The Adaptive Control
WP 3 Report

ACES project
Adaptive Control of Energy Storage

Final Version

Embriq
2021-02-12

INTERNAL REFERENCE:

Deliverable name	Work package 3 report
Author(s):	David Westerlund (Embriq) Johan Stenfeldt (Metrum Sweden) Marcus Odlander (Embriq) Martin Andersson (Embriq) Roger Jacobsen (Embriq)
Contributor(s):	
Reviewer(s):	Ivan Löfgren (WSP) Gerhard Kleineidam (Mincom)
Released by:	David Westerlund (Embriq)
Lead Partner:	Metrum Sweden AB
Document (File):	ACES_WP3_sub_report_final
Issue (Save) date:	2021-02-12
Confidentiality (TLP):	**COLOR - WHITE**

DOCUMENT SENSITIVITY

☐	**Not Sensitive**	Contains only factual or background information; contains no new or additional analysis, recommendations or policy-relevant statements
☒	**Moderately Sensitive**	Contains some analysis or interpretation of results; contains no recommendations or policy-relevant statements
☐	**Sensitive**	Contains analysis or interpretation of results with policy-relevance and/or recommendations or policy-relevant statements
☐	**Highly Sensitive Confidential**	Contains significant analysis or interpretation of results with major policy-relevance or implications, contains extensive recommendations or policy-relevant statements, and/or contain policy-prescriptive statements. This sensitivity requires SB decision.

TABLE OF CONTENTS

VERSION MANAGEMENT

Version	Status	Date	Changes
1.0	Draft	20201127	Added text to chapters
1.1	Draft	20201203	Updates to chapters and illustrations
1.2	Draft	20201213	Updates and modifications after review
1.3	Draft	20210111	Adding pictures, references, and review updates
1.4	Draft	20210118	Added text
1.5	Draft	20210126	Correction of misspellings. Added additional explanatory text
1.6	Final	20210212	Correction of First page and internal reference.

TRAFFIC LIGHT PROTOCOL (TLP)[1]

The Traffic Light Protocol (TLP) was created by the UK Centre for the Protection of National Infrastructure (CPNI) in order to encourage greater sharing of information. In order to encourage the sharing of sensitive (but unclassified) information, however, the originator needs to signal how widely they want their information to be circulated beyond the immediate recipient, if at all. The TLP is based on the concept of the originator labelling information with one of four colours to indicate what further dissemination, if any, can be undertaken by the recipient. The recipient must consult the originator if wider dissemination is required.

Sharing of information is classified with four states (colours). The four colours and their meanings are:

RED	**Personal distribution for named recipients only** Information is shared in the context of a meeting, for example. RED information is limited to those present at the meeting. In most circumstances, RED information will be passed verbally or in person.
YELLOW	**Limited distribution** The recipient may share YELLOW information with others within their organisation, but only on a ‘need-to-know’ basis. The originator may be expected to specify the intended limits of that sharing.
GREEN	**Community wide distribution** Information in this category can be circulated widely within a particular community. However, the information may not be published or posted on the Internet, nor released outside of the community.
WHITE	**Unlimited distribution** Subject to standard copyright rules, WHITE information may be distributed freely, without restriction.

---

[1] RULES OF PROCEDURE FOR THE EUROPEAN FORUM FOR MEMBER STATES (EFMS) ON PUBLIC POLICIES FOR SECURITY AND RESILIENCE IN THE CONTEXT OF CRITICAL INFORMATION INFRASTRUCTURE PROTECTION, Version 3.0 FINAL – May 2011 “Traffic Light system”

ABSTRACT

The change of power usage and increasing power quality challenges calls for alternative ways for control and operation strategies of the smart grid. This coupled the more variable and stochastic renewable energy integrated in the smart grid made us look for new ways an energy storage could operate to alleviate some of these challenges.

The current increasing deployment of energy storages throughout the grid presents an opportunity to enable the power balance by storing energy during off-peak and then redispatch the energy when its needed. That would further enhance load and market operations through the realization of an adaptive range of services instead of just one or two services. The energy storage technology would provide significant opportunities to further enhance the efficiency and operation of the grid.

The project partners devised a requirement specification stating what we need to do perform our experiments. Our experiments where first simulated with historical data, then the functionality of the system was tested and performed using a full-scale physical model.

A 20kW energy storage system is present at one of our demo sites in Magdeburg, Germany. The system is designed to simulate problems with power quality and shifting loads. The second demo site a 7 kVA storage is operating alongside an apartment complex with approximately 50 residents with an active consumption between ~10 kWh and ~50 kWh (depending on the season), and a solar production with production peaks at roughly 17 kWh.

Legal Disclaimer

Copyright

Managing Partner:

Partners:

Observers:

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646039.

1. Acronyms

ACES project	Adaptive Control of Energy Storage project
ACES Service Receiver	The ACES Service Receiver is a user of energy storage services provided by the ACES Service Provider. The ACES Service Receiver pays the bill and thus covers CAPEX, OPEX and profit in the business model of the specific ACES application.
ACES Service Provider	The ACES service provider is meant to be the operator of energy storage services comprising energy / battery management, order processing and billing. The ACES Service Provider causes OPEX which is necessary to calculate the economic value of an ACES business application. The ACES Service Provider expects remuneration of OPEX plus profit.
ACS	Adaptive Control System: the system that is responsible for selecting the appropriate state for the energy storage(s). This is the system that is used by energy storage owners for high level management of the sites.
API	Application Programming Interface
AWS	Amazon Web Service: on-demand cloud computing platform by Amazon Inc.
Battery cell	Smallest unit in battery system, one single cell which is connected serial and/ or parallel to reach needed system specification (voltage, charge-/ discharge capacity, storage capacity, etc.)
Battery owner	The Battery economic Owner is the party which invested into ACES technology, where the main share of investment will be related to the battery. The Battery Owner causes CAPEX which is necessary to calculate the value of an ACES business application. The Battery Owner expects ROI including coverage of CAPEX (interests, depreciation) plus profit or any other value.
Battery Stack	Serial and/ or parallel connected single battery cells
Battery Storage	Consists of multiple strings to reach requirements on capacity
Battery Storage System	Includes all components, (such as AC/DC converter, battery Storage, battery management system, battery energy management system, battery safety system, ICT interfaces and systems, etc.), to fulfill requirements on battery storage system

Battery String	Consists of serial connection of single stacks to reach DC voltage operating system
BMS	Battery Management System: any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it [Barsukov and Qian 2013]. In this case it interfaces all components in battery storage system and is central management control system of the battery storage system. It provides the external interfaces and data transfer. It processes commands and sends controls to AC/DC converter to charge and discharge. It ensures that the battery storage system is only working within the given limits of the battery management system, etc.
BO	Battery Owner: the battery facility is either owned or hired by the battery owner.
BRP	Balance Responsible Party
BS	Billing System: the billing system is responsible for aggregating billing data and grouping it per customer and per invoice period.
Business Use Case	A business use case is a logic combination of services that a single battery energy storage, owned by one actor on a certain location in the power system, can provide.
Capex	Capital Expenditure
CT	Current Transformer
DER	Distributed Energy Resource
DSO	Distribution System Operator
DSOA	DSO Aggregator. The DSOA handles the interaction between the DSO and the energy storage owners. The DSOA provides these with a revenue stream for providing services and readiness to the DSO.
DUT	Device Under Test
RMS	Root Mean Square
ROI	Return on Investment
RVC	Rapid Voltage Change
Service	A functionality of the battery storage that, during operation, shall create a benefit for any relevant stakeholder
Service Stack	A group of services that is performed at a single energy storage site
SoC	State of Charge
SoF	State of Function
SoH	State of Health

TS	Tariff Service: The system that is responsible for calculating a suitable price for different services.
TSO	Transmission System Operator
UPS	Uninterruptable Power Supply
EMS	Energy Management System: generally, this is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. In this case it refers to the system that controls the dispatch and thereby energy flows (charging, discharging of batteries) between the battery storage system and the electrical grid it is connected to.
EV	Electric vehicle
FCR-D	Frequency Restoration Reserve – Disturbance
FCR-N	Frequency Restoration Reserve – Normal
GEC	Glava Energy Center
GUI	Graphical User Interface: a form of user interface that allows users to interact with electronic devices through graphical icons and visual indicators such as secondary notation, instead of text-based user interfaces, typed command labels or text navigation. [Wikipedia – Graphical User Interface. 2019]
HSB	Swedish real estate company
HRS	Hydrogen refilling station
IIS	Windows Internet Information Service
kW	Kilowatt
kWh	Kilowatt hours
kWp	Kilowatt Peak: the maximum power delivery from a solar panel, in the best possible environment. In Sweden a solar panel typically delivers 800-850 kWh/year for every 1 kWp.
MODBUS TCP	Modbus is a serial communications protocol originally published by Modicon (now Schneider Electric) in 1979 for use with its programmable logic controllers (PLCs). Modbus has become a de facto standard communication protocol and is now a commonly available means of connecting industrial electronic devices. Modbus TCP is a Modbus variant used for communications over TCP/IP networks [Wikipedia – Modbus. 2019]
MVP	Minimum Viable Product
ML	Machine Learning
NPS	Nanoplasmonic sensing
OPEX	Operational Expenditure
PQ	Power Quality

PT	Potential Transformer
PV	Photovoltaic
REST	Representational State Transfer: a software architectural style that defines a set of constraints to be used for creating Web services.

2. Introduction

This document is intended to describe the work of work package 3 in the ACES project.

The Adaptive Control of Energy storage (ACES) project has been performed by a consortium of ten [8] partner organisations: lead partner Metrum Sweden AB (Sweden), Glava Energy Center (Sweden), RISE Research Institutes of Sweden AB (Sweden), Insplorion AB (Sweden), Embriq A/S (Norway), MINcom Smart Solutions GmbH (Germany), Fraunhofer Institute for Factory Operation and Automation IFF (Germany), ABB AB (Sweden).

The overall objective of the ACES project is to develop, implement test advanced measurement technology and adaptive control algorithms for energy storage systems in order to allow for improved economics of operation. By reaching the project objectives, the ACES project aims to contribute to an affordable 100% renewable power system with smart battery storage solutions using artificial intelligence.

Creating adaptive control of energy storage, through developing advanced measurement technology and adaptive control algorithms, energy storages in the grid can be more economic and contribute more to the stability and optimal use of the power grid. Combined with new business models and innovative billing solutions, we aim to trigger wide-scale deployment in the power grids, a critical success factor for the renewable energy transition.

