reduces the risk of fault propagation and general system failures (Renewable energy integration group, 2024).

5.2 Cybersecurity risks

The main problem with the integration of SCADA and DAS is that DAS handles large amounts of data coming from SCADA, which are often stored on the cloud or other storage platforms. If an attacker gains access to DAS, the breach could potentially open a path to SCADA and allow the attacker to gain direct control of critical systems or, in the worst case, perform physical damage to the BESS (Dixon, 2024). The following section describes how DAS integrated with SCADA can pose cybersecurity risks and how a separation of the two systems can benefit.

5.2.1 Potential risks and solutions

Weak authentication and authorization are two of the vulnerabilities. If DAS and SCADA are integrated, attackers can manipulate DAS data which leads to SCADA basing its decision on incorrect information. The absence of multi-factor authentication and poor access controls form security gaps which attackers can exploit and gain access to. By having very basic authentication and authorization, makes it easy for attackers to crack it and gain access to the SCADA environment. Separating the two systems can therefore reduce the risk of SCADA's operational part using incorrect data to monitor the BESS (Skrodelis et al., 2024).

It is also recommended to configure the authentication per user and to use authorization and logging controls. A token-based authentication can also be implemented, which adds an extra layer of security by requiring digital token (often as a one-time code) in addition to a password (Alcala, 2021). It is also very important to strengthen the authentication measures, implementing complex passwords and multi-factor authentication (MFA) to reduce the risk of unauthorized access (Dixon, 2024).

Insufficient network segmentation and poorly defined security perimeters allows attackers to get into the DAS system and then the SCADA system, potentially compromising critical infrastructure. It can for example lead to unauthorized access and data breaches. A weak network design or if DAS and SCADA share the same network, makes cyber threats even more dangerous as it is easier for ransomware or malware to spread from DAS to SCADA. This underlines the need for strong and clearly defined security measures (Skrodelis et al., 2024).

One of the solution is to separate the two systems but also more proper network segmentation. This includes isolating key components and using firewalls which helps restrict unauthorized access and reduces the impact of potential cyberattacks (Dixon, 2024). Another alternative is to separate the SCADA network into different zones based on their functions and risk level. This improves security by preventing intrusions from spreading. By implementing strict access controls, only authorized operators can access important SCADA components which strengthens the networks protection. This solution also makes it harder to access every bit of SCADA information if an attack occurs in the DAS system (Skrodelis et al., 2024).

Outdated software and firmware in SCADA systems is a big problem today as it increases the risk of an attacker gaining access to the DAS system and later to the SCADA system. Attackers can exploit weaknesses, as many systems no longer receive security updates while running on outdated operating systems. From this, attackers can gain unauthorized access or disrupt operations. To reduce this risk, regular updates should be applied to ensure that the system continues to be protected against known threats (Dixon, 2024). Regular vulnerability assessments are also crucial as it helps identifying and addressing potential vulnerabilities in SCADA systems. It could involve scanning the system for weaknesses, such as outdated software, misconfigurations, or weak authentication mechanisms. This helps organizations to catch these vulnerabilities before they are exploited by cyberattackers (Dixon, 2024).

5.3 Cost aspects

When separating SCADA and DAS from each other, both additional and reduced cost can be expected. This change in architecture will introduce new expenses related to hardware, integration and maintenance but can also result in significant long-term savings. Understanding the cost trade-offs is essential for evaluating the feasibility and benefits of separating these two systems.

One added cost from separating DAS from SCADA is hardware and infrastructure costs. These include additional servers, storage and network equipment which are necessary to support the operation of DAS (Smith, 2024). Added cost for software and license may also arise when implementing a separated DAS as it often requires a new software license. This typically includes the core DAS platform along with any required data handling component to store and organize the collected data. In many cases, system customization is also needed to ensure compatibility between DAS and the existing SCADA infrastructure (Dewesoft, n.d.-b).

Implementation and integration costs are also something to consider. These costs usually include engineering and IT labor for the system setup, configuration, and testing. The price will depend on factors such as system architecture, the vendor, and data format (Meta bytes, n.d.).

Maintenance is also an added cost and includes ongoing IT-support for tasks such as software updates, hardware replacements, troubleshooting, and regular system checks to prevent failure (A. Erickson, 2023). Additionally, robust cybersecurity measures are often required to prevent sensitive information to leak, which adds to the total cost. Maintenance cost and support can be incorporated into the price when buying the DAS but can also be a separated cost (Meta bytes, n.d.).

The separation also comes with reduced costs. As SCADA no longer will be responsible for data collection tasks, it will reduce the processing loads, leading to improved performance. This will result in fewer maintenance requirements on the operational side. SCADA will be relieved from heavy data logging tasks, reducing risk of latency delays and system failures. This will lead to long-term cost savings (SCADA info, n.d.).

Additionally, separating these systems lowers data processing and storage costs within SCADA. Since SCADA generate large volumes of data which requires storage and analysis, moving these functions to a separated DAS, reduces the need to store large datasets as well as decreasing the server and storage costs (SCADA info, n.d.).

5.4 The separated DAS system

Below is a simplified image over the setup with the new separated DAS included.

