Innovative solutions to be tested in the demos V1.0

Deliverable D8.3

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Deliverable 8.3 Provides a detailed description of the solutions that are tested in WP8, including communications and control strategies

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EXECUTIVE SUMMARY

The transition to a low-carbon energy system requires a high penetration of renewable energy sources (RES) and efficient utilisation of energy. The incorporation of intermittent RES entails challenges due to their variable power output, which stresses the need for flexibility options that provides sufficient grid balancing functions. Two demonstration projects have been implemented by E.ON, within the framework of the EU-funded project INTERFLEX, to integrate and test innovative technical flexibility solutions to create smarter grids. The overall purpose of the project is to understand to which extent these solutions can provide support in the integration of RES in the system. At the same time, understanding the customers willingness to participate in new solutions.

Within work package 8, E.ON is testing the following solutions on thermal energy networks and the electricity grid:

Demand side response through thermal inertia
Through utilising thermal inertia of buildings, shifting of energy demand in time is enabled via the E.ON Modular Platform (EMP). By connecting building management systems (BMS) to the platform via a gateway, the houses can support the district heating grid by lowering heat demand in each building connected to the platform or in a specific area of the heating grid. EMP is a cloud platform, which serves to gather and structure information, optimise on accessible data and generate a corresponding steering signal. The customers participating in the trail should not experience a temperature deviation of more than ± 0.5 C° from the desired set point.

Low temperature balanced thermal grids
Bidirectional low-temperature networks are used simultaneously to supply buildings with heating and cooling services. For this purpose, the buildings are equipped with heat pumps and chillers that use the thermal network as an energy source. Buildings with different energy demands are connected and residual thermal energy flows are balanced between them. Thereby, bidirectional low-temperature networks effectively use and reuse all available thermal energy and make it possible to decrease both pollution and energy consumption within a city district. The concept aims to exchange as much energy as possible between different users.

Grid automation
The Energy Management System (EMS) serves as the main controller in the microgrid control system and controls the RES generation and operational mode of battery system. It has direct control over the power breaker at the point of common coupling so that it can command island mode operation by switching off the breaker when certain requirements are fulfilled. The system is able to run in island mode, suggesting that the microgrid is disconnected from external grid during operation. Virtual island mode is a further mode of operation, where islanding can be simulated by determining the power exchange across the breaker. When

the system is turned on it is fully automated and can seamlessly change between grid-connected and islanded mode.
Furthermore, design, implementation and evaluation of advanced control algorithms for microgrid energy management are carried out by RWTH University, Aachen. The objective is to improve the control strategies currently implemented in Simris to increase the flexibility potential without adding more capacity.

Battery Energy Storage System

The power rating of the Simris battery storage system was set to 800kW to meet the local demand. During the design phase, even though the battery is larger than any individual RES generation, Enercon advised that a minimum battery size should be 2MW to guarantee stable operation of the WTG.
An additional concern was the capability of the battery to seamlessly change between grid-connected and islanded mode, without altering the battery system operational mode. Alternative solutions were also evaluated to address this issue. An alternative was to accept a temporary outage while the battery system shut down, changed modes and re-started. A further option included an installation of a semiconductor switch at the point of network connection, giving a clean, high speed disconnection to allow the battery system to change modes.

Since the commissioning of the system in October 2017, both concerns have been addressed and is no longer considered a potential issue.

Demand Side Response

Distributed flexibility technologies are tested within the Simris demo where customer loads can be steered and shifted in time. Thereby, peak demand can be diminished and a more efficiently grid operation, in terms of matching supply and demand, can be attained. Customers are offered to install Power-to-Power or Power-to-Heat steerable assets for Demand Side Response (DSR) purposes. Customers can either invest in a subsidised PV/battery solution (Fronius) or a subsidised air-water heat pump (Nibe). Additionally, retrofit solutions for existing heat pumps (Ngenic Tune) or hot tap water boilers (Bobbie), are offered to customers free of charge.
An electric vehicle charging pole will also be installed in Simris to evaluate the impact of an additional infrastructure providing support to the local energy system.
The DSR assets within the Simris project are managed by a separate IT system than the microgrid, provided by ICONICS. The overall system has been designed this way in order to increase replicability.
As with grid automation, work is being carried out by RWTH Aachen to determine the possibility to utilize more flexibility per asset without increasing capacity.

Through these efforts, E.ON, RWTH Aachen and the INTERFLEX consortium hopes to provide the means to increase RES penetration and making the customers active participants in the energy transformation.

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1. INTRODUCTION & PROJECT BACKGROUND

1.1. Scope of the document

The scope of this deliverable document is to:

- Describe the solutions chosen for the project.
- Describe the functionalities and architecture of the systems involved.
- Describe the expected value of the chosen solutions for customers.

1.2. Notations, abbreviations, and acronyms

The table below provides an overview of the notations, abbreviations, and acronyms used in the document.

Table 1: List of acronyms

ACK	Acknowledgement signal
BESS	Battery Electrical Storage System
BLC	BESS Local Controller
COP	Coefficient Of Performance
DER	Distributed Energy Resources
DSO	Distribution System Operator
DSR	Demand Side Response
EMS	Energy Management System
EMP	E.ON Modular Platform
EVSE	Electric Vehicle Supply Equipment
HV	High Voltage
IoT	Internet of Things
LES	Local energy system
LMU	Local Measurement Unit
LSTM	Long Short Term Memory
MPC	Model Predictive Control
MV	Medium Voltage
PCC	Point of Common Coupling
PV	Photovoltaics
RES	Renewable Energy Sources
RTU	Remote Terminal Unit
SoC	State of Charge
VPN	Virtual Private Network
WP	Work Package
WTG	Wind Turbine Generator
REST	Representational State Transfer
TRL	Technology Readiness Level
ACK	Acknowledge
BESS	Battery Electrical Storage System
BUG	Back-up Generator
DER	Distributed Energy Resources

DSO	Distribution System Operator
HTW	Hot tap water
KPI	Key Performance Indicator
P2H	Power-to-Heat
WPL	Work Package Leader
REST	Representational State Transfer

1.3. EU Expectations from InterFlex

INTERFLEX is a response to the Horizon 2020 Call for proposals LCE-02-2016 ("Demonstration of the smart grid, storage, and system integration technologies with increasing share of renewables: distribution system").

This Call addresses the challenges of the distribution system operators in modernizing their systems and business models to be able to support the integration of distributed renewable energy sources into the energy mix. Within this context, the LCE-02-2016 Call promotes the development of technologies with a high TRL (technology readiness level) into a higher one. In this case, solutions that have been field tested are supported to develop tools, insights, and competencies to facilitate their market entrance e.g. roll out.

1.4. Introduction: Demo 4A

E.ON Customer Solutions has as part of a previous EU project, FINESCE, a project that ended in 2015 under the Future Internet Public Private Partnership (FI-PPP), developed a platform for managing flexibility within district heating networks. A trial has been carried out in the Malmö region in southern Sweden and INTERFLEX demo 4A intends to further develop the outcome of FINESCE. The purpose of demo 4A is to increase the product maturity level to handle large scale applications and to better understand the customer interactions to elicit more active participation and create attractive business models to increase market penetration.