We hope that this research contributes to the digitalization of the power system. Battery storage will be an essential part of the digital grid. The battery storage can both produce and consume energy through discharge and charge of the batteries. That means that you can balance the power flow, both in cables and transformers. You can measure and control power quality parameters like voltage fluctuations and harmonics with a modern inverter. If you charge or discharge fast, then the storage can be a part of the regulating market and deliver services like frequency regulation.

With many battery storages connected in the grid it´s possible to aggregate several battery storages and be a part of the regulation market with support from energy retailers. We envision a solution that will aid the management and control of a fleet of installations. Each installation may support different sets of services. That will enable larger actors to control a large fleet of batteries adaptively. It would also align with a business model where such an aggregator offers “Batteries as a Service”. That kind of an actor would be particularly interested in using an energy storage site optimally, as the gains would increase with the number of installations.

The ACES project has received funding from the Swedish Energy Agency, The Research Council of Norway and the German Federal Ministry of Economic Affairs and Energy in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union’s Horizon 2020 research and innovation programme.

More information on the ACES project can be found on: http://www.acesproject.eu/

PURPOSE

The ACES project has been organized in six [6] different work packages with multiple dependencies and collaborations in-between. The purpose of this report is to present the findings and conclusions related to project goals of work package 3. In addition, a general description and evaluation of the project execution is given, in order to share not only findings related to the project objectives, but also learnings about project methodology and tools in order to further contribute to the research community regarding successful project design.

GOALS AND RESEARCH QUESTIONS

The goals of WP3 was to facilitate:

- A data platform handling input data on Electricity market prices, Ancillary services prices, Power quality status and impact, Battery SoC and SoH, load factors of grid components, network status parameters, generation and consumption patterns and other external data such as calendar events and weather conditions
- Enabled data integration through specification (data conversion tables)
- Develop pattern recognition algorithms that optimize the business case depending on all the selected use cases and the input data
- Based on analysis and conclusions in the project an adaptive software system, using new pattern recognition technologies, to manage our energy storage demo sites.

DELIMITATIONS

The project did not include measurements of the surrounding grid into account since we didn’t acquire that data from a DSO. We also didn’t regard that data as relevant if it was not collected from the immediate surroundings of the demo site.

We also did not collect measurements from any hydrogen storage since they for the reasons that they dropped out of the project.

There were several services that where not developed due to prioritizing from the project consortium.

3. Background information

Energy storage is a key solution and enabler for the transition to a renewable power system. Control of all electrical quantities by using latest technologies of artificial intelligence, integrating systems and by innovative business models will increase and enable the usage of effective energy storage solutions to deliver real-time services in various markets.

ACES is a new demonstration project but also builds further on the ERA-NET SG+ European Pattern Recognition and RIGRID projects. By combining innovative technology companies, service provider, two research institutes and energy trading and distribution companies, ACES combine scientific content with commercial product development and stakeholder engagement.

The aim of the ACES project is to develop, implement and test advanced measurement technology and adaptive control algorithms for energy storage systems to integrate storages in more economic and technically optimal way into the modern power grids. Wide-scale deployment of energy storages will contribute to the power grid stability, while matching balance between demand and supply, mostly from volatile renewable energy sources and open new business opportunities in the energy market.

The purpose of WP3 was to develop an adaptive control system for the energy storage demo sites. For that to work we needed to set the requisites for the solution. An IT architecture, securing measurement data, understanding the demo sites setups from a hardware, business logic and a connection perspective. A lot of studies were conducted by WP2 in order to investigate what business use cases that were relevant. These use cases where like guiding lights in our development process. Note that not all of them were not developed in the ACS.

METRUM PQ4CAST (AI) FORECASTING APPLICATION

The Metrum PQ4Cast application is an application producing forecasts on a number of electrical parameters such as voltage, unbalance, power and THD. The application is using historical data with high accuracy from Metrums power quality instruments to predict coming variations the measured parameters. The application will support the adaptive control system with data to be able to decide when and how the energy storage should be used for best practice.

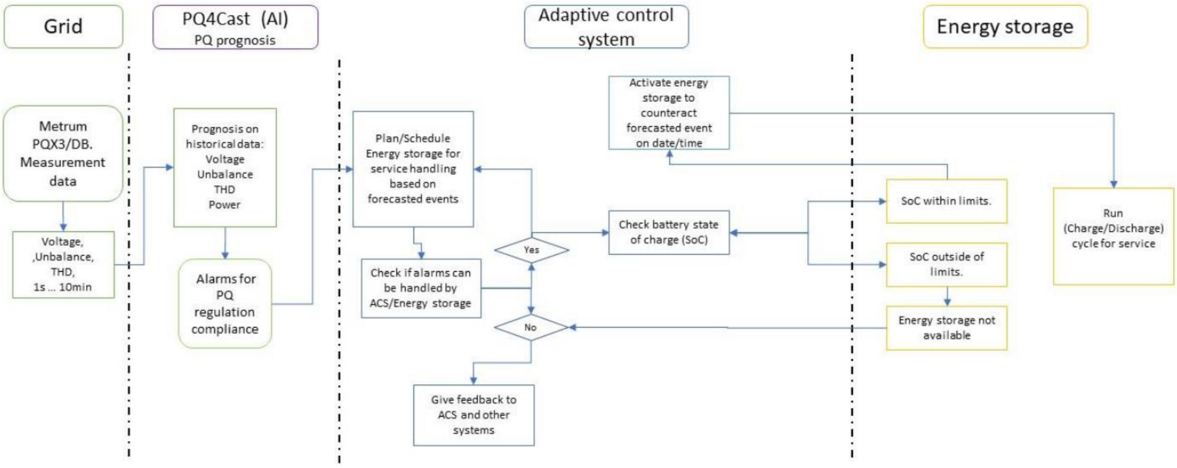

Figure 1. Metrum forecasting flow

4. Methodology

Breaking down each use case scenario

For the team to understand how each use case is achieved, we needed to break them all down. There was a need to understand their purpose and workflow to know how a solution could be developed. We started out with a description of each use case followed by identifying what data was required and what source the data should be extracted from. We investigated if there were any limits that we needed to take into consideration. And we also considered different scenarios for each use case. For example, if the consumption peak doesn’t occur according to our forecasts. Or if the battery state of charge where to reach a level lower that planed. It´s also important to identify parties that in turn need access to the raw data or processed data. In our case we decided that data should stay in the ACS and that it should be exposed via a web interface. It’s like any other process, there is some input to the process that needs to be handled and produces a valuable output. It is information about measurement data from the site, pricing, net fees, solar production, battery state of charge, state of health and so on. Billing data is then sent through to the billing system. Thereafter we wanted to conclude which actions to perform. There soon arose a need to prioritize features like must have, should have and nice to have. Since the work needs to align with the project goals and what we tough was reasonable and doable from a use case perspective.

This pre-work is a part of the basis for the requirements to the API specifications. It's also great input for the IT-architecture that needs to support the experiments. A requirement specification and the setup of a test environment for the development. We wanted the architecture to support a scalable solution to in cooperate several energy storages. And then we add the complexity of adding an adaptive control and the ability to weigh what service to perform in different situation. And at the same time being aware of the cost for the operation which also is a part of the adaptiveness.

We all needed a good understanding of the business before we can start with modelling a solution and knowing what data is required. After a couple of iterations with workshops, mail conversations and work meetings we finally produced what we called a minimal viable product (MVP). From the MVP we continued our work, adding functions and visualizations. As the work is done there are always new "things" that will pop up. For things you didn't plan for or things that were more complicated than initially assessed we suggest a pragmatic but structured approach with a transparent and frequent dialogue.

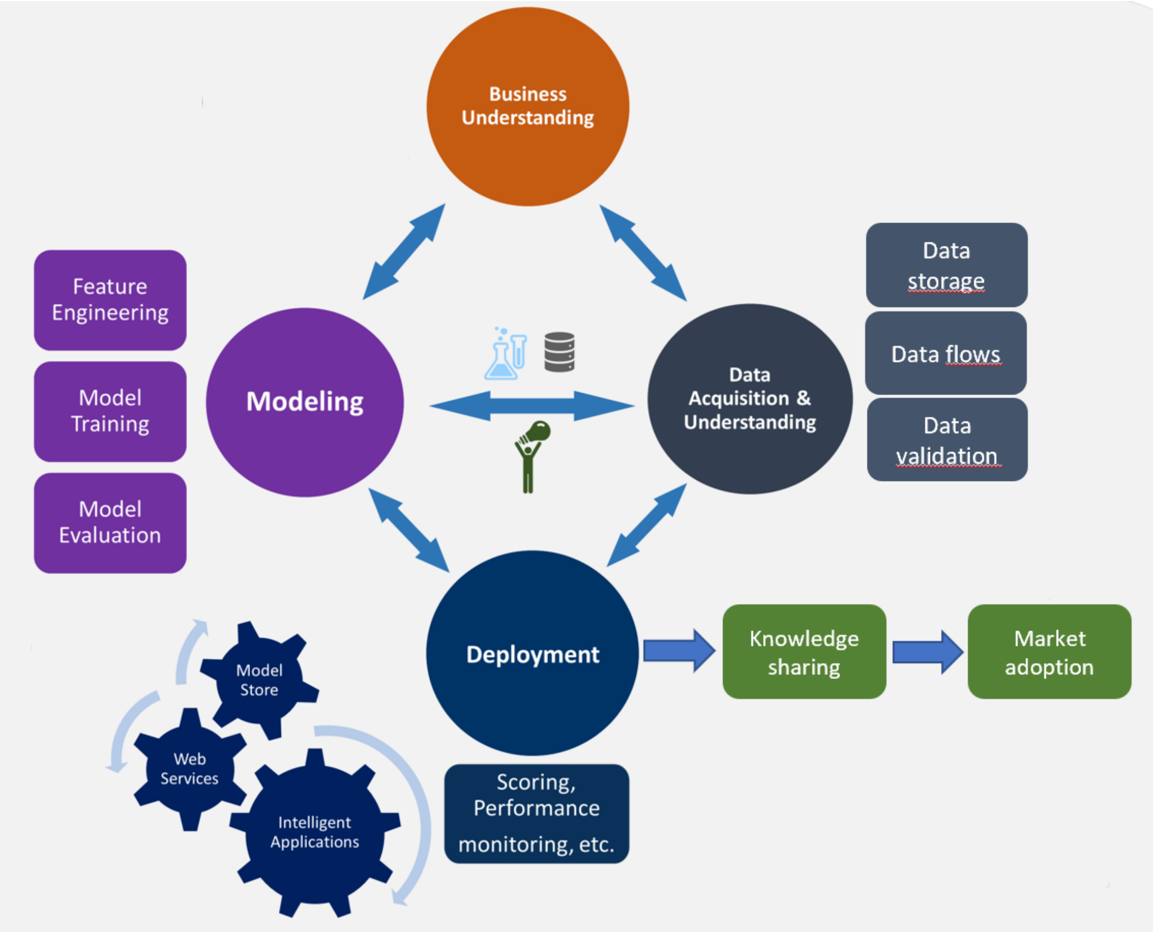

Figure 2. Generic methodology

The next part of the project activities was in accordance with our initial work breakdown structure. We did change the order in which some of the work was performed.