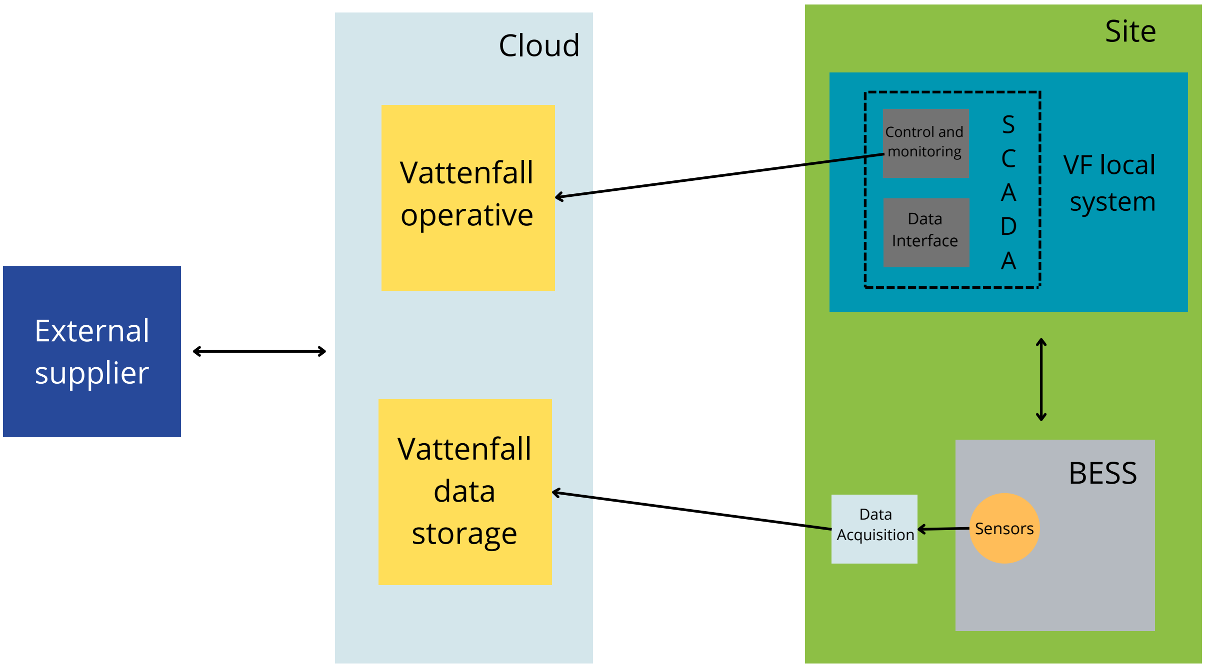

Figure 2: Visualization of the new system with the DAS solution.

In the new setup, the DAS system is directly integrated into the battery sensors. The operational part solely handles the real-time monitoring and the control, leaving the data logging to the DAS. The operational part of SCADA then reports directly to Vattenfall's operative section and the DAS to the data storage of Vattenfall. This representation acts as a guide for how the whole setup would look like with the new implemented DAS system.

In the following section, three different solutions from suppliers are displayed. Though, the images in the solution section only included the DAS hardware setup. Therefore, Figure 2 is used for a more general overview of the new system with the separated DAS.

5.4.1 DAS setup solutions

The following section introduces the three different DAS solutions. It describes how the hardware operates, their scalability, pricing, and how they integrate with storage systems.

Solution 1

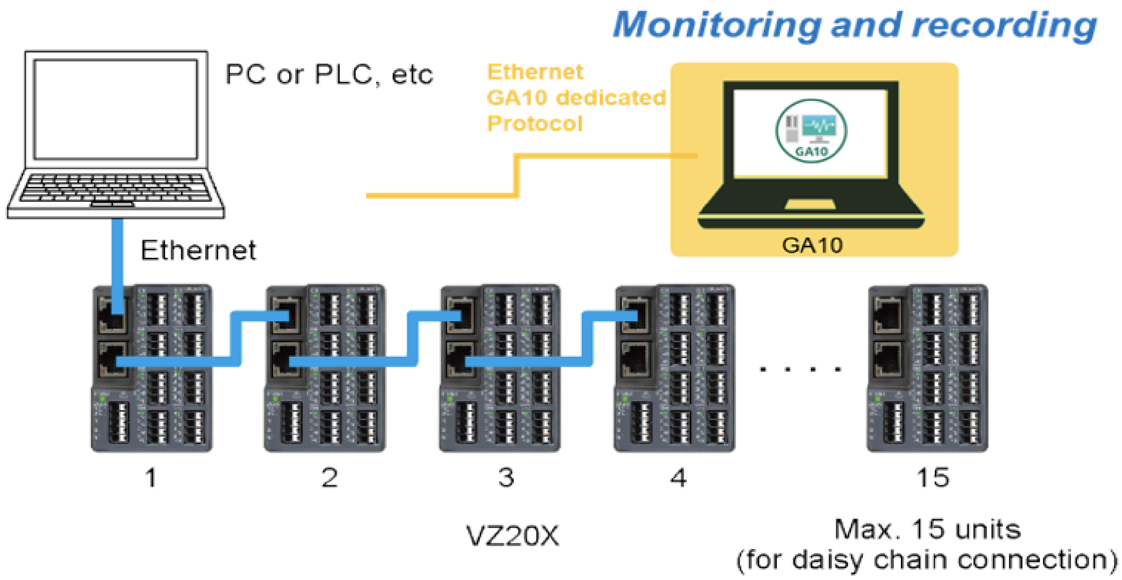

Figure 3: Set up of solution 1(Yokogawa, 2025).

The first solution suggested by Yokogawa can be seen in Figure 3. Yokogawa is the leading provider of industrial automation and test measurement solutions, based in Japan. They have a history in control systems and instrumentation, providing hardware and software solutions for industries such as energy, manufacturing and infrastructure (Yokogawa, n.d.).

This system serves as a high-precision DAS device which collects analog signals from numerous sensors and transmits them to a host system for analysis. The life span of this solution is over 30 years.

This solution is based on a compact analog sensing unit (VZ20X) which is directly connected to the external sensors. These sensors measure parameters such as voltage, frequency and temperature and produce a corresponding analog signal.