Furthermore, new applications are to be tested on the same technology foundation, including the potential for low temperature thermal networks as a supplement to the central district heating network.

The overarching goal of the Malmö demonstration 4A is to exploit untapped potentials within systems such as the building envelope thermal inertia and heating/cooling networks. Making use of the thermal inertia given by such systems would enable integration for renewable energy systems by adapting electrical heating and cooling assets. Furthermore, the aim is to introduce more advanced control strategies and quantify the potential flexibility through extensive functionality testing.

Through the application of two use cases, demo 4A will validate technically and economically, the enabling roles of DSO for different energy carriers to increase the local energy system efficiency by activating system flexibilities at all possible levels. The assumption is that by integrating different energy carriers, more flexibility can be utilized.

It should be noted that the technological platform developed earlier is subject to immaterial propriety rights of E.ON and not open for sharing within INTERFLEX. However, all subsequent findings from the application of the technology is.

1.4.1. Demo site information use case 1

The demo 4A use case 1 will be carried out in the town of Malmö, the third largest city in Sweden with over 340 000 inhabitants and one of the fastest growing areas in Sweden. E.ON operates a large district heating network in Malmö, see Figure 1, and it also served as the test bed for the FINESCE project where the underlaying IT platform, CESO (Customer Energy and System Optimization), was originally developed and tested. The use of CESO technology has the potential to enable flexibility in the energy system, and the aim is to quantify this flexibility in technical terms by conducting functionality tests of the system.

As part of INTERFLEX, new installations will be required but due to the existing infrastructure, local expertise and customers who already participated in FINESCE, Malmö was chosen as the demo site. The customers (building owners) have buildings spread geographically across Malmö and therefore enables the possibility to assess the impact of a large scale roll out.

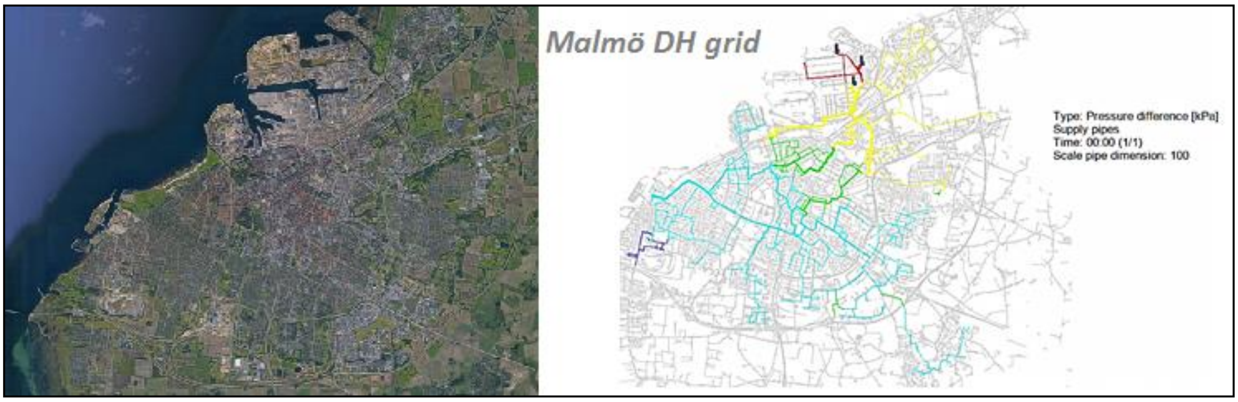


Figure 1: Schematic overview of the district heating grid typology in Malmö

1.4.2. Demo site information use case 2

The demo site for the ectogrid use case is located in the E.ON Energy distribution office at Nobelvägen in Malmö, and consists of several buildings that are connected to and supplied by the central district heating and cooling networks. A heat pump is integrated into the return lines of the two networks, and is used to couple the local thermal networks to recycle the heat dissipated for comfort cooling and to use as large a proportion as possible for the supply of domestic hot water and heating to achieve a high efficiency. The idea is to provide part of the heating and cooling demands simultaneously by using the heat pump.

To provide flexibility for the electricity grid with this concept, the heat pump can be operated based on signals from the electricity grid. This is made possible by the fact that the heat pump is used as an additional system and the security of supply is guaranteed by conventional supply systems. This concept realizes the coupling of the heating, cooling and electricity systems and is shown schematically in Figure 2.

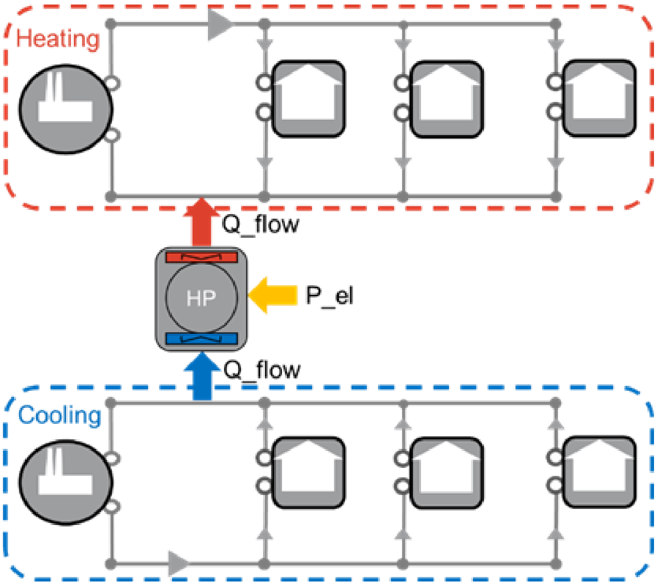


Figure 2: Coupling of heating and cooling networks with central heat pump

1.5. Introduction: Demo 4B

In 2015 E.ON Energidistribution decided to start the design and development of a pilot trial. This trial would be able to demonstrate that an electrical system can host a penetration of up to 100% of power sourced from renewable sources (PV and Wind) by using field-proven and currently market available technologies. With this trial, E.ON Energidistribution would also prove that as a company it possesses the technical capabilities to deliver such a system. For this pilot project, called Local Energy System (LES), the small village of Simris in the south of Sweden was selected due to their optimal technical conditions and their already existing PV farm and Wind Turbine connected to their electricity grid. In Figure 3, the geographical location including a more detailed view in Simris and the respective energy park is presented.