WBS 3.3 included WBS 3.8. WBS 3.12 was done earlier in our MVP, but as a simulation since we lacked some of the measurement data. Note that we had access to a lot of historical data from the sites. So, the data was highly relevant for our experiments.

WBS 9 is also an iterative part that has been part large part of 3.13 as well.

Having access to data really sounds simple but is often quite the opposite. APIs need to be specified, understood and work as intended. For this purpose, we created a times database (Dynamo DB (Structure data), Influx time series database).

Knowing what to do with the data is also a challenge. Which indicators shall we look for and act on? What shall we do when they occur? There are also regulations that needs to be upheld hence monitored and if possible, even predicted. The ACS can I a sense also be utilized as a monitoring solution that can identify and with some additional smartness also suggest what action to take and even suggest what battery tech and battery size that is needed. It´s like a reversed AIR BNB for DSOs that finds tenants to fill the DSOs different needs.

3.1 Functional Requirement for Adaptive Control

3.2 Data Requirements

3.3 IT Architecture Design

3.4 Implement Data Storage Solution

3.5 Integration Requirements

3.6 Integration Architecture Design – took a while longer before it started

3.7 Gather Test Data for Adaptive Control – took a while longer before it started

3.8 IT Architecture schema & Security – was incorporated in the architecture

3.9 P.R. Selection of algorithms & classification of events – was moved to a later stage and is more a part pf 3.3 what we do in.

3.10 Develop Data Integration solution – done on the fly

3.11 Analyze Demo Data – was done quite fast

3.12 Develop 1st Version Adaptive Control Algorithms & Software – was done quite late but with no bigger issues.

3.13 Iterative Development next versions Adaptive Control System – we are still there. Adding and improving the solution.

A requirement specification

The purpose of a Requirement Specification is to document the requirements, constraints, and limitations in one document for the development phase. The first released version of this document is the main formal deliverable of Milestone 1.

The challenge in specifying requirements for ACES demonstration sites results from the fact that adaptiveness in combination with business use cases and their service stacks have never been defined before and many of the components that shall be installed and tested, such as the Adaptive Control System, billing system and NPS sensors inside battery cells, are not yet developed. The document therefore specifies the general and most important requirements. It may be regarded more a requirement guide with a very high level of abstraction than a real requirement specification as known in engineering project development.

To avoid being locked in a suboptimal solution and ensure the capturing of knowledge and client feedback gathered during the project, the project uses a lean, iterative approach on the development of the ACS system: starting with a Minimum Viable Product (MVP), a working system with a minimal functionality and further adding functionality in consequent iterations. Therefore, the ACES Requirement Specification was a living document with updates released when new functionality was added to the ACS and Demonstration sites according to a prioritization process, between Milestones 1, 2 and 3.

During the end of the second quarter of 2020 we have been performing several iterations in a faster pace as we had to experimented more and received more feedback about the ACS functionality. Hence adding features and failsafe´s to scenarios we didn’t foresee, pushing the ACS further. Making changes to the data model and APIs takes time. But they are necessary to improve the solution. Before we made our system tests there where a lot of manual work to create running plans for the battery. These are now performed semi automatically. The requirement specification was continuously updated with new fields and new data throughout the project.

Interactions between systems.

We needed to understand the interactions in the scenarios. So, we used flow charts and a table that described the information flow. These interactions start as a DSOA determines that it needs the ACS to produce or consume a certain amount of power for a given duration at a certain time. The DSOA acts on behalf of the DSO(s).

The collaboration between DSOs and DSOAs will look different in different legal- and market environments. The TS will need to be able to calculate an approximated suitable price based on the anticipated savings made by the DSO and the anticipated cost of the operation, which is provided by ACS.

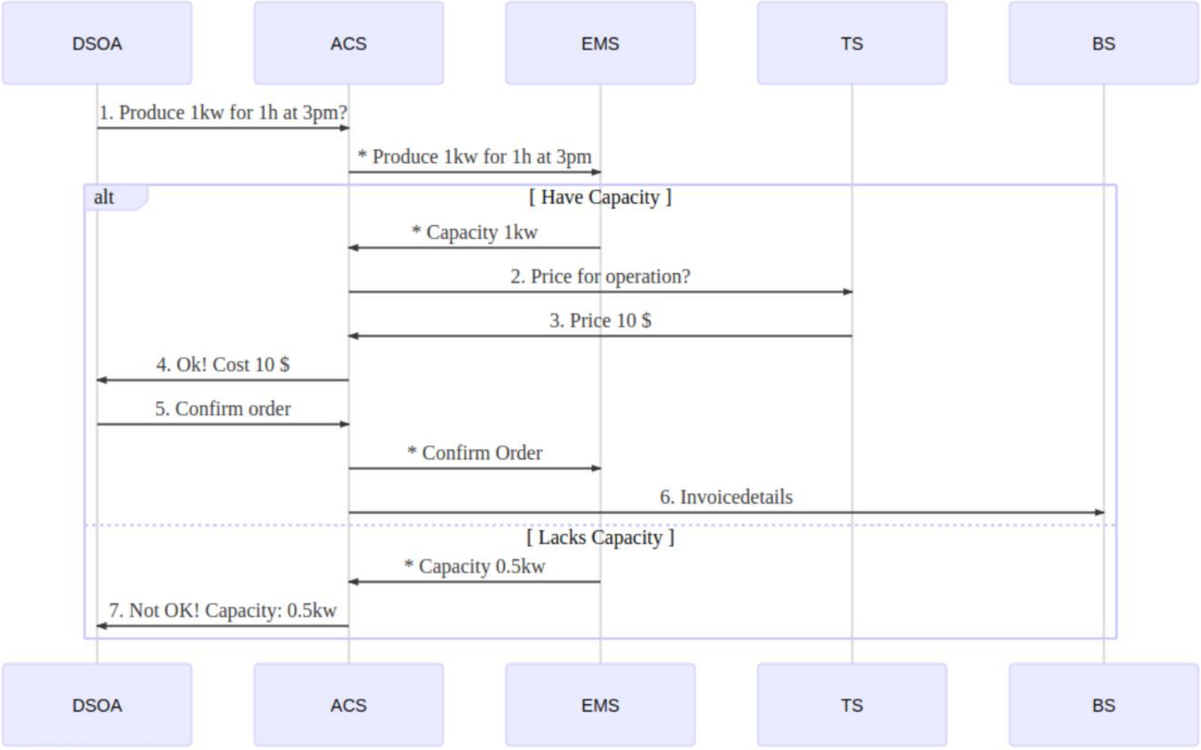

Figure 3, System interaction

MEASURMENT DATA

Data Is generated at each measuring point. At the facility, the solar cell, the energy storage. Our position is that each point consumption or production must be measured separately from each other. Having control of your data quality is as always of great importance. Check that you are collecting the measurements, for example max, min and average voltage every set cycle. Not just snap shots of the average at a given hour. Another thing that is equally important is comparing apples with apples, in a case like ours when using measurement data from different sources we need to check that we are looking at the same time period (GMT+-, summer time, winter time (aka standard time). Otherwise we run a risk of drawing the wrong conclusions. Missing data might also be or become an issue. So, you will require mechanism for that eventuality. You will also require handling of the data that is collected and mechanisms for validating the data. So, you can handle crappy measurement values (missing, unreasonable and reversing).

HOURLY DATA VS HIGHER RESOLUTION

As illustrated in the pictures below you can see that a higher resolution of measurement data will help you to hit the valleys and peaks. A higher resolution and more datapoint will also add to your machine learning algorithms.