The VZ20X uses high-speed A/D converters to digitize the analog signal. The device is built up on a chain connection with a maximum of 120 channels on 15 units. Each unit can be mounted in a container and connected with Ethernet to each other. Therefore, multiple channels can be measured all at once. VZ20X samples signals with a rate as fast as 1 ms. This is the step in data extraction where the raw input is converted into digital values that the system can understand and use. After being processed, the digital data are transferred, using Ethernet, to a storage system.

Solution 1 is centralized when it comes to data logging setup, but the DAS hardware is distributed as the VZ20X units are divided between the battery containers. The units are treated as single systems, but they are all transmitting their data and information through one central software, the GA10. GA10 serves as logging software to collect and analyze historical data before sending it to a storage system.

In this solution, an external server is required for data storage where the GA10 software can be installed for monitoring and recording of the devices. It supports multiple devices and allows for display screens, making it suitable for various industrial implications.

Solution 2

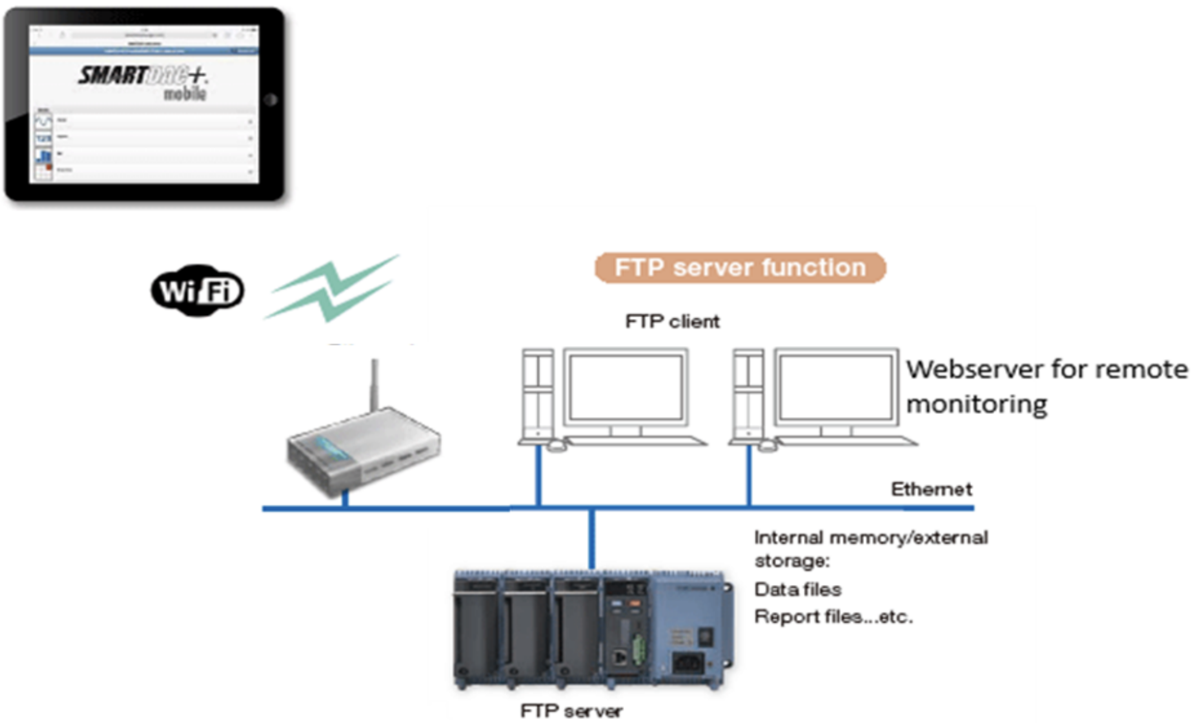

Figure 4: Set up of solution 2 (Yokogawa, 2025).

The second solution is also by Yokogawa and the setup can be seen in Figure 4. The setup uses a modular data acquisition and control system called SMARTDAC+ GM. It is used for measuring, and monitoring various types of input signals. The SMARTDAC+ GM system receives analog signals from connected sensors to extract the data. The sensors are wired into analog input modules. Each module supports multiple sensor channels, allowing the system to collect data from many sources at once.

Like solution 1, the analog signal is converted to a digital value using the systems built-in A/D converters. The SMARTDAC+ GM system also supports high sampling rate. Similar to solution 1, the system is capable of recording data at intervals as short as 1 ms.

In this solution, there are two choices. Either a centralized system, where there is one main unit where each container is connected to. The other option is a decentralized setup. This means that devices can be put in each container, bringing the data acquisition closer to the actual sensors. In that case, the users need to consider the need to add four different devices where each has to be placed in each battery container. These systems are: Power supply module GM90PS, GM90MB base module, GM10 module (1 per container) and GX90XA, an input module with a max of 10 channels. GM90PS powers the other modules in the container. GM90MB is the physical board in which all modules are plugged into. GM10 is the control module which handles signal processing, data logging and communication. GX90A receives signals from the sensors. Together, they operate by logging and processing the data and then forwarding it to a cloud storage using Ethernet.

The data can also be stored, either in the internal memory or SD cards, depending on system configuration. This local storage feature allows for long-term data logging and buffering during network outages. This means that the system will be more reliable and continue to log data without the need for continuous external connectivity. It can then transmit the data further to a cloud storage when the connection is restored.

As solution 2 does not have a viewing software like GA10, it is not possible to make advanced visuals. Though automatic extraction of raw data on an FTP server is possible. Trending in graphical views and as a sheet are available through a web server.

This solution also has a life span of over 30 years and the cost of having a centralized system cost 27% less than solution 1. When considering a decentralized system, it is important to note that the cost will increase.