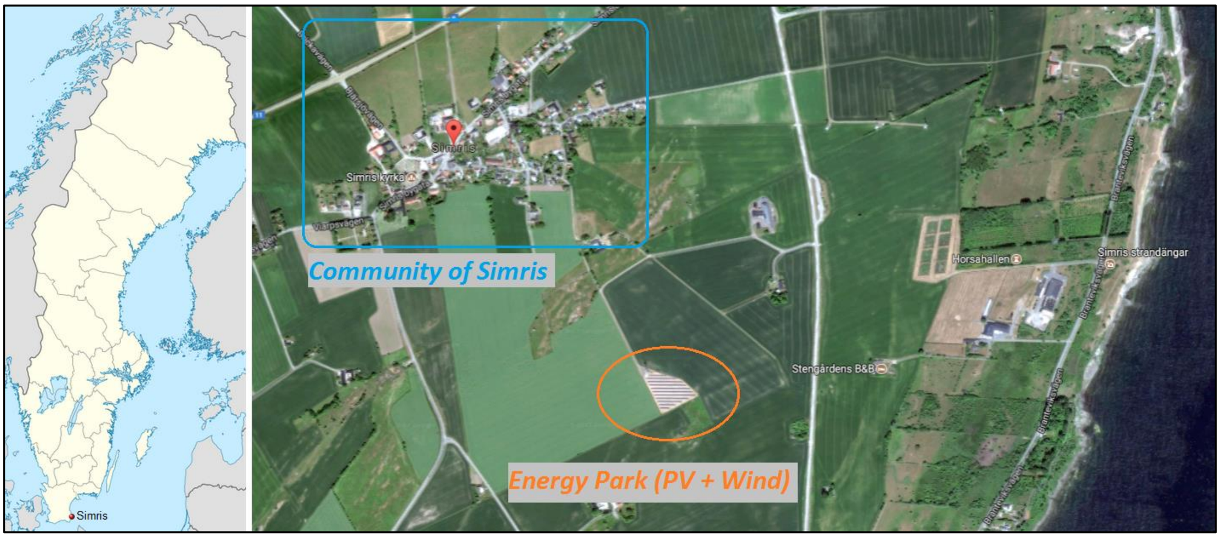


Figure 3: Geographical location of Simris included a detailed layout of the village and respective energy park [1], [2]

During the first phase of this project, the main focus has been on addressing technical aspects to attain a successful implementation of the microgrid. Wind power serve as the main source of generation, supported by a PV-farm, a Battery Electrical Storage System (BESS) and a bio-fuel backup generator (to be used only in case there is not enough available power from renewables). With a central micro-grid controller, the system will have the capability to seamlessly switch between interconnected and islanded mode. The main challenge of this project is managing the volatility of the power sources whilst keeping the same high standard power quality level of the supply to the Simris inhabitants. This first phase of the project has been commissioned and inaugurated on October 18th, 2017.

The second phase of LES Simris is part of the EU partially funded INTERFLEX project. With the use cases 3-5, E.ON Energidistribution intends to show-case how distributed residential customers can support the integration of renewables by enabling the use of their sources of flexibilities for the benefit of the overlying system. In this DSO<->Micro-grid<->Customer interaction, several different technical, commercial and regulatory topics are addressed.

Use case 3 – Introducing DSR equipment to support the frequency and power management

Use case 4 – Turn passive consumers into active participants through peer-to-peer market mechanisms

Use case 5 – Simulation and analysis of congestion management

The project area of Simris encompass about 150 households who are all existing customers of E.ON Energidistribution (DSO). In Figure 4, a rough overview of Simris' grid topology is presented.

Figure 4: Schematic overview of the grid topology for the community of Simris

The network of the local Energy System (LES) of Demo 4B was created around an already existing grid. Within the grid, there are six secondary substations 11/0,4 kV with several customers connected (see Figure 5). The number of connection points within the LES is 151. The feed in point to the LES is via a substation “SRS” 20/10 kV from a 10 kV bay (SRS bay 7). The bay is equipped with a power breaker, voltage and current transformers and relay protection devices. To the string at bay 7 (LES bay), there were existing PV and wind generation connected.

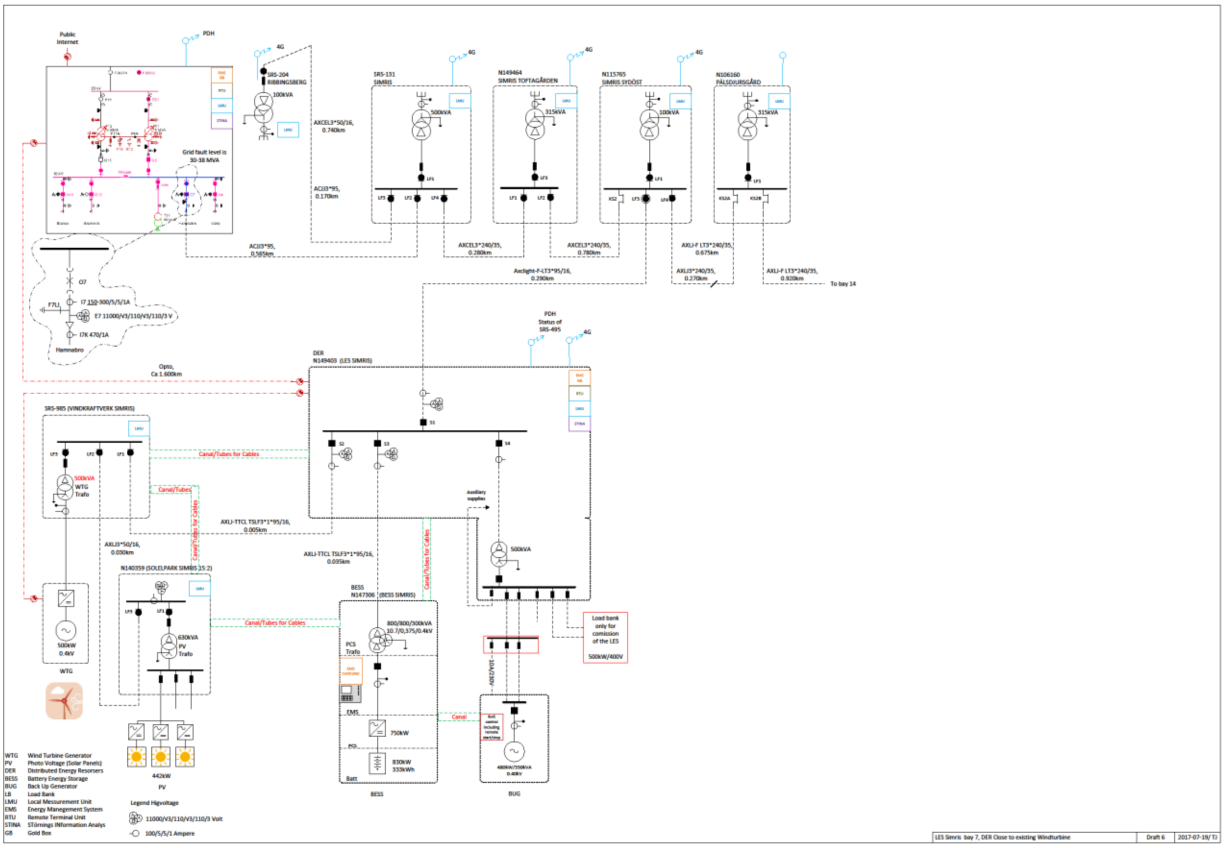


Figure 5: Demo 4b Single Line Diagram of Simris LES

In addition to the existing grid and renewable energy sources, the main assets forming the LES are: a central battery system, a grid station and a backup generator together with a sophisticated control system that is the intelligence asset of the microgrid. The control system ensures that all production units can communicate with each other so that the LES delivers electricity within the conventional power quality limits. The main central battery system operates as the grid forming unit and is in charge of the instantaneous balancing of the microgrid.

To be able to conduct the project, some changes have been made to the grid in Simris, e.g., the exchange of one secondary substation 11/0,4 kV; a section with overhead lines was changed to underground cable; and a state of the art secondary substation (DER-substation) was built next to the existing WTG and PV-plant. The DER-substation is fully equipped with all the necessary communication devices, protective relay devices and control system devices that are needed to run the LES.