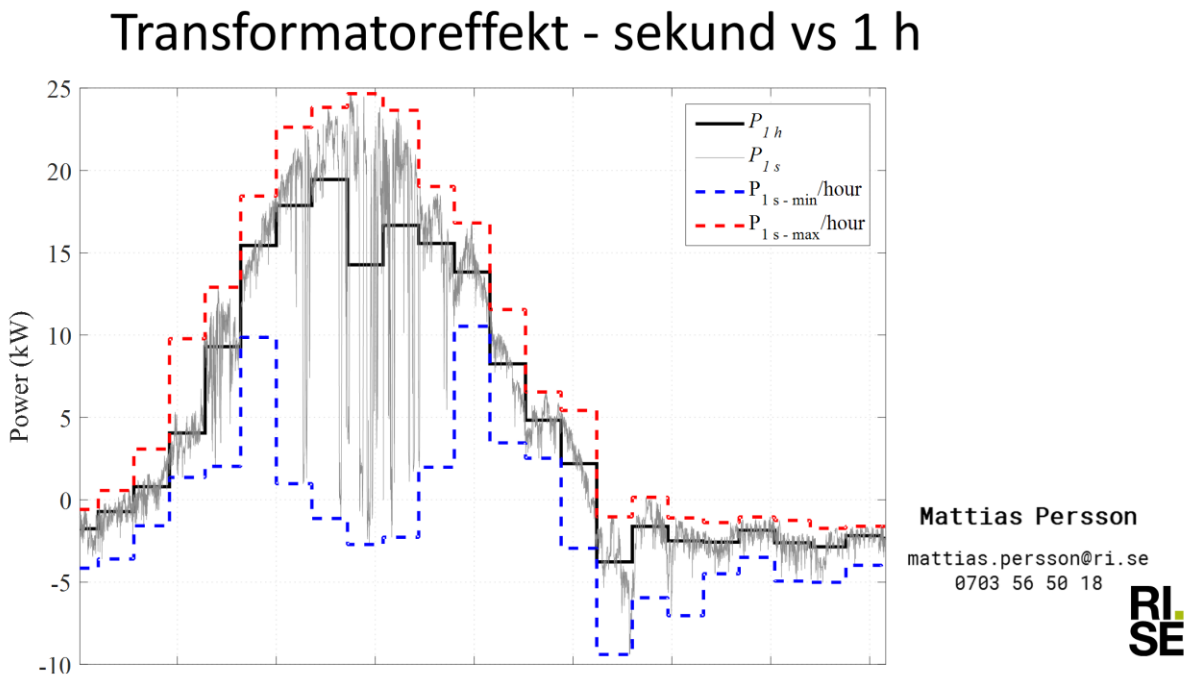

Figure 4, Measurements with a second resolution versus hourly measurements

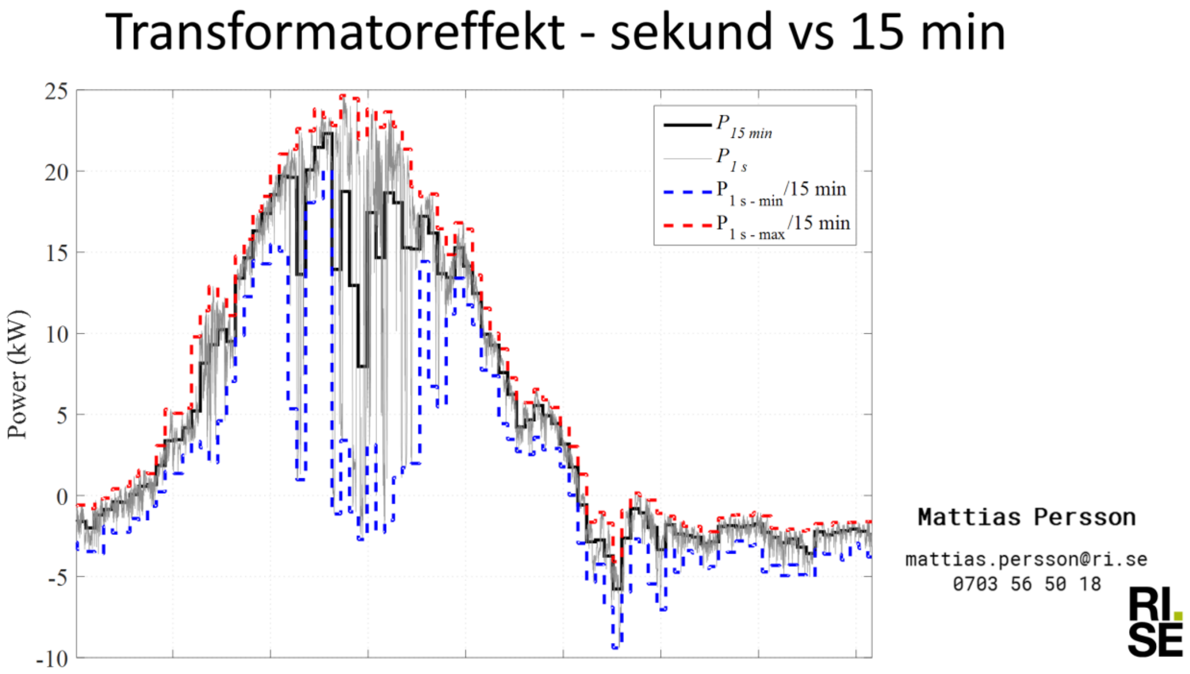

Figure 5, Measurements with a second resolution versus quarterly measurements

DATA COLLECTION (CONNECTIONS AND API)

We have been collecting data through APIs, collecting data each hour from the measurement systems. From the BMS we have trough MQTT (IOT connection standard) been collecting data every minute. The ACS sends billing data to Mincoms billing system whenever a billable service has been performed.

IT-ARCHITECTURE

The choice of technological stack, i.e., Amazon Web Services (AWS) infrastructure combined with Java server and front-end, was based on the following reasons:

- The developers working with the system had greater and more recent experience with this technological stack than other common stacks (e.g., React, .NET, C#, Azure)
- AWS offers a wide range of easy-to-use cloud services such as data storage, server hosting, authorization handling, and database servers.
- AWS offers AWS Forecast for powerful and easy-to-use Forecasting on-demand.

Note: The choice of using this technological stack does not necessarily mean that the system is bound to only use the implemented languages, frameworks, and cloud services.

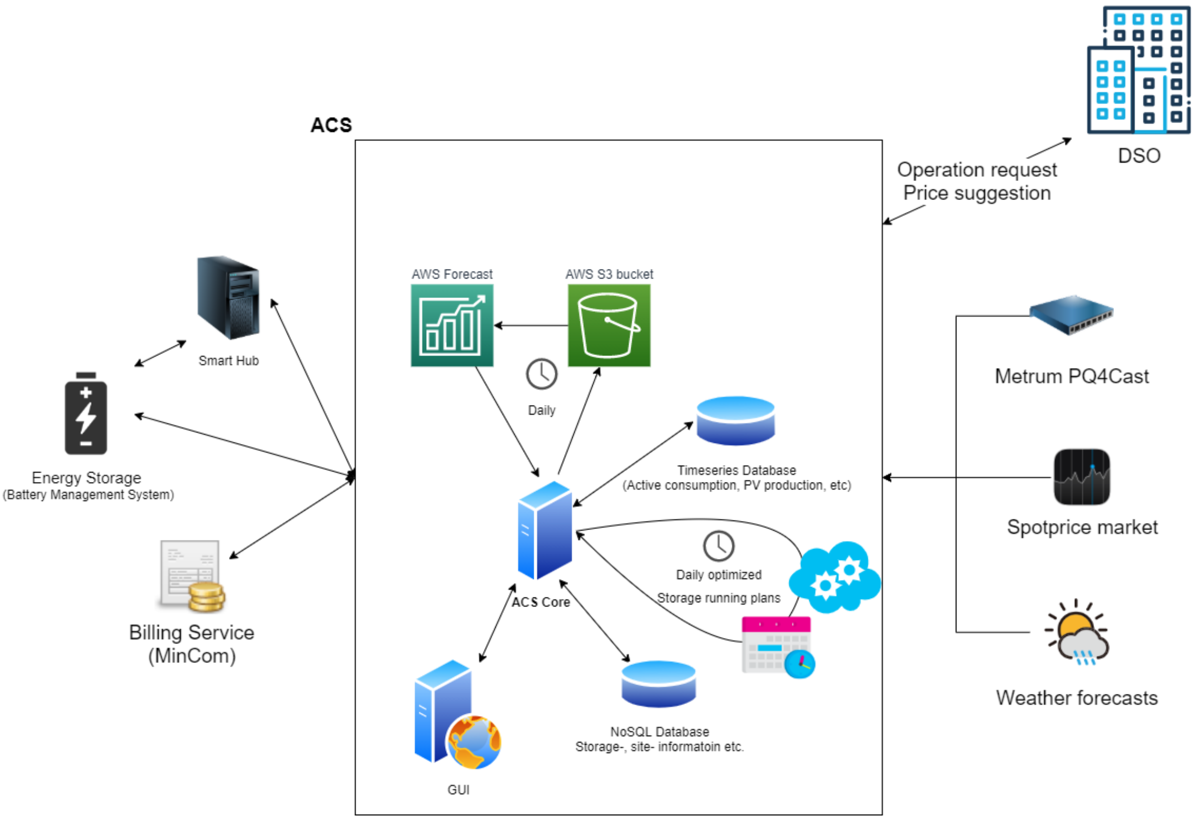

Figure 6, ACES IT architecture

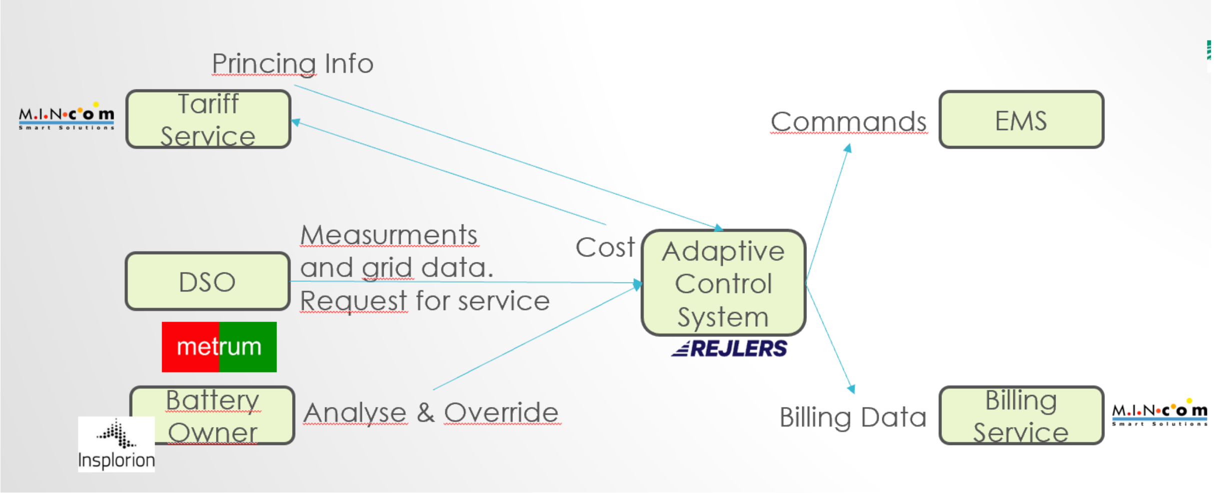

Figure 7, ACES System chart

IT SECURITY

ACES has been developed with a strong security philosophy. Some key points are:

- Principle of least privilege. Users and components are granted access to just the data and services they need.
- Defense in depth. The VPC (Virtual Private Cloud) is divided into several security zones, with limited cross-zone and internet access.
- Strong encryption at rest and in transit. All transmitted and stored data is encrypted with AES-256. In addition, ACES support an extra layer of encryption using tenant-specific rotating keys.
- Authentication and authorization. Users and services need explicit grants to access data.
- Compliance. ACES comply to governmental requirements and regulations, including GDPR.
- Man-in-the-middle prevention. DSO requests are an important part for the ACES project. Only authenticated users can get price offers. When getting a price offer, the authenticated user also gets a token and a valid period connected to that price offer, making sure that all placed orders are from the authenticated user.
- Availability. The ACS project is hosted in the Cloud for seamless patching and resilience against hardware faults and e.g., DDoS attacks.