Solution 3

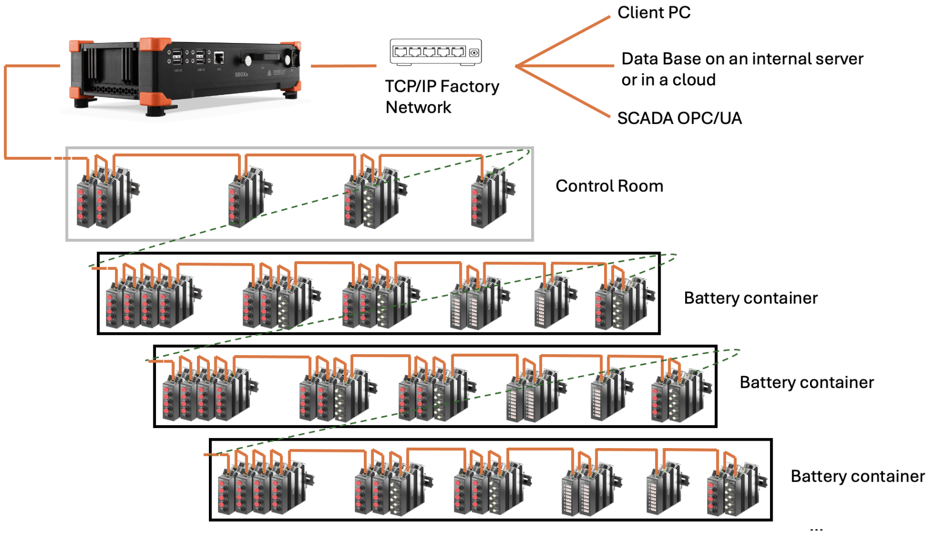

Figure 5: Setup for solution 3 (Dewesoft, 2025).

The third solution is provided by Dewesoft and setup is shown in figure 5. Dewesoft is a Slovenia based company that designs and manufactures systems within data acquisition, signal processing and testing. Dewesoft's systems are used in various industries such as energy, automotive, aerospace and research (Dewesoft, n.d.-a).

The components within the battery containers constitutes of Dewesoft IOLITE Modular system which is a highly flexible and scalable DAS. IOLITE modular is designed for both real-time monitoring and data recording. The system also uses Ethernet for Control Automation Technology (EtherCAT) as communication protocol, which ensures real-time data transfer and synchronization accuracy down to 1 ms. EtherCAT is a real-time industrial Ethernet protocol. This is a set of rules that lets devices, such as computers or sensors, communicate over a wired network.

The setup are also daisy-chained, meaning that the unit are connected in series. With the IOLITE components, parameters such as voltage, current and temperature can be measured. By placing these DAS units as close as possible to the sensors, the system can reduce signal noise and ensure better electromagnetic immunity, which is essential in electrically noisy environments, such as in BESS. This design not only simplifies wiring but also enhances system reliability and scalability.

All data are preprocessed in the IOLITE DAS units before they are transmitted to the DAS master device, a SBOX, using EtherCAT. The SBOX is a powerful data processing computer and data logger. It acts as a central controller for Dewesoft's IOLITE system. The SBOX is connected to a TCP/IP (Ethernet) and can therefore send the data forward to client PCs, internal servers or cloud storages.

The Dewesoft system is built for a life span of over 10 years and as it is connected in daisy-chains, the system is easily expandable. This is as new DAS units can be added to the chain as needed. Due to the single-cable architecture, the installation time is reduced and the overall cost depends on the amount of channels.

5.4.2 DAS comparison

Table 1 shows the three presented solutions compared to one another based on different features.

Table 1: Comparison of the different DAS solutions.

Feature	**Solution 1**	**Solution 2**	**Solution 3**
Direct sensor input	✓	✓	✓
Compatible with cloud storage	✓	✓	✓
High scalability	✗	✓	✓
Fully modular and expandable from start	✗	✗	✓
Built - in storage	✗	✓	✗
Sampling rate of 1 ms	✓	✓	✓
Cybersecurity	✓	✓	✓
Long lifespan	✓	✓	✗
Low cost	✗	✓	✗

From the table, it can be seen that all the solutions have direct sensor input, sampling rate of 1 ms, and good cybersecurity measures. However, parameters such as scalability, storage, lifespan and cost are more critical and require more comparing.

6 Case study

In this section a case study has been conducted. It aims to evaluate the data which are transferred between the DAS and the cloud storage. Specifically, it focuses on studying the file sizes across three different data formats. The purpose of this analysis is to guide decisions regarding requirements of the DAS, as well as to estimate the necessary bandwidth for the battery park. As modern BESS installations often rely on real-time data logging and remote control, it is essential to ensure that the communication of the future DAS system can support efficient data transfer.

6.1 File comparison

A pivot table of a site with five battery containers and a control container was provided by Vattenfall. This table was the base for modeling it further in the program MATLAB. The idea was to create a dataset that mirrors the data output from an operational battery site. To achieve this, each column in the pivot table was transposed into individual rows in the dataset, with each row representing the amount of data coming from each parameter of one battery container. The dataset was constructed to simulate one hour of operation, with each parameter divided into sensors according to data frequency. This was done to simplify differentiation between data originating from sensors operating at various sampling rates. The resulting table was then chronologically ordered based on time and then exported into three file formats: Comma-Separated Value (CSV), JavaScript Object Notation (JSON) and Extensible Markup Language (XML). CSV is a file format which stores data in a table format, where each column is separated by a comma. While it can adapt to various types of software environments, it is most commonly used to communicate with Microsoft Excel (Adobe, n.d.). JSON is a text-based format, widely used for both exchanging and storing data. Originally, created to seamlessly work with Javascript, it is now supported by almost any programming language (J. Erickson, 2024). XML uses a hierarchical tree structure, often referred to as an XML tree. The file format is primarily used to structure and classify data (Microsoft, n.d.-b). These formats were chosen based on their common use in BESS. They represent levels of structure and verbosity, making them suitable for comparing how file format affects bandwidth usage.