Supervisory control and data acquisition (SCADA)

The LES in Simris is closely monitored 24/7 from the central control room for E.ON's grid in Sweden. In the control system, operators can:

- See operating mode (island, virtual island, grid-connected)
- See real-time active and reactive power, currents and voltages from the different components
- See common warnings and alarms
- Trending
- Switch on/off power breakers

In Figure 6 below, a screenshot from the control system is displayed, mainly showing the controllable breakers in the DER-station.

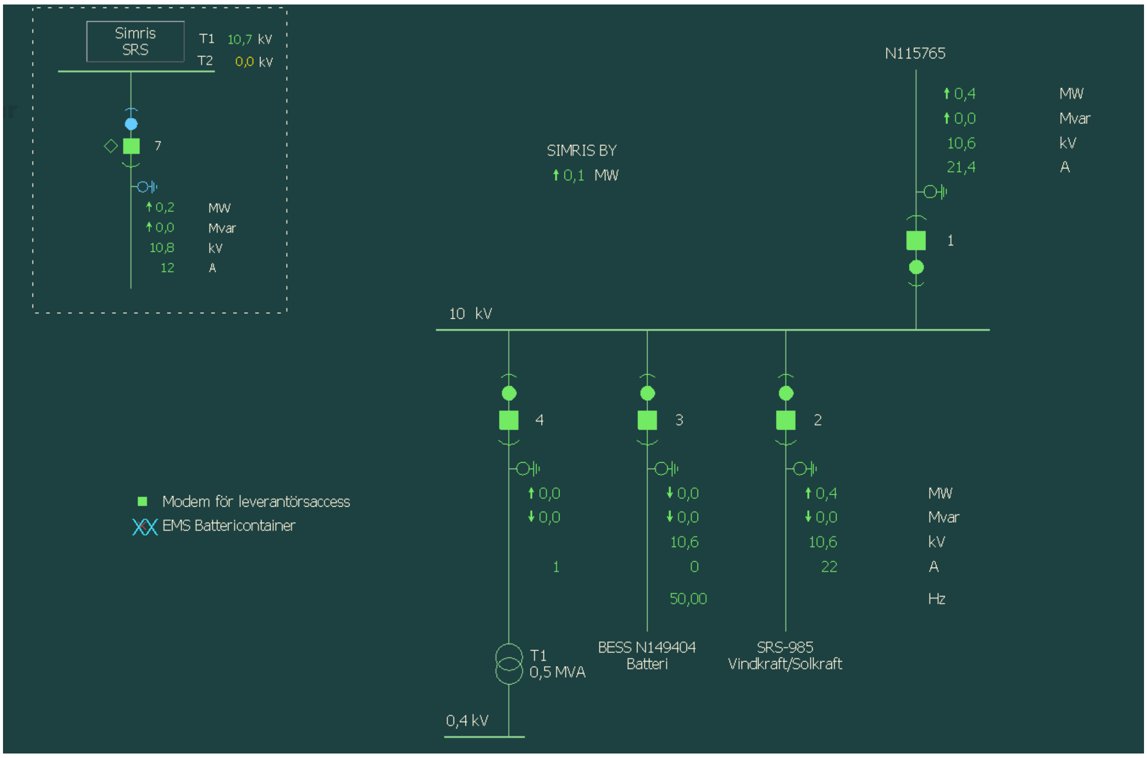


Figure 6: SCADA SLD for Simris LES

To be able to communicate with the LES-site, a Remote Terminal Unit (RTU) was installed in the DER-substation. The RTU communicates with E.ON's SCADA system through existing fiber and radio infrastructures. The RTU also communicates with the Energy Management System (EMS) through the Modbus RTU protocol, which makes it possible to get common warnings and additional information from the different components in the LES.

The in-depth control is done from the EMS system (see Figure 7 below), where detailed information about the system and the components is available. In the EMS control system, the following can be managed:

- Change of modes (island, virtual island, grid-connected)
- Detailed information from the battery system (capabilities, etc.)
- Manual operation of each component, i.e., setting set points for the PV-plant, the WTG and the Battery making it possible to manually control active and reactive power flows
- Changing parameters affecting the ramping rates for components, synchronization, droop parameters and much more
- Detailed warnings and alarms
- See real-time active and reactive power, currents and voltages from the different components