MACHINE LEARNING

Machine learning (ML) is a sub-field in computer science that has been developed from studies in pattern recognition and artificial intelligence. ML arose in the border between mathematics, programming, and statistics. ML can provide insights and knowledge about data that can be used for two different things, prediction, or inference. Prediction is about making predictions about a thing by training a model that has identified basic patterns in data. In prediction applications, it is of course central to identify models that have good predictive ability on data, ie. have low errors. Conclusion is about understanding how variables are linked and gaining insights into the underlying structure of the data set.

ML's popularity has grown in recent years for examples like:

- Digitalisation of society and industry
- More data provides better algorithms.
- Computing power has become cheaper, better and more accessible.

These developments make it interesting to use ML in several different applications. Insights into data make it possible to develop new services that can either streamline established processes or identify new market areas. The first step in prediction is to define a hypothesis of the thing you want to predict and X pieces of dependent variables, the measurable quantities that are assumed to affect the thing. Which parameters are included depends two things. What data you have access to and the assumption about the function.

The purpose is to weight the data you have access to and the assumption so that the error is as low as possible. Here is where one of the main challenges with ML comes in to play. the more data you have and the more flexible models you use the lower the prediction error. This is because the model adapts to all the variations. Ultimately the prediction error on a new set of test data can be high and the error can even become higher. This is problem called over-adaptation and is one of the primary challenges with ML. The balance can be achieved in several different ways. Using the most appropriate model for the problem or using the most important independent variables.

There are different options for finding the best model; such tools as Aikakie Information Criteria, Bayesian Information Criteria or ridge regression.

METHODS that are included in the ML toolbox.

With the tree in figure 8 you can see the levels in the ML. the first ones are the supervised resp. unsupervised methods. Monitored methods mean that you have a set of independent variables that are used to predict a dependent variable. In an unattended method, you have independent variables. The point is to understand how groups of these variables are connected.

The tree of subfamilies of methods continues under monitored methods that are divided into Regression and Classification. A regression example is if you want to predict electric prices e.g. given the amount of availability, tariffs and geographical location. Or to predict whether a patient has cancer given different risk factors are examples of a classification problem when the answer is whether the person has cancer or not. Both these monitored ML families have specific methods that are listed in the diagram below. The differences between the specific methods are the levels of complexity and representability.

Unsupervised methods are divided into clustering and dimension reduction. Clustering is about grouping related observations. Clustering is used to identify key patterns of how the independent variables belong together and understand how to divide data into subsets.

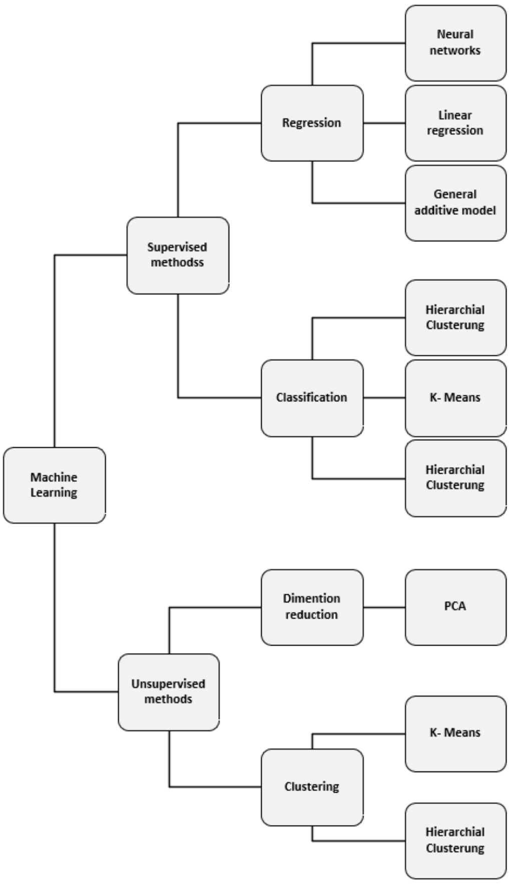

Figure 8, Maschine Learning tree

5. Results

We have achieved our goals and verified adaptivity of battery storage control and that the solution adapts it´s control to reflect changing conditions and that can control several different energy storage solutions. WP3 managed to establish a platform and integrate the necessary data sources, connect all necessary systems, and use the data to monitor, predict, react to changing conditions and send running plans to the energy storage. This is done with several pattern recognitions algorithms working together to creating a running plan for the energy storage. WP3 also solved the provisioning of underlay for handling invoices, creating a solution that handles the entire process from measuring, analysis, forecasting, adaptive controlling and billing together with the project partners.

The ACS

The ACES Adaptive Control System (Thr ACS) functions as a flexibility enabler and an aggregator of energy storages. The ACS also handles data integrations to the entire chain of market actors. Embriq have achieved to create added functionality to existing energy storages. It allows the energy storage to create value at a facility and it creates new opportunities when the energy storages can provide services to the surrounding electricity grid.

ADD NEW PARAMETERS IN METRUM PQ4CAST TO SUPPORT FOR NEEDS IN ACES PROJECT

To add value for the ACES-project Metrum has included further development of the earlier launched AI forecasting and prediction software “Metrum PQ4cast”. The forecasting software solution includes possibility for proactive trend analysing of several power quality parameters such as voltage, harmonics, and unbalance. Metrum has used the platform and further developed it with included forecasting and trend analysis for active and reactive power. The forecasting and trend analysis of reactive power is included for the ACES service “Reactive power management”.

ADD INTEGRATION FROM METRUM PQ CONTROLLER DB SYSTEM & METRUM PQ4CAST SERVICE TO EMBRIQ DATABASE SYSTEM BY USING API

To get the best possible total value for the ACES-project it was early defined that Metrum should include development for possible system integration. Metrum has therefore developed a web API from which all types of power quality parameters and event types can be retrieved. Even forecasting data and trend data from Metrums forecasting application Metrum PQ4Cast can be read from the web API. The system integration API has been used by Embriq for their new developed control system.

EVALUATION OF PREDICTIVE CAPABILITIES USING METRUM PQ4CAST

This report details an internal evaluation of the accuracy and predictive powers offered by METRUM’s PQ4Cast software, to be used in estimating the short-term future power usage of the energy storage.

Methodology

The basic methodology used in the evaluation is a series of iterative trials of the software using real electrical power data from one "point off connection" (p.o.c). In each iterative trial, the real-world data is used to train a PQ4Cast predictive model, the model is then compared to the real data of the corresponding timeframe. The "Mean absolute percentage error" (MAPE) was chosen to indicate the accuracy of the prediction in every case. MAPE is a measure of prediction accuracy of a forecasting method in terms of relative error, each forecasted point is compared to the corresponding real data-point and subsequently averaged without any imposed bias. In short, all points are equal in shifting the total MAPE score.

The electrical power data used consists of 1-minute Power RMS averages spanning the full year of 2019, from 1/1/2019 00:00:00 to 31/12/2019 23:58:00 and the data was retrieved from the Swedish power utility Umeå Energi.

The p.o.c operated at 130kV. The total number of available data-points from the p.o.c is in total 525599. The p.o.c is studied in isolation, the interconnectivity between other p.o.c's and their surrounding grid environment will be a source of interference we do not account for in this, so no cross-correlations are investigated.

The data was later subdivided into smaller intervals ranging from one day up to two weeks to test the PQ4Cast capabilities. Each trail prediction consists of two parts, a training part where real historical data was used to train the PQ4Cast model and one "predicted part" where new data points was generated as a prediction. These newly generated data points (the prediction) has the same 1-minute time spacing as the original real data points. The two different parts of the data was iterated over semi-independently as follows. Irrespective of the predicted length (one day – two weeks) we used a set of varying training data, starting from an equal time frame as the prediction itself (one day training data for a one-day prediction) up to and beyond a five time multiple. This was performed in order to do a thorough evaluation of possible PQ4Cast scenarios. To be concise in this report we only show the predictions with the lowest MAPE we generated for that specific test-case.

Larger timespans were avoided to limit computational resource usage. We also recognise that longer term predictions tend to unavoidably be less reliable.

Results of evaluation of predictive capabilities using Metrum PQ4Cast

We will now present three example predictions made using PQ4Cast:

Figure 9, Metrum One week prediction

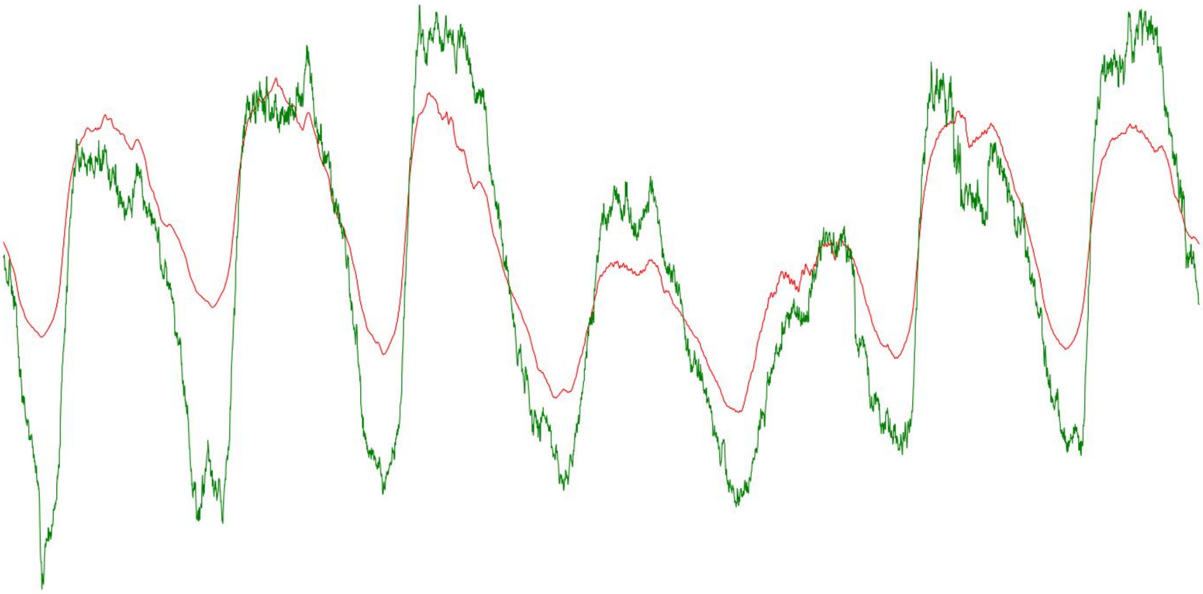

Figure 9 shows a one-week prediction (in red) compared to one week's worth of real data (in green). The prediction when compared to the real-world active power data (Ptot) produce a MAPE score of 8.07%. The data spans one week in May 2019.