By comparing the three formats, a comparative analysis of file size and structure across formats was performed. The result of the simulation is presented in the following diagram:

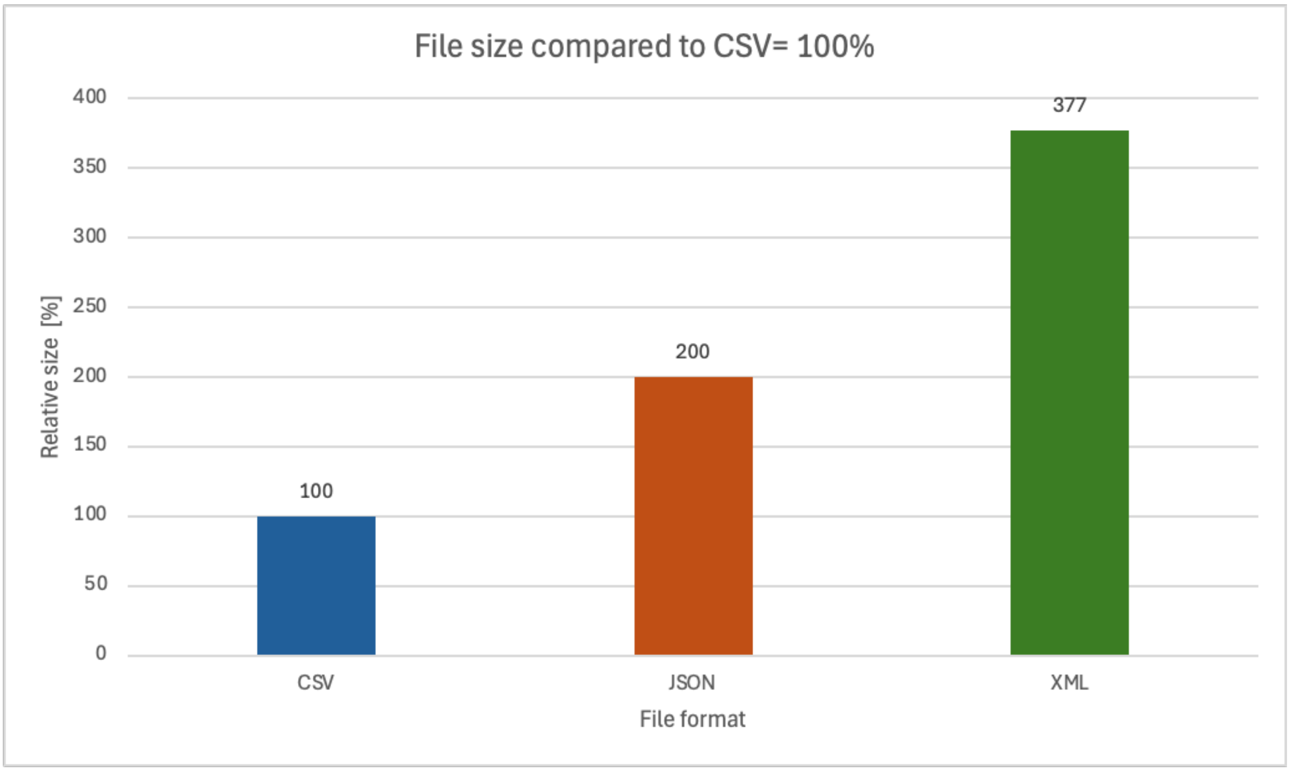

Figure 6: File sizes normalized to CSV format.

From the diagram, it is clear that the CSV file format is significantly smaller than the rest of the two. JSON files are approximately twice as large as CSV and XML files are nearly four times the size. Thus, CSV files are faster to transmit as they consume the least storage. This is essential for low-latency communication.

This results directly affects the transmission time, particularly under low bandwidth conditions. This is further investigated in section 6.3.

6.2 Divided file format

During the modeling process, the dataset was also divided into smaller segments to assess whether the size would influence the transmission performance. Instead of transmitting one big segment with one hour's worth of data from the battery park, the data was divided into 12 segments, each capturing five minutes of data. This approach was used to evaluate whether smaller, more frequent transmission would generate different results compared to a single larger transmission.

The results indicated that segmenting the data into five minute intervals, did not affect the overall transmission efficiency. Transmitting 12 smaller segments resulted in the same total data load as sending one larger segment.

However, it is also important to consider the associated cost implications. If the dataset is divided into multiple smaller segments, higher processing requirements will be introduced. This is because each segment needs separate handling, packing and transmission processes. Therefore, this could lead to increased computational demands and high system resource consumption, making the cost aspect of it essential to keep in mind.

6.3 Speed comparison

To go deeper into the case study, the three different file formats were compared by examining how they would impact the use of available network bandwidth during the transmission of data from the DAS to a cloud storage. The chosen rates were 1000 Mbit/s (fiber), 100 Mbit/s (Ethernet) and 50 Mbit/s (mobile broadband). It is important to note that during the transmission window, the full bandwidth is occupied by the data transfer. This means that, during this period of time, temporary network interruption may occur. It can also affect the responsiveness or communication within the battery site.

Table 2 shows how the three data formats, CSV, JSON and XML, affect the transmission times under various network conditions. From the table, it can be concluded that while the choice of file format makes little difference over fiber, it becomes significantly more important under lower bandwidth conditions such as for Ethernet or a mobile broadband. Thus, the CSV format was shown to be more efficient in constrained network environments.

Table 2: Comparison of different bandwidth rates which impact the data transmission time within the battery site.