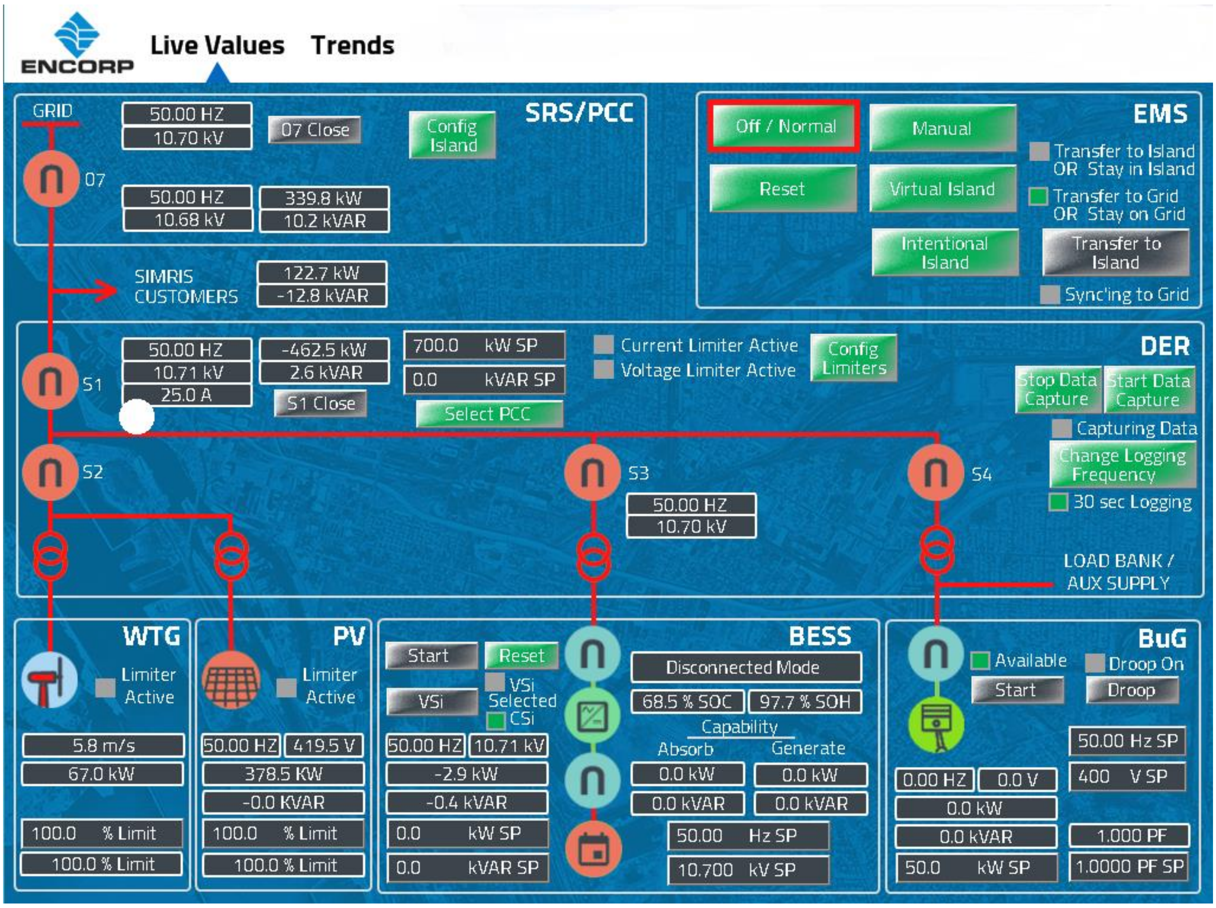


Figure 7: EMS main HMI

2. INNOVATIVE SOLUTIONS IN DEMO 4A

2.1. Thermal Energy Networks

For the analysis of the demand response potential of thermal networks dynamic simulation models for thermal networks were developed. A distinction is made between different thermal networks; on the one hand, conventional heating and cooling networks are considered and on the other hand, the innovative concept of bidirectional low-temperature networks is also examined.

To provide a basis for the investigation, dynamic simulation models of the individual components of conventional thermal network were developed in a first step. The simulation environment Modelica/Dymola is used for this purpose. These component models can be combined to system models to enable the dynamic simulation of thermal networks. The main components of conventional heating networks consist of the central energy supply, the hydraulic distribution network and the buildings connected to the network.

One application of the system models already investigated in this project is the coupling of heat and cooling networks with a central heat pump. The idea behind this concept is to operate the central heat pump based on the demand of the electricity grid. If there is a surplus of electricity, the heat pump can be operated as an auxiliary heating system to provide flexibility for the electricity grid on the one hand and to replace part of the conventional heat supply on the other.

2.1.1. Demand side response through thermal inertia

By utilizing natural flexibility through thermal inertia, buildings connected to the E.ON Modular Platform (EMP), can support the district heating grid by lowering heat demand in each building connected to the platform or in a specific area of the heating grid. The solution can help minimize new production units when expanding the district heating grid. It can also synergize production, distribution and end-users to create a more engaged community in a more digitalized supply chain.

To ensure a comfortable climate for the residents, the indoor temperature is monitored and is not allowed to deviate more than ± 0.5 C° from the desired set point. This could potentially allow for a 50 percent power reduction over a period of approximately five hours, a result which will be determined by the outcome of INTERFLEX.

To meet overall energy demands the system automatically pre- and after heats the buildings, effectively reducing the peak power generation demand, increasing the overall efficiency. This is illustrated in Figure 8.

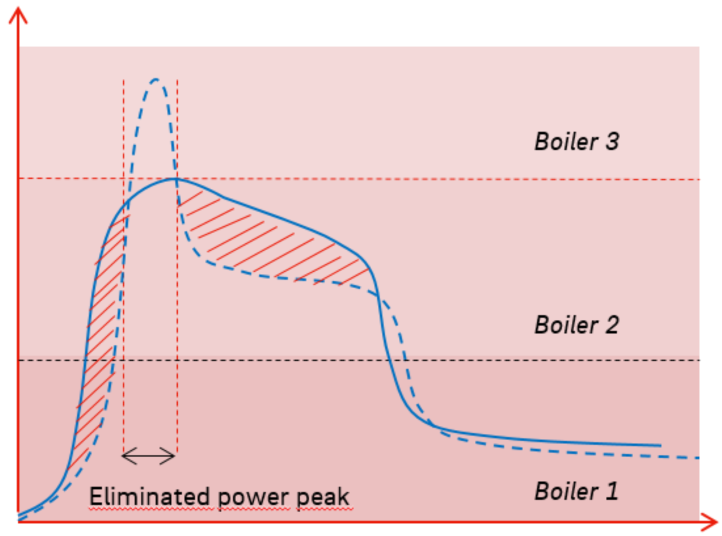


Figure 8: Arbitrary illustration peak power reduction through basic operation

The system can be operated through either manual or automated scheduling.

Manual scheduling

The DSO can access the system through an operator interface where the available aggregated flexibility and the outcome of previous actions are displayed, as shown in Figure 9. The system allows the operator to set multiple schedules with a specific set point for desired power demand reduction based on available flexibility.

Figure 9: DSO operator interface of the EMP

Automated scheduling

The system can also be setup to automatically set schedules based on external conditions such as price, CO_2 emissions and electricity power balance. This optimization is based on cost functions, which can be created using different boundary conditions. Examples are, pricing information from the Swedish energy exchange or production/distribution costs for delivering district heat. The algorithm converts the generated cost function and translates this to a flow temperature offset. In Figure 10, an example of this is presented where the price for delivering district heating/MWh is displayed on the left y-axis and the corresponding flow temperature offset is shown on the right y-axis.

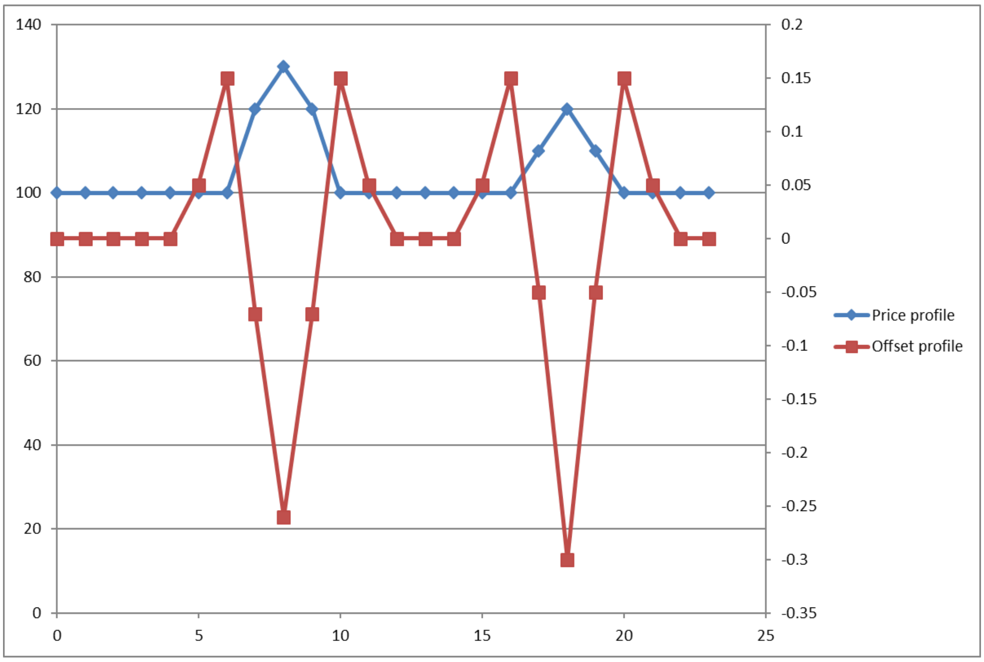


Figure 10: Example of generated offset profile from price data series.

Currently the system is only able to optimize against one parameter at the time and the general strategy is to be examined and developed through the course of INTERFLEX.