Figure 10:

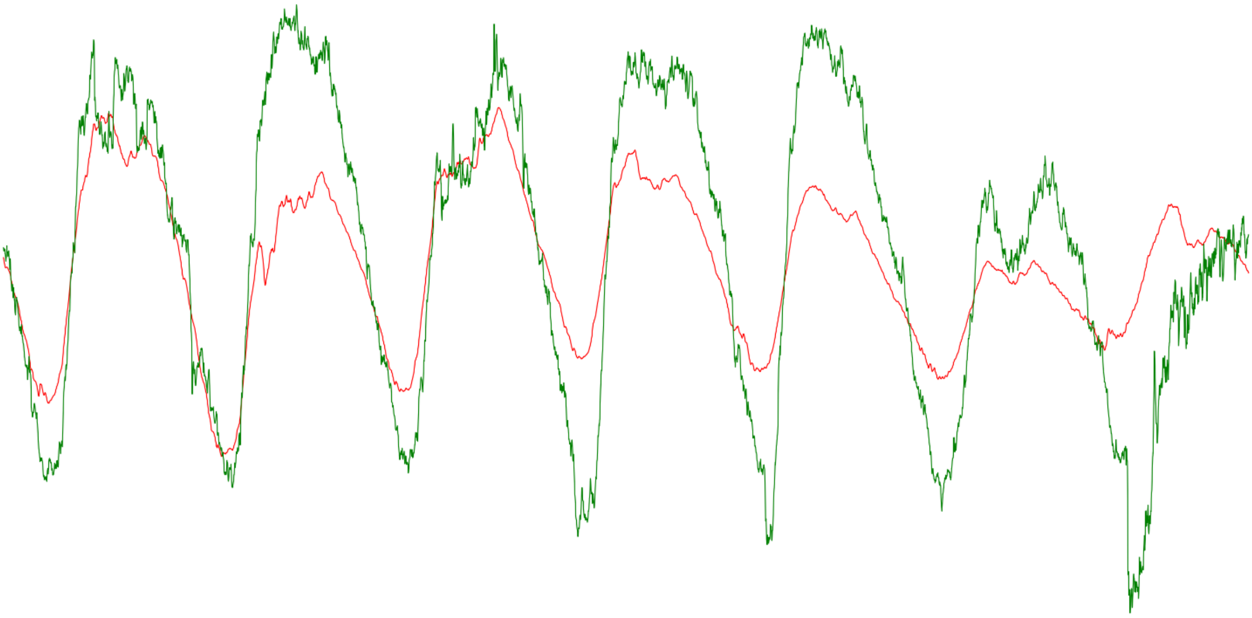

Figure 10, Metrum One week prediction

shows a one-week prediction (in red) compared to real-world active power data (Ptot). The data spans one week in July. The MAPE for the prediction is 7.40%.

Figure 11:

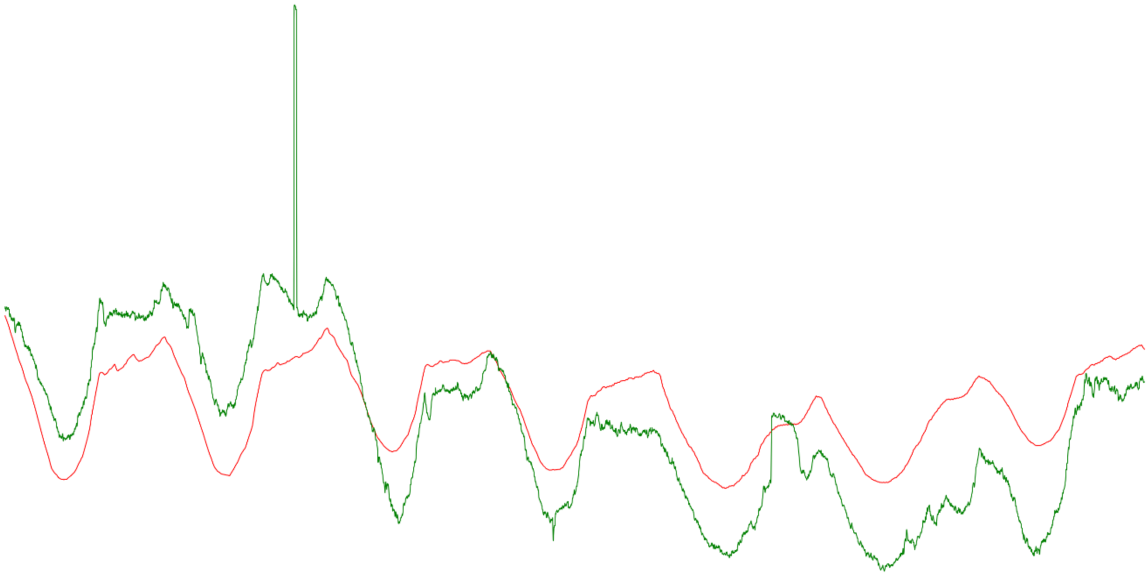

Figure 11, Metrum graf 3

shows a one-week prediction (in red) compared to real-world active power data (Ptot). The data was recorded in late January 2019. Note that the outlier (in green) is not reproduced in the PQ4Cast prediction. The MAPE score for the forecast is 15.80%

As we can see from the images above, the PQ4Cast prediction follows the general appearance of the real data curve, however it is not a perfect match as the PQ4Cast curve (in red) tends to centre around the average of the training data and eliminates the outliers. The centred prediction does provide a reasonable basis for the expected average of the provided data.

From the figures above we make some observations worthy of discussion.

The PQ4Cast predictions wary in accuracy depending on a few factors. Outliers are effectively eliminated as shown in figure 3. While this is useful in a number of forecasting scenarios as it provides statistical stability for general use cases, if the desired goal is to catch sudden power spikes or similar outliers in the data, appropriate refinement of the PQ4Cast model needs to be implemented.

A potential first step in order to prioritize outliers in the available data is a fine-tuning of the model's hyper parameters, adding outlier detection, application of specific weight functions for peak values are a few examples of strategies one can use. Supplementary data (weather conditions etc.) may also be useful in improving forecast accuracy. We also note that any forecasting model trained on historical data is unable to predict sudden large changes occurring without historical precedent.

6. Discussion

The IT infrastructure

The IT infrastructure is crucial to enable the project goals. The control-algorithm uses forecasted load profiles, spot prices, and energy storage information (e.q., nominal capacity, SoC, SoH) in addition with multiple cost functions that fulfill the subproject goals of energy storage, peak shaving, demand-response, curtailment of generation, and local power quality support. When generating the optimized storage running plans the control-algorithm utilizes almost all components in the IT infrastructure.

The control-algorithm is explained more in (Jacobsen, 2020). The forecasted load profile (including active consumption, PV production, and reactive power) is either collected from Metrum PQ4Cast or generated internally in the ACS system. The internally generated forecasts use historical data or directly from the energy storage and related data such as weather forecasts.

The collected spot prices are collected from Nordpool API. Static energy storage information (e.g., nominal capacity) is retrieved from the NoSQL database and non-static energy storage information (e.g., SoC, SoH) is retrieved via MQTT (standard IoT messaging) directly from the EMS. The support of demand-response is fulfilled via a Web-API where the DSO can request operations and retrieve price suggestions. That functionality is also available in the ACS GUI.

Price suggestions are forwarded to the billing service, and as soon as am operation requests is executed on the energy storage, the ACS system also sends billing information to the billing service.

Service Stacking

One use case has of course a value. Being able to perform several use cases then has even more value. What services a battery can provide is not just software related. Hardware constraints limits or enhances what you can do with a battery. Simply put, different battery technology enables different services. Use cases where the starting point for the project pursuing the ability to address each use case and provide a service that could handle a situation.

We focused on a couple of use cases for our MVP and the went on to the next one. The MVP was to attempt to keep the dialogue in a little more practical level, which had a good effect on project progress. We knew from the start that these service at some point needed to interact. We called it service stacking. Hence giving the battery the ability to perform more services outside the facility. Not just looking at the facility itself but also being able to supply services to the grid (DSO) and to society.

The whole purpose of the project is to look at and test an adaptive control that will open new possibilities to control batteries more often, giving them a higher window of operational time The need of these services is a thing that also needs to be taken into consideration. If you don´t have a problem with voltage, then skip it. But if you do have a problem with voltage, wouldn’t it be nice to be able to active that function.

There are possibilities to let the algorithms decide on their own what action to promote. But there is also the possibility for us to emphasize actions. Let’s say that you what to award the algorithm that takes the SPOT price into account. Fine, do that. But don’t freak out if that that at some point goes against reducing local bottlenecks in the grid. So, there is a balance you need to figure out on how you want the system to act, if you can, remember that there are hardware limits. Then being able to aggregate more batteries, controlling them with the same ACS tech creates even bigger opportunities for all parties. Even if it´s smaller amounts of energy it’s still energy that can be used in a more effective way, or not produced at all. The reason for the adaptiveness is that we believe a battery with a little smart adaptive control has more to offer. And that there a new revenue streams and environmental gains to find. There are now several markets for flexibility. There are certain levels that need to be reached to participate in these markets. With the ability to aggregate flexible resources you can reach these levels.

We believe some of these levels and very local and not on the same scale as these levels. Therefor we believe on new markets on a root level that can help mitigate smaller but still challenging problems. One use case for the energy storage is letting it act as a fail-safe for power outages. That could be a great way of keeping household items staying powered during the power outage, which keeps residents happy. However, one problem with using the energy storage as a fail-safe when utilizing peak shaving is that when the power returns, an active consumption peak can be expected due to many household items starting at the same time. If the entire energy storage is discharged during the power outage, it cannot be used to reduce the active consumption peak afterwards. There might be a trade-off between customer experience (being able to use household items) and what the customer would be paying for the non-shaved peak.