Different speed	**CSV**	**JSON**	**XML**
Fiber - 1000 Mbit/s	0.1 s	0.2 s	0.4 s
Ethernet - 100 Mbit/s	1 s	2 s	4 s
Mobile broadband - 50 Mbit/s	2 s	4 s	8 s

During these transmission windows, the network bandwidth may be fully occupied by the data transfer process. Therefore, it can lead to network disruptions, latency spikes and temporarily affecting the responsiveness or communication within the battery site. For example, transmitting a large XML file over a mobile broadband connection would result in up to eight seconds of total bandwidth occupation. This is remarkably longer than the other formats which increase the risk of delayed control signals or disrupted coordination with other site components during this time.

Furthermore, this analysis acts as a guide to inform the design and specification of the DAS itself. By understanding how different file formats perform over different bandwidths, stakeholders can make more informed decisions when selecting data formats for transmission, especially on sites where bandwidth may be limited. The results of this case study serve as guidance when choosing both the communication infrastructure and the internal data handling strategies of the DAS to meet operational and performance requirements.

7 Discussion

This chapter of discussion is divided into four different sections. The first explains the separation of DAS and SCADA, outlining the advantages and disadvantages of keeping these systems separated. The second discusses the three proposed solutions, analyzing which configuration and setup would be the most ideal for the intended purpose. The third focuses on the bandwidth of the park, comparing the three file formats and determining the most suitable one. The fourth and final section highlights the potential of future research, suggesting areas that could be further studied.

7.1 The separation of the two systems

The separation of DAS and SCADA involves several important considerations. While the integration of these systems offers optimized automation and reduced amount of components, the separation provides even greater benefits in many cases. When being separated, SCADA only has the responsibility for monitoring and controlling the BESS, leaving the data logging tasks to DAS only. This reduces system overloads and performance delays as it reduces the burden of additional data collection and analysis from SCADA. It also improves the cybersecurity measures by reducing the risk of a cyberattack. This is achieved by improving weak authentication, insufficient network or outdated software and firmware. These measures reduces the risks of attackers gaining access to the DAS and later the SCADA environment.

The cost aspect should also be taken into account. The separation of DAS from SCADA comes with both added and reduced costs. As a new architecture will be introduced by adding a DAS, cost of servers, storage, and network equipment will arise. Implementation and integration costs, as well as robust cybersecurity measures, will also be added. The reduced cost includes fewer maintenance requirements, as the separation of these systems will result in less latency delays and system failures. It will also lower data processing and storage costs within SCADA.

Both the potential savings and the additional expenses associated with the separation play an essential role in the decision-making process. However, the final choice depends on the user's budget and by weighing the disadvantages and advantages of the operational and cybersecurity risks.

7.2 The three solutions

When comparing the three different solutions, the advantages and disadvantages need to be studied. For all solutions, the sampling rate can be up to 1 ms and they all have the possibility of having direct sensor input which enhances the cybersecurity as the DAS solution will not be directly connected to the operational part of SCADA.

For solution 1, the system is more compact compared to the other two and supports series connection up to 15 units. It is integrated with the GA10 software which enables logging and visualization. It also has a high lifespan of 30 years. However, the disadvantages are that it lacks a built-in storage and display, making it rely on external software for data management. The system is also one of the most expensive systems since the units of the VZ20X system are a high precision and compact analog input device. These are made for fast sampling and accuracy, which makes them more expensive. By connecting these units in a series, leads to a rapid increase in the cost.

For solution 2, the advantages are the high lifespan, as solution 1, and the flexibility of being able to choose either a centralized or decentralized solution. The centralized solution is the most inexpensive one while for the decentralized option, users need to keep in mind that four extra devices need to be added in each of the battery containers. This can therefore increase the cost. The SMARTDAC + GM system also includes a built-in data storage as well as a web-based interface for configuration and real-time monitoring. On the downside, while being modular, the system may need more physical space as it is not as compact as solution 1. This may limit the total number of modules that can be connected per unit.

For solution 3, the advantages are that the system is connected through daisy-chain and the distributed setup allows the DAS to be closer to the sensors in the BESS. It also simplifies the wiring and cable setup, as well as the expansion, making it easy to add new units. The disadvantage of this solution is that it may require special support and configuration as it relies on EtherCAT. The setup is also less suitable for small-scale systems or setups which require centralized monitoring. As solution 3 are based on a per-channel pricing, which easily can rise in price depending on how many channels the users want to measure, this solution is considered expensive. Though, it is easier to scale and keep track of the cost when expanding compared to the other two solutions.

Based on the discussion of the three different solutions, the two best suited for this system setup are solution 2 and 3. As all three solutions have direct sensor input, the decision will come down to the architecture of the DAS setup. Specifically, the parameters which will determine are scalability, storage, and cost.

Solution 3 is highly expandable as new units can be added when in needed. Each unit is also placed close to the sensors which reduces signal degradation and simplifies the wiring. In solution 3, there are also specific DAS for each of the parameters, for example voltage, current, and temperature. In addition to its modularity, the per-channel pricing offers an effective way of growing the system while being able to keep track of the costs.

Likewise, solution 2 offers high scalability and a choice between a centralized or a distributed solution. The second mention enables the ability to expand and customize, allowing users to add units as needed. The difference between solution 2 and 3 is that solution 2 requires more space and wiring effort when wanting to expand it. Therefore, when considering scalability, solution 3 is preferable. Unlike solution 3, solution 2 has its own built-in storage. This enables standalone operation and resilience against sudden network outages. This means that the system will continue to log data locally and forward the data to the cloud when the connection is restored. Solution 1 and 3 do not have the same local storage, which means that if the connection between the DAS and the cloud breaks, data may be lost unless they have local buffering. The centralized setup of solution 2 is also the most inexpensive one, and the solution also offers a web-based interface where operators can track real-time monitoring.