2.1.2. Low temperature balanced thermal grids

To investigate the concept described at the demo site "Nobelvägen", of coupling two thermal networks with a heat pump and to test different control strategies for the heat pump, a dynamic simulation model in the simulation environment Modelica/Dymola is used. The system model is composed of the coupled models of the thermal networks for heating and cooling, the models for the conventional energy supplies, as well as the substation models, which represent the energy consumption of the buildings.
The model of the heat pump is parameterised with manufacturer data so that the real performance of the heat pump is well reproduced. For this purpose, simulations were carried out and the results were compared with measured data. The results for the heat output of the heat pump and the outlet temperatures are shown in Figure 11.

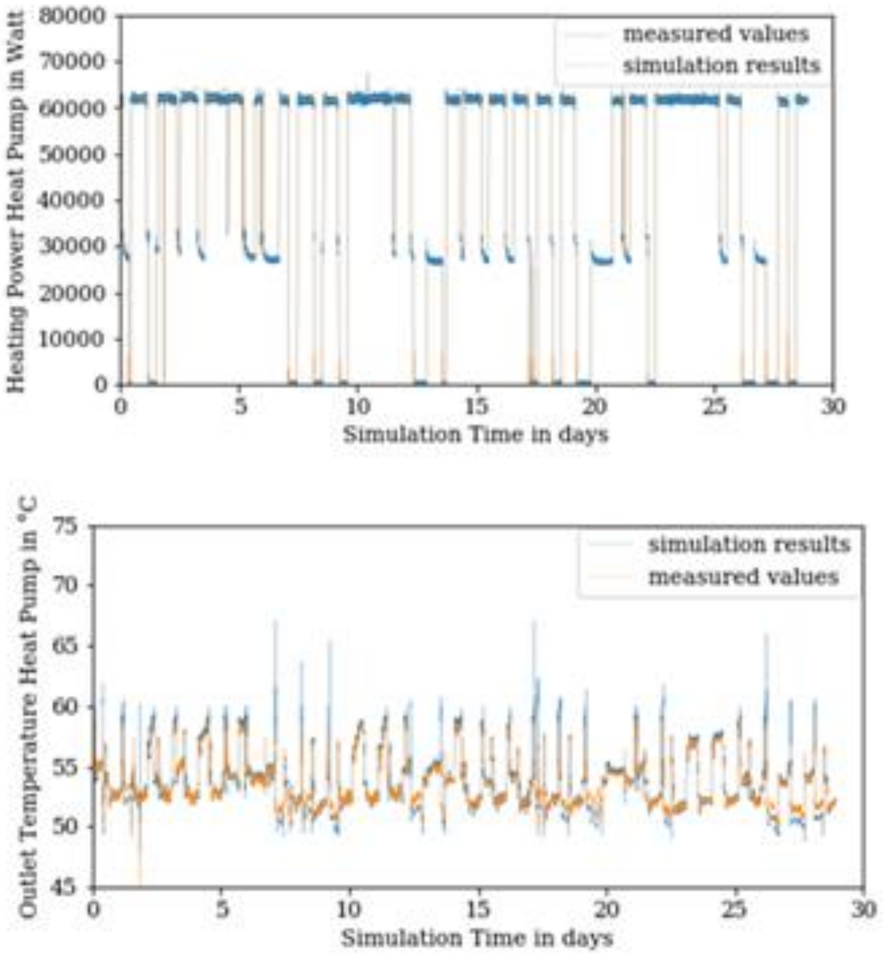


Figure 11: Verification of the detailed heat pump model with measured values for the heating power and the outlet temperature of the heat pump

The described dynamic simulation model is used to test different control strategies for the heat pump. For this purpose, a demand-based control of the heat pump was first developed. The heat pump is only operated if there is a sufficiently high heat and cooling demands at the same time, so that the heat and cooling provided by the heat pump can be effectively used. In a next step, the possibility of providing flexibility to the power grid was explored by the integration of decentralized renewable energy by extending the system model with a photovoltaic system model. Only the power provided by the PV system is used to operate the heat pump. Therefore, the heat pump is operated to support the conventional supply system if heat and cooling demands exist and PV power is available simultaneously. The PV system is a typical source of fluctuating renewable electricity, and the use of the electricity for thermal purposes reduces the amount of electricity fed into the distribution network. Figure 12 shows the switching on and off operations of the heat pump with the two control strategies.

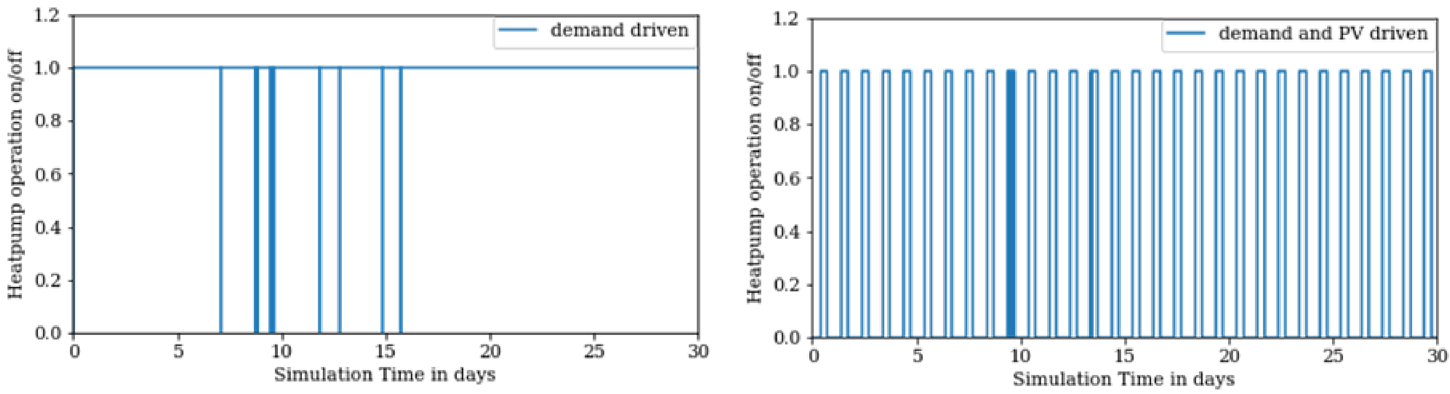


Figure 12: Demand driven and PV power based on/off-signal of heat pump

In addition to conventional thermal networks, bidirectional low-temperature networks are also being investigated in this project. Bidirectional low-temperature networks are used simultaneously to supply buildings with heat and cooling. For this purpose, the buildings are equipped with heat pumps and chillers that use the thermal network as an energy source. By connecting buildings with different needs and balancing residual thermal energy flows between them, bidirectional low-temperature networks effectively use and reuse all available thermal energy and make it possible to decrease both pollution and energy consumption within a city district. The concept is to exchange as much energy as possible between different users. Three different stages of energy balancing are considered for this purpose:

1. Energy balancing within a building
2. Energy balancing between buildings
3. Energy balancing of the network via central unit

Energy compensation within a building takes place with simultaneous heating and cooling requirements in the same building. In addition, the bidirectional low temperature network enables energy balancing between different buildings with heating and cooling demands. To ensure that the network temperatures do not exceed or fall below limit values, a central balancing unit is used, which either provides or extracts thermal energy from the network.
To investigate the concept and operation of bidirectional low-temperature networks, dynamic simulation models of individual components were developed. The main components are the buildings, in particular the integrated equipment such as heat pumps and chillers, the distribution network and a central balancing unit.
Three different models were developed for the buildings, representing buildings with only heat demand (equipped with heat pumps), only cooling demand (equipped with chillers) and buildings with heat and cooling demand (equipped with heat pumps and chillers). Figure 13

schematically shows the energy systems of the different building types. Buildings with a pure heat demand extract water from the warm grid side of the thermal network (red) to provide hot water and heat. In buildings with simultaneous heating and cooling demands, energy compensation takes place as much as possible within the building, so that only part of the energy needs to be taken out of the thermal network (Figure 14).