Local bottlenecks I low voltage grids

Embriq has since 2017 had services that helps DSO locate bottlenecks in low voltage grids different levels, substations, secondary substations, outgoing cables and so on. The ACES project was according to its goal supposed to also look at 1.2.6 Load factors of grid components and 1.2.7 Network status parameters. That was not possible since we did not acquire access to that data from an DSO. A DSO should have been part of the consortium to secure that data. The demo sites where from a capacity perspective not large enough to affect or mitigate any grid related challenges. But still, introducing energy storages that can offer grid support is foregone by an assessment of the grid situation.

From a grid perspective you need to regard more than just the load. Power quality measurements are also equally important. Voltage level have proven to fluctuate more when concentrations of small-scale solar production increase. The measurement data is just one piece of a larger puzzle. More data from other surrounding system is needed to make more detailed analytical conclusions. More data will in turn provide more intel on what challenges the energy storages can alleviate. And the DSO won´t know what the challenges are until they start to measure and analyse their data in a tool like the ones that Embriq has and continues to develop.

Battery sizing:

It would have been nice to not only know the size of the batteries but also about the facility. In other words, know the demo sites entire picture. Not just the hardware, APIs or where you measure or what you measure with. The reason being that a battery might make a smaller impact in the solar production or energy consumption is much higher in proportion to the battery. Then the battery simply can´t make that large of an impact. The project demo sites where otherwise situated in adequate locations with a good mix of other things happening. Like solar cells on the rooftop and the ability to simulate reactive power and voltage events.

Aggregation Functionality

We envision a piece of software that will aid management and control of a fleet of installations. Not just these demo sites in the ACES project. Therefore, these two demo sites with different hardware and software setups. Each installation may support different sets of services. Aggregation will enable larger actors to control a large fleet of batteries adaptively. It would also align with a business model where such an aggregator offers "Batteries as a Service". These kinds of an actor would be particularly interested in using an energy storage site optimally, as the gains would increase with the number of installations. Looking at today markets for flexibility where you need to reach a certain quantity of energy then smaller actors are not included. But the ability to aggregate these smaller flexible resources opens for new opportunities.

Deploying a new site

You need power quality measurements (voltage and reactive) to provide that set of services, but we are dependent on those for other services to work, like peak shaving or optimizing your self-consumption. We need to secure the following measurements. Note that we are not dependent on all measurements.

- Active consumption measurements from the facility / every consumption source
- An energy storage and its specifications according to our spec-list.
- Input regarding local tariffs and net fees.
- Secure connection to BMS so that we can monitor and issue commands signals.
- Solar production measurements (active production). If there is any at the site.

Everything else we currently need is already in place. Weather data, spot prices, integration with Mincoms billings system and Metrums power quality measurements system.

The billing solution

Implementing a billing solutions that allow billing, clearing and compensation for all stakeholders in business models related to battery energy storage functionalities has been implemented by ACES partner Mincom and their system receives data from the ACS so it can produce invoices or credit notes for the performed services to the requesting party. More in depth information about the billing solution can be found in the Final ACES WP5 Report – "Deployable Storage to Cash Solution".

Spread Knowledge

Even if Covid-19 has hindered us from attending conferences and seminars physically we have still been able to inform and show the project work to people and stakeholders every chance we get. The project purpose and goal, partners and progress. We are often meet with curiosity and often about other battery project. There are many of them out there. Often from a different but similar angle of questions they want to answer but none with the same goal as us.

Another action that the hole project agreed upon was the series of short project videos. With the purpose of spreading information about ERA-Net Smart Grid and about the Horizon 2020 program as well as the project itself. The partners, what they do and what we have been working on. We believe that with the current circumstances surrounding Covid-19 this was a complement to the lesser opportunities presented to attend conferences and seminars.

RELATION TO THE THREE-LAYER RESEARCH MODEL FRAMEWORK

At an early planning stage, we defined the challenges that are already known before the project. The known challenges are of two types; market related and technology related challenges.

The market related challenges are addressed in the chapter of WP5.

The technology related challenges where more to WP3 (Embriq, Metrum and Fraunhofer):

- Machine learning software for battery storage is not mature
- A common IT-architecture is needed for exchange of data that are needed to provide for example energy and ancillary services. This common architecture does not exist today
- IT security issues will arise when developing (remote) controlled solutions for operation and monitoring of battery storage

To address the above challenges required an approach that include all the tree layers.

From a technical point of the development of an adaptive control system for the battery storage system will be required. There is a severe technical challenge since, as far as we know, this has never been made before. During our work, we will face the technical challenges mentioned above. To address these, we need the involvement of several groups of stakeholders.

Hardware development, performed in WP 2, involve battery technology suppliers and the academy as well as the research institutes.

The development of the adaptive control system itself also involved several groups of stakeholders such as

- Technology/software suppliers
- Research institutes
- The energy companies
- The technology providers

We can now show through our test that we have reached a higher level of TRL when it comes to being able to control a battery using ML software. We can still agree on that there is no common it-architecture. We do at the same time conclude that the need for open and fast system with open APIs are necessary for exchanging data between system.

ADAPTIVITY BY ARTIFICIAL INTELLIGENCE

The general challenge that the ACS was supposed to solve is to use energy storages in an adaptive way. We wanted to finding a near optimal sequence of battery commands based on the “facts” and “forecasts” available to the system at any time. By facts we mean energy storage capabilities, surrounding environment etc. By forecasts we mean both the prognosis we gather from external parties and the ones we would need to produce ourselves. There are two main problems in this scheme that is particularly interesting to solve using artificial intelligence methods. The first problem is a search problem where the aim is to find the sequence of battery operations that is optimal with respect to profits. The second problem is to produce accurate prognosis for consumption, production and energy pricing.

Forecasting

Forecasts will be gathered from different external sources. ACS will however also produce its own forecast. At present, a credible consumption forecast is very important. For the purpose we looked at DeepAR, this is an algorithm for regressive forecasting of time series. The Deep AR algorithm can produce forecasts with confidence intervals for future values based on multiple other inputs. A paper that outlines the algorithm is DeepAR: Probabilistic Forecasting with Autoregressive Recurrent Networks [David Salinas et. al. 2019]. Training data for this functionality will be historic time series of many dimensions such as weather, calendar, prices, power quality etc.

Sequence of Operations

The selection of battery operation sequence will initially be solved using a simple manually designed decision tree. As the number of possible ACS operations, we should investigate more methods of producing an optimal sequence of commands to the energy storage. One way of accomplishing this is through Reinforcement Learning. This would require us to create a software-agent with the capability of suggesting naive sequences and then incrementally improve them based on feedback. We would also need to create a piece of software that can calculate the cost or gain of any sequence of operations in each environment. The mentioned decision tree will initially be trained by manually entering the correct choice in given situations. It is not unlikely that we end up with a manually designed decision tree where several leaf nodes represent a “get the trained RL agent to suggest the next operations”. A scientific paper on the use of Reinforcement learning on a similar problem is available in [Panov et.al. 2018].

Reference experiments

Reference experiments should be executed before the adaptive approach is tested. We wanted to establish a baseline that will help us determine the potential gains of an adaptive solution. These reference experiments should use a well-defined set of naive heuristics to select the sequence of energy storage operations during the experiments. The planning of such an experiment includes setting up one or perhaps several timelines for the environment that is tested. The timelines must stretch over a significant time in order to reflect realistic versions of the scenario at hand. They should also include events and loads that are relevant in the tested use case. Since we are to repeat the simulation again with the adaptive solution, we need to ensure repeatability of all the experiments. The timelines should therefore be scripted, to aid automation, and versioned, to aid verifiable repeatability. The ACS GUI should also be able to display all the relevant time-series and charts that are needed to verify and compare the execution and outcome of the experiments. It includes:

1. Relevant time series (Consumption, production, prices, etc.)
2. The sequence of energy storage operations
3. A record of relevant external events, for example DSOA offerings.

The integration with the billing system will ultimately deliver the conclusion of the experiments in the form of an actual number which represent the performance of the operation during the experiment, i.e. capital gains. ACS is available to authorized personnel on the Internet, hence no further infrastructure is needed at site of the experiments.

Se more details about the experiments in appendix, (Odlander, Peak Shaving with Energy Storage. A case studie in Karlstad, Sweden, 2018)

Stakeholder adoption / End-user acceptance

During 2018 the project participants worked with work breakdown structure and detailing project activities for all work packages. Information channels, scheduling meetings and overall communication where set up. Project logo and document templates took shape. And the first use cases where discussed and investigated. That was an important step in identifying what scenarios to explore and which customer segments that might have a need for energy storage services as well as to what these services may require.

The first part of 2019 the project participants worked with several different use case scenarios. Starting to break the scenarios down, looking more into battery technology, communication, data, systems and integration. The participants also worked with structuring the work revolving the use case scenarios and possible dependencies. For that purpose, the project participants have meet twice in Sweden (Stockholm and Gothenburg). The project was presented at Elfack in Gothenburg 2019-05-09 and 2019-05-10. The project was also presented for 6 DSOs in Oslo, Norway during a Embriq customer workshop.

The project has carried out several events, presented ACES to EnergieCampus, reference group members and at the ERA-Net family conference 2019. Newsletters have been delivered and communication activities through the project website. A business model report is also provided by the project and WP5. Mock-ups where designed for both the nano sensor and the adaptive control system (ACS). Before the reference group meeting in Paris there were also a survey distributed to stakeholders. The findings from our study are summarized and reported.

During the work period, there were also changes in the organization as Metrum has changed CEO and as there is a change with project management. To speed up the activities, some of the project partners have allocated additional resources. Following and agreeing on requirements is a prerequisite for planning and coordinating the participants project activities. The business models went further in-depth validation through both literature studies, stakeholder interviews and further research.

This report provides more information on the stationary market for battery storage compared to many other sectors of the electric power industry. Also looking at global investments in photovoltaic systems. A large proportion of today's operational network-based storage systems for battery energy are used to provide services to TSOs, especially frequency management. Furthermore, grid-based batteries are installed in combination with large photovoltaic systems or wind power projects increasingly common. The storage market behind meters is often supported by incentives to connect a battery with a distributed photovoltaic system

7. Conclusions

There is still much more to do in this field of research. This is also true from a technological perspective. The current technology and market situation is somewhat different then when we applied for the project. New marketplaces for flexibility have been established and are more accessible. Even if it´s for larger actors. The marked for fast frequency regulation is booming in Sweden. Market actor are more aware of the challenges and more curious about the possibilities. That is also reflected in the amount of energy storage related project that are rolling or about to start all over the globe. Many more energy storage suppliers have also entered the scene. And many other actors are looking into ways of using energy storages, quite similar to our project.