7.3 Bandwidth of the battery park

When considering the bandwidth of the battery park with these potential DAS solutions, it is important to choose the right format. From the case study (Chapter 6), it is clear that when fiber is available, the choice of file format is insignificant. According to SoBa, all three bandwidth rates exist in their battery parks. They use whatever is available. This highlights the importance of choosing the right file format for DAS to avoid large gaps where the network bandwidth is fully occupied. As all solutions use Ethernet to send data to the cloud storage, the CSV format is recommended based on Table 2. With this choice, the bandwidth will only be occupied for 1 s, compared to 2 s and 4 s for the format JSON and XML.

However, shifting focus from the bandwidth rate, the benefits of XML and JSON include being more readable for operators. Compared to CSV, the data are more structured and organized. Therefore, they can be used for back-up logs as they are easier to understand in terms of using the data for human analysis.

7.4 Future research

In a future research, a validation of the selected DAS solutions could be performed. This could be done by conducting a pilot implementation in a live battery site, followed by analyzing its performance. The study could include testing all the parameters included in Table 1, but also installation and maintenance requirements, since the selected DAS would be tested in a real battery environment. Together with the validation, the future research could examine how each system behaves when scaled to hundreds or thousands of channels across a large-scale battery park. As mentioned above, it could include an analysis regarding the performance and the compliance.

Another idea of a future study could be to use both Artificial Intelligence (AI) and Machine Learning (ML) to further help monitor and collect data. The research could investigate how both systems could improve the monitoring of DAS. This could include automatically identifying performance trends, abnormalities, or early signs of component failures. As management teams spend a lot of time on data collection after the data have been sent to a cloud location for storage, AI and ML could enhance this efficiency. By studying how these two systems could be integrated into the data acquisition, the research may explore algorithms to automatically label, clean, prepare, and categorize sensor data. This would help to reduce the manual postprocessing time as well as the eventual manual errors. This could lead to improved data accuracy for long-term analysis and give more time to share data to mobilize action. Using AI and ML could also enhance the cybersecurity, as they would discover threats and identify unusual patterns much faster.

8 Conclusion

This thesis has investigated alternative ways to separate DAS from SCADA. From the research, it can be concluded that the separation of DAS from SCADA can be done by excluding the operational part of SCADA from data logging tasks. Instead, it can focus solely on monitoring and controlling the BESS while the DAS manages the data collection and the transmission of data to storage systems. The advantages of this separation are the ability to limit system overloading or performance delays as the operational part of SCADA no longer will carry the burden of both data collection and monitoring tasks. The separation also improves cybersecurity measures. By improving weak authentication, insufficient network or outdated software and firmware will help reduce cyberattacks in which attackers can gain access to the SCADA system through DAS. The cost advantages include reduced costs in data processing and data storage since SCADA will be released from heavy data logging tasks. It will also result in lower maintenance cost, as the separation will reduce the risks of latency delays and system failures.

However, the disadvantages are that when SCADA and DAS are integrated, they optimize industrial automation and reduce the number of components in the system. The separation can also include added costs, such as additional hardware and infrastructure costs. This can include additional servers, storage, or network equipment. Expenses associated with implementation and integration can also contribute to additional costs. These often include engineering and IT labor for the system setup and configuration.

The thesis also presents various solutions offered by different suppliers with a focus on security, scalability, and cost. These solutions are: solutions 1, 2 and 3. While all the solutions fulfill the cybersecurity requirement of not integrating into SCADA's operational part by having direct sensor input, solution 1 does not meet the key requirements. Solution 1 is the most expensive out of the three and has limited scalability. Solutions 2 and 3, on the other hand, are more expandable. Based on budget and how the operators want the system to be setup, they can choose between solution 2 and solution 3.

For solution 2, offered by Yokogawa, the users can customize if they would like a centralized or decentralized solution. Either there is one main unit in which each container connects to (centralized), or a setup where each control module can be placed in each of the battery containers (decentralized). For the later setup, the users need to consider adding four different devices in each of the containers to be able to make the system work. The centralized version of solution 2 is the most inexpensive one. Solution 2 also comes with its own built-in storage and has a high lifespan.

For solution 3 by Dewesoft, each unit is chosen to measure each of the parameters and is placed close to the sensors. This solution, unlike solution 2, is fully modular and distributed from the start without the need to add more systems to work efficiently. In this solution, there is also one central control unit, the SBOX, which each IOLITE unit transmit its data to. Solution 3 also bases its pricing per channel, which can become costly depending on the number of measurement channels required. Though, this solution makes it easy to expand the system while keeping track of the cost.

When it comes to the requirements of the new DAS, this report has been studying the bandwidth of the battery park by conducting a case study. It involves analyzing three different file formats, comparing storage space and the bandwidth they consume while being transmitted. The study shows that when fiber is available, the file format used by the DAS makes a little difference. This is because the transmission time is sufficiently small across all file formats. Though, when using either Ethernet or a simple mobile broadband, the file format plays a more essential role. This is because JSON and XML are twice and four times larger than CSV. This results in CSV being the most well-suited file format to use for the new DAS as it does not occupy the bandwidth in the same way as the other two formats. As all solutions use Ethernet to transmit the data to a storage location, CSV would be the preferred format to select for the new DAS.

Based on all analyses, the recommended solutions for BESS are solution 2 by Yokogawa and solution 3 by Dewesoft. These solutions are the most preferable when choosing a new DAS setup, along with the CSV file format for transferring data to a cloud storage using Ethernet. How to choose between solutions 2 and 3 is based on the user's budget, as they differ in cost, as well as in scalability and storage. This is because the two solution has two different approaches when it comes to expanding the units in the systems. When considering storage, users need to think about how much they value having a built-in storage.