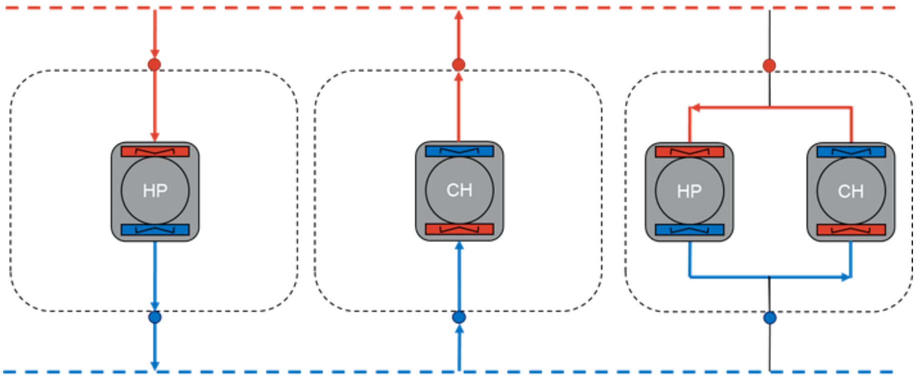


Figure 13: Schematic representation of building energy systems and their connection to the thermal network

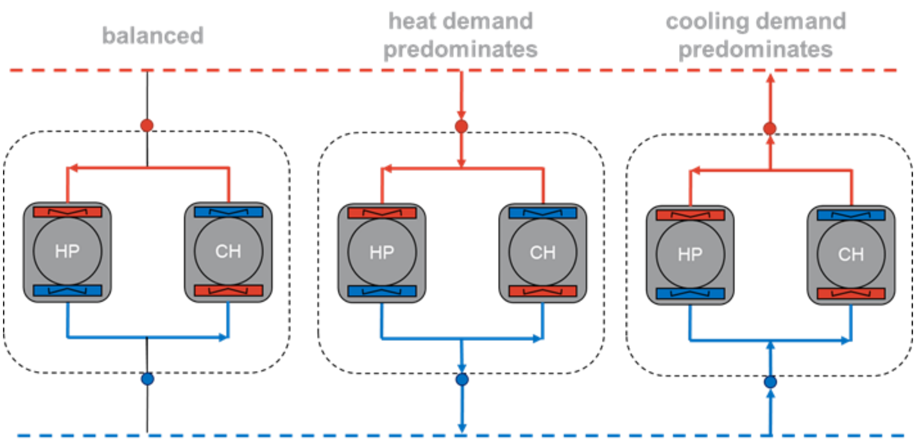


Figure 14: Schematic representation of energy balancing inside the building

Due to the high complexity of bidirectional networks, which result primarily from constantly changing mass flows and flow directions within the network, the component models were first combined into a system model and the functionality of the system model was tested. For this purpose, a model of a bidirectional low-temperature network with five buildings was constructed, which is shown in Figure 15. Three buildings only require heat (red), two buildings require heat and cooling (red and blue).

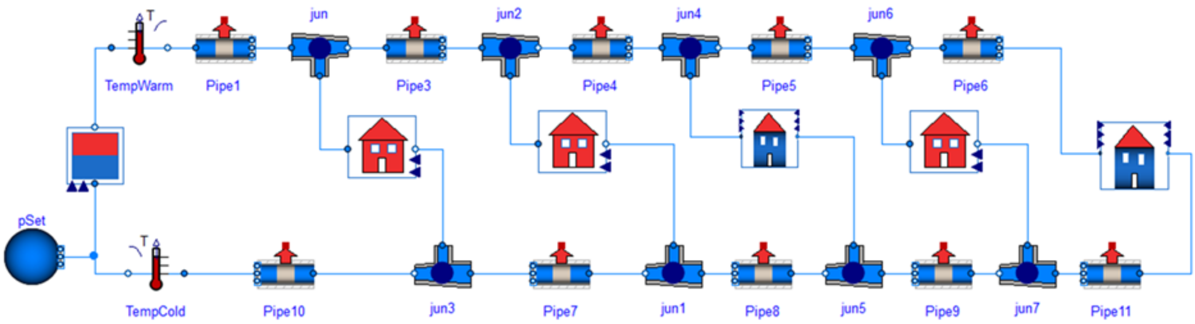


Figure 15: Dynamic simulation model of a bidirectional low temperature network

Figure 16 compares the aggregated energy consumption of the buildings with the central energy supply through the central heating and cooling networks. This example shows that only about 50 percent of the heat requirement and about 43 percent of the cooling requirement still must be covered by the central networks. The remaining requirements can be covered by using the heat pumps and chillers by balancing energy within the buildings and within the network.

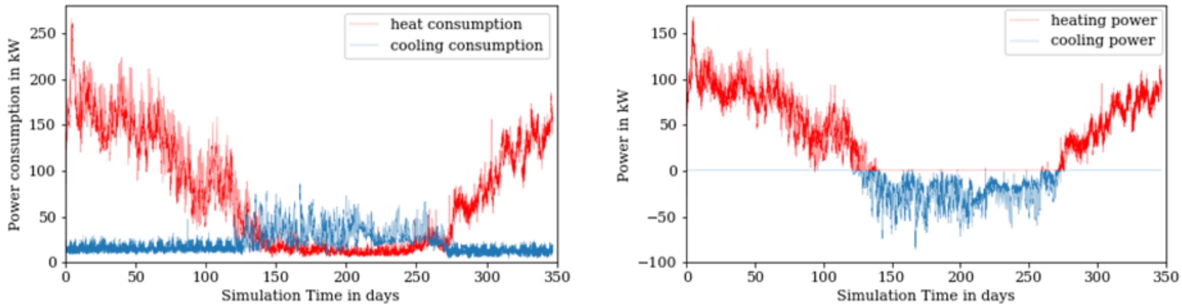


Figure 16: Comparison of the aggregated heating and cooling consumption (left) and the heat and cooling supply of the central balancing unit

2.1.3. The E.ON modular platform

The E.ON Modular Platform (EMP) is the underlaying technology enabling the demonstration of use case 1 & 2, that was developed as part of another EU funded project FINESCE (concluded in 2015) and is owned by E.ON. The following sections describes the application in more detail.