For further information about the adaptivity and about the result from our experiments see the reference documents. Chapter 8

RECOMMENDATIONS FOR FUTURE STUDIES

Schedule time to work

Just scheduling time to work might be a way to shorten the time to getting something done. You might send a question that isn’t that hard to answer but the other party is simply busy with something else. Scheduling work meetings improved our productivity, and we would highly recommend that you schedule time for your project to focus on project tasks, especially if there are dependencies between your organisations. If there aren’t, then at least you have time to focus on your project tasks.

We should have spent a lot more time together in the first parts of the project. Getting to know each other better and figure out more in detail what we needed to do in order to get the demo sites up and running, ascertaining measurement data and mediate what each use case really translates to relative an adaptive control. For your understating and knowledge, you need several different parties to come together and have a collective understanding. Covid-19 did not help us in this regard even if the possibility to interact digitally trough Skype or Teams is a possibility. Covid-19 also had the effect that some companies had to partly permit personnel. Not that anybody was sick but still unable to work as normal.

Having a plan is of course necessary but do take a while to verify the prerequisites before you get started with an activity otherwise you will lose valuable time. Reality tends to eat plans for breakfast, but we continued after some adjustments and managed to catch up. Some assumption needed to be made to speed up the process. Some assumptions might not have been necessary if we had somebody to answer our questions. We felt that the project lacked a partner with more battery knowledge. Indirectly we had access to one trough Glava Energy Center and their demo site in Karlstad. But they could not support or involve themselves more due to other and previously committed commitments. That is an interaction that could have been great to test more since the battery suppliers don´t (from what we today know) have an adaptive control system.

Consortium and resources

Do take some more time to think through which partners to include in your project. The part they play and dependencies between partners. We managed to establish a good enough communication to get the job done. Having an even closer dialogue with more

DSOs would have been preferable. Also remember to include IT personnel. There are access points, firewalls, ports, IT-security, and other questions that need to be addressed at some point. It simply saves time to at least have them close at hand.

Battery health

We had an awesome solution with Insplorions battery sensor. But what if you don’t have access to that technology? How do you monitor the battery health and its degradation in a more accurate way? There are studies done in this field but there are many different battery solutions that are used for different purposes. Are they idle a lot of hours or are they constantly performing operations? Our model does not handle all these variances. There might be room for a study regarding the assessment of the battery’s states of health.

Adaptive control for heat pumps

Using the same mechanism, we already had for determining grid congestions together with the ACES ACS could be used to control cooling or heat pumps. There are many of the installed in the low voltage grid and could, if aggregated amount to a lot of flexibility. A solution also needs to handle the recurrent load. Since starting them al at the same time would create a peak. Embriq just got a new RnD project approved that will look into flexible housing together with RISE. There we hope to use the ACES ACS to control heat pumps.

Control system complications

During this project we came across some challenges about the making of prognosis for electric parameters that has been of interest, when at the same time controlling the same parameters to improve the network power quality for specific situations. I.E when using the energy storage for peak shaving by inputting power to the network that will hopefully lead to a better situation in the grid with a more balanced power profile resulting in lower costs for the user subscribing to the peak shaving service. If the measurements of current and power used for prognosis is situated only at the point where the peaks are present and you do not know anything about when the energy storage is being used for suppressing the power peaks, then the prognosis will be affected by the controlling operations.

For the following weeks, the prognosis will change and be adjusted due to the controlling operations. The power peaks will be flattened out and hence the need for peak shaving will seem to disappear. This can be dealt with in different ways, however due to lack of time and resources there was no way to implement handling of this situation during the project, and therefore for future system development this is an important part to take into consideration. Also if the ACES controlling system should be able to handle many energy storages distributed on different point in the grid and being used at different times for different services then this need to be handled more effectively so that forecasts are weighed together with the controlling operations performed by the ACES system.

One way to deal with this is to measure at the connection point to the energy storages so that it can be seen when the energy storages is being used and when not and compare the current or power draw with how the situation is affected at the point where the system is intended to perform a certain service. Measuring at the energy storage will however not always be possible which has been shown during this project at the demonstrator Glava Energy Center (measurements performed in facility owned by HSB Karlstad) where the energy storage was coupled together with other equipment in a DC network behind an inverter. Due to the closed environment of that system it was not possible to achieve a direct measurement on the energy storage itself with the Metrum power quality instruments. As there were existing measurements within the hub of the energy storage system itself Embriq was able to implement functionality to read those measurements via an API. Due to COVID-19 pandemic Metrum was in lack of resources within the timeline of the project to implement functionality to take advantage of the existing measurements and use them with the forecasting calculations. So, for future different scenarios when running the ACES system in bigger environments where there can be many different energy storage system solutions, measurements at the energy storage will perhaps not always be possible to achieve in an easy way. Then alternatives for measurements at other locations need to be considered (discussed further down in a later paragraph) or if it is possible to get access to data from within the energy storage systems and adapt the forecasting solution with that external data input.

A second possible way could be that the ACS system gives input to the Metrum PQ4Cast application on when controlling operations are performed and how much power is injected to or ejected from the grid. Metrum PQ4Cast could then build a new prognosis where the power input from the ACS system is weighed into a new forecasting model. This second way could maybe also be turned the other way around and instead the ACS system has to accept that the prognosis will change after time once the controlling operations are running and with the knowledge of when the ACS has made controlling operations it can conclude how much effect it has had on the prognosis.

A third alternative which probably need to be coordinated with one of the previous mentioned alternatives is to try to arrange the measurement that should be used as a basis for the prognosis at a measurement point where the prognosis are not affected depending on whether the power is coming from the local energy storage or from the grid itself. An example of this measurement configuration is explained with the help from the below figure and following text.

The picture shows an industry facility in which there is a local energy storage but also internal power users like bigger machines or specific industry processes. The objective is to cut power peaks of imported power from the grid at specific times during the day or week when such can be expected based on historical variations and the typical operation of the industry internal processes. To observe the current and power usage a measurement (Measurement 1) is required in the industries connection point to the grid. Within the industry is a local energy storage which can be used by the ACS system to control the power profile of the industry and the idea is that the energy storage should be used as a power reservoir giving back power to the industry at times when the power is forecasted to peak.

When the energy storage is used and injecting power to the industry the imported power from the grid measured at Measurement 1 will drop and if this scenario continuous the power prognosis made for measurement 3 will be affected and show less future power peaks. This could be a problem for the ACS system if this prognosis is being used to decide when the energy storage should be activated to shave power peaks, since the ACS system or the Metrum PQCast does not take into consideration that the energy storage has been used historically for controlling the imported power at the connection point to the grid, which have resulted in changed power profiles in the connection point.

Inside the industry there is third measurement on the main process of the industry or the total internal power consumption downstream of both the grid and energy storage. In this measurement point there will not be a difference regardless of whether the power is coming from the grid or the energy storage and hence this is the best place to put the measurements for the peak shaving service as the prognosis will not be affected by the ACS system controlling the energy storage. However, for other scenarios like controlling the voltage this measurement setup will not be enough since voltage is distributed differently and could be affected on all different measurement points.

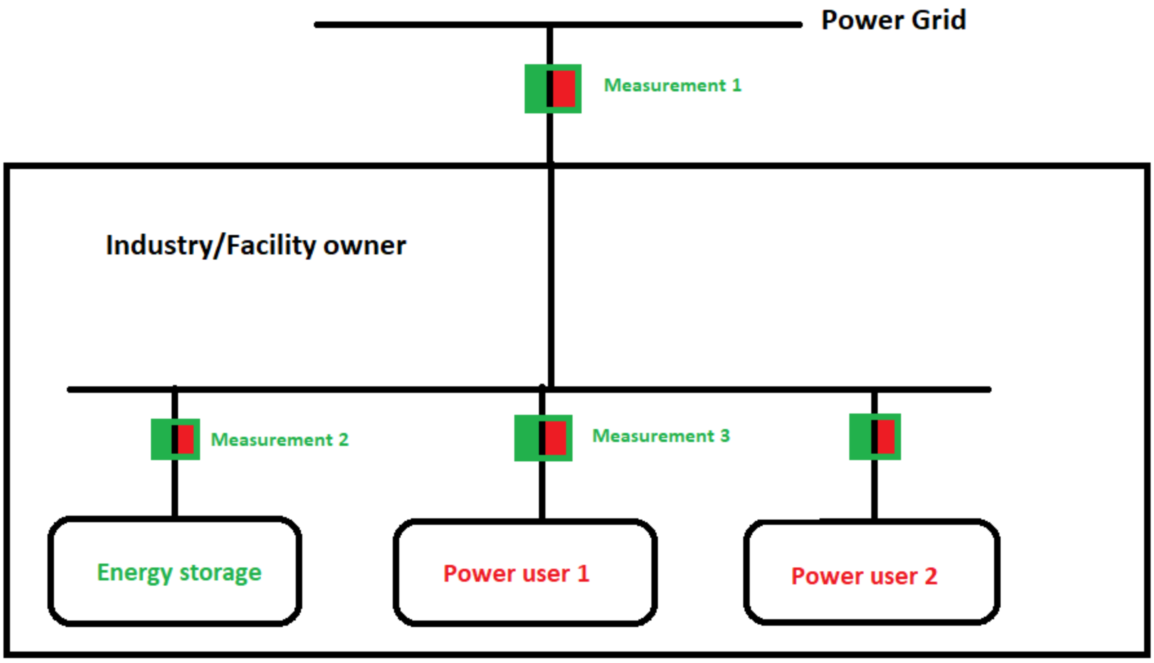

Figure 12, Example of measurement setup.

8. Referenses

al, S. e. (2019). *DeepAR: Probablilistic Forecasting with Autoregressive Recurrent Networks.*

et.al, A. I. (2018). *Grid Path Planning with Deep Re-inforcement Learning: preliminary results. Procedia Computer Sci-ence 123, pages 347-353. 8th Annual International Conference on Biologically Inspired Cognitive Architectures.*

Jacobsen, R. (2020). *Finding the best energy storage running plans.* Uppsala, Sweden.

Odlander, M. (2018). *Peak Shaving with Energy Storage. A case studie in Karlstad, Sweden.*

Figures