References

Adobe. (n.d.). *What is a csv file?* https://www.adobe.com/acrobat/resources/document-files/what-is-a-csv-file.html [2025-05-28].

Alcala, F. (2021). *Protecting scada systems from cyber-attacks*. https://www.compassitc.com/blog/protecting-scada-systems-from-cyber-attacks [2025-03-17].

Alwakeel, A. (2021). *An overview of fog computing and edge computing security and privacy issues*. https://pmc.ncbi.nlm.nih.gov/articles/PMC8708798/#sec3-sensors-21-08226 [2025-02-11].

Bigelow, S. (2021). *What is edge computing? everything you need to know*. https://www.techtarget.com/searchdatacenter/definition/edge-computing [2025-02-11].

Dewesoft. (n.d.-a). *About us - we are dewesoft!* https://dewesoft.com/about-us [2025-06-10].

Dewesoft. (n.d.-b). *Data acquisition products and hardware you will love at work*. https://dewesoft.com/products [2025-05-09].

Dewesoft. (2025). Suggested iolite architecture [Personal communication via email, May 13, 2025].

Divya, K., & Østergaard, J. (2009). *Battery energy storage technology for power systems—an overview*. Technical University of Denmark.

Dixon, M. (2024). *Scada systems and cyber threats: A threat intelligence approach*. https://www.cyberintelinsights.com/industries/scada-systems-cyber-threats-threat/ [2025-03-17].

Earney, S. (2022). *Is the edge or cloud better for security and privacy?* https://xailient.com/blog/is-the-edge-or-cloud-better-for-security-and-privacy/ [2025-02-11].

Erickson, A. (2023). *What price should you expect for scada systems and maintenance?* https://www.dpstele.com/blog/scada-price-maintenance-cost.php [2025-05-08].

Erickson, J. (2024). *What is json?* https://www.oracle.com/se/database/what-is-json/ [2025-05-28].

Fazeldehkordi, E., & Grønli, T.-M. (2022). *A survey of security architectures for edge computing-based iot*. Department of Technology, Kristiania University College.

Fernandez, M., Go, Y., Wond, D., & Früh, W.-G. (2024). *Review of challenges and key enablers in energy systems towards net zero target: Renewables, storage, buildings, grid technologies*.

Hewlett Packard Enterprise. (n.d.). *Edge to cloud*. https://www.hpe.com/se/en/what-is/edge-to-cloud.html [2025-02-11].

Kubiak, P., Cen, Z., López, C., & Belharouak, I. (2017). *Calendar aging of a 250 kw/500 kwh li-ion battery deployed for the grid storage application.*

Li, Z., & Deusen, D. (2025). *Role of energy storage technologies in enhancing grid stability and reducing fossil fuel dependency.*

McCrady, S. (2013). *Designing scada application software.* Elsevier.

Meta bytes. (n.d.). *How much does system integration cost?* https://www.metabytes.se/en/metacademy/how-much-does-system-integration-cost [2025-05-08].

Microsoft. (n.d.-a). *What is cloud computing?* https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing [2025-02-11].

Microsoft. (n.d.-b). *Xml for the uninitiated.* https://support.microsoft.com/en-us/office/xml-for-the-uninitiated-a87d234d-4c2e-4409-9cbc-45e4eb857d44 [2025-05-28].

Park, J., & Mackay, S. (2003). *Practical data acquisition for instrumentation and control systems.* Newnes.

Parmar, D. (2024). *Cloud and edge computing get better together.* https://www.nutanix.com/theforecastbynutanix/technology/edge-and-cloud-computing-together [2025-02-11].

Renewable energy integration group. (2024). *The importance of scada and das systems in a utility-scale solar pv farm.* https://www.reig-us.com/the-importance-of-scada-and-das-systems-in-a-utility-scale-solar-pv-farm/ [2025-03-13].

Reza, M., Mannan, M., Mansor, M., Ker, P., Mahlia-Indra, T., & Hannan, M. (2024). *Recent advancement of remaining useful life prediction of lithium-ion battery in electric vehicle applications: A review of modelling mechanisms, network configurations, factors, and outstanding issues.*

Saini, K., Pandey, U., & Raj, P. (2022). *Chapter nine - edge computing challenges and concerns.*

Saldarini, A., Londo, M., Brenna, M., & Zaninelli, D. (2023). *Battery electric storage systems: Advances, challenges, and market trends.*

SCADA info. (n.d.). *Scada maintenance.* https://www.scadainfo.com/scada-maintenance/ [2025-05-09].

Skrodelis, H., Kelle, R., & Romanovs, A. (2024). *Cybersecurity in scada systems with advanced ai and ml techniques.* Information Technology and Managment Science of Riga Technical University.

Smart Vatten. (n.d.). *The pitfalls for water utilities of solely relying on scada systems for data analytics.* https://www.smartvatten.com/en/news/the-pitfalls-for-water-utilities-of-solely-relying-on-scada-systems-for-data-analytics [2025-03-13].

Smith, G. (2024). *Data acquisition (daq) - the ultimate guide*. https://dewesoft.com/blog/what-is-data-acquisition [2025-05-08].

Thomas, M., & McDonald, J. (2015). *Power system scada and smart grids*. CRC Press.

U.S. Department of Energy. (2024). *Battery energy storage systems report*.

Vattenfall. (n.d.). *Organisation*. https://group.vattenfall.com/se/om-oss/organisation [2025-04-10].

Wali, A., & Alshehry, F. (2024). *A survey of security challenges in cloud-basedscada systems*. Faculty of Computing and Information Technology, King Abdulaziz University.

Yokogawa. (n.d.). *Company overview*. https://www.yokogawa.com/about/company-overview/ [2025-06-10].

Yokogawa. (2025). System setup proposal for data acquisition [Personal communication via email, April 29, 2025].