EMP cloud

The cloud platform is built upon Microsoft Azure components and serves to gather and structure information, optimize on accessible data and generate a corresponding steering signal. The cloud handles and coordinates data from several different sources. The algorithms that are embedded in the cloud converts accessible data into optimized control signals, which then are forwarded to each Energy manager. The platform is continuously monitoring operational data such as:

- The flow line temperature delivered to the building heating system
- Return temperature sent back to the distribution system
- Valve position for relevant heat exchange
- Indoor temperature (and set point)
- Asset setpoint

When applying optimization schemes and advanced control strategies external information is also collected by the EMP cloud:

- Weather forecast data such as, sun hours, rainfalls wind speed.
- Updated energy price information, electricity, waste, natural gas, oil.
- Production and distribution operation data.

Based on the above input, the system generates an offset signal that is applied to each asset to alter the systems flow temperature.

The EMP cloud communicates to the Energy Manager through the de facto standard IoT protocol, MQTT.

Energy Manager

The Energy Manager (Figure 17) is a gateway device that is installed on location to communicate between the local assets and the EMP cloud. The gateway is an industrial computer based on the Linux operating system. The Energy Manager connects to the cloud using a built in GPRS/LTE modem.

Figure 17: The local Energy Manager gateway

In Figure 18, a schematic illustration of the Energy Manager is shown. The main component of the Energy manager is a SQL database which organizes, stores and forwards relevant data. There are also two main interfaces, one which handles the data exchange with the cloud and one which manages information flow with the connected BMS. Additionally, the Energy manager also contains algorithms which complements the ones placed in the cloud. The purpose of placing algorithms in the Energy manager is to make sure that during connection failures with the cloud, the Energy manager will still be able to generate control signals to the asset. There is also a supervisory functionality within the Energy manager called “Watchdog”. It continuously controls the operation of the Energy manager by using a timer function. If the Energy manager malfunctions this triggers a timeout signal and automatically initiates corrective actions.

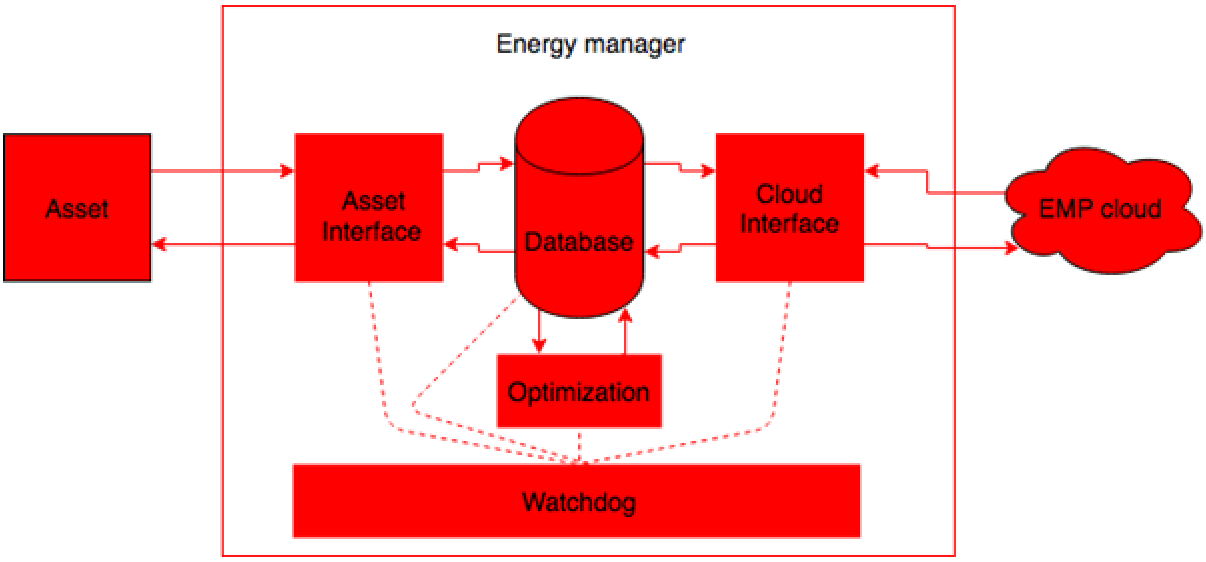


Figure 18: Schematic illustration of the operating functionalities within the Energy manager

The Energy manager communicates with the asset through either Modbus RTU or TCP, the standard in automation and industrial electronics, and delivers optimized control signals created in the cloud. The control signal is an flow temperature offset value, which is added to the original setpoint for the heating system calculated within the asset. In a normal heating system, the setpoint for the radiator system is calculated from a setpoint curve, a linear function related to the outdoor temperature. The Energy Manager adjusts this setpoint by simply adding the generated offset value. The signal enters the PID-controller, which regulates the valve-degree accordingly, as shown in Figure 19. The actual value is feed back to the controller.

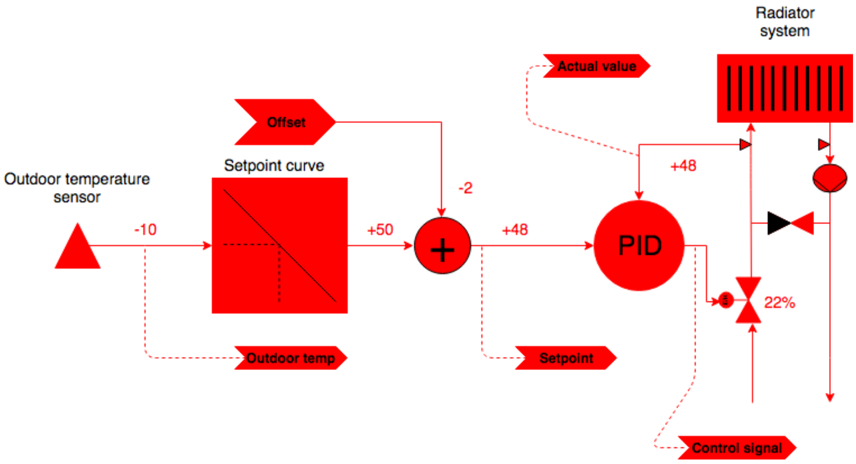


Figure 19: Schematic picture of control mechanism for a building heating system and the interaction obtained through CESO

3. INNOVATIVE SOLUTIONS IN DEMO 4B

3.1. Grid automation

3.1.1. Remote Terminal Unit (RTU)

A Remote Terminal Unit (RTU) type Netcon 500 is currently installed in the DER-substation (N149403). As anticipated, the RTU provides the operators in the control rooms with crucial information and enables fast control of the breakers in the substation when required. The utilization of RTUs is standard for supervising the high voltage network and substations in Sweden, it is however uncommon to deploy RTUs in the medium voltage network amongst distributed generation. There are different types of RTUs, the one deployed in the DER-substation has the same complexity level as a RTU that would normally be deployed in a HV/MV substation.

In the existing primary substation Simris, a ABB RTU560 is in operation and connected through our own infrastructure (Radiolink) to the SCADA system to provide relevant information from that substation to the control room. This is shown in Figure 20. To connect the RTU in the DER-substation to the SCADA system, a fiber link between the DER-substation and the Simris substation was used and from Simris the information can be transmitted to the SCADA system. This solution guarantees that even if the other interfaces go offline (Remote EMS HMI, BESS-HMI) the control room will always have visibility of the state of the grid to ensure the integrity of supply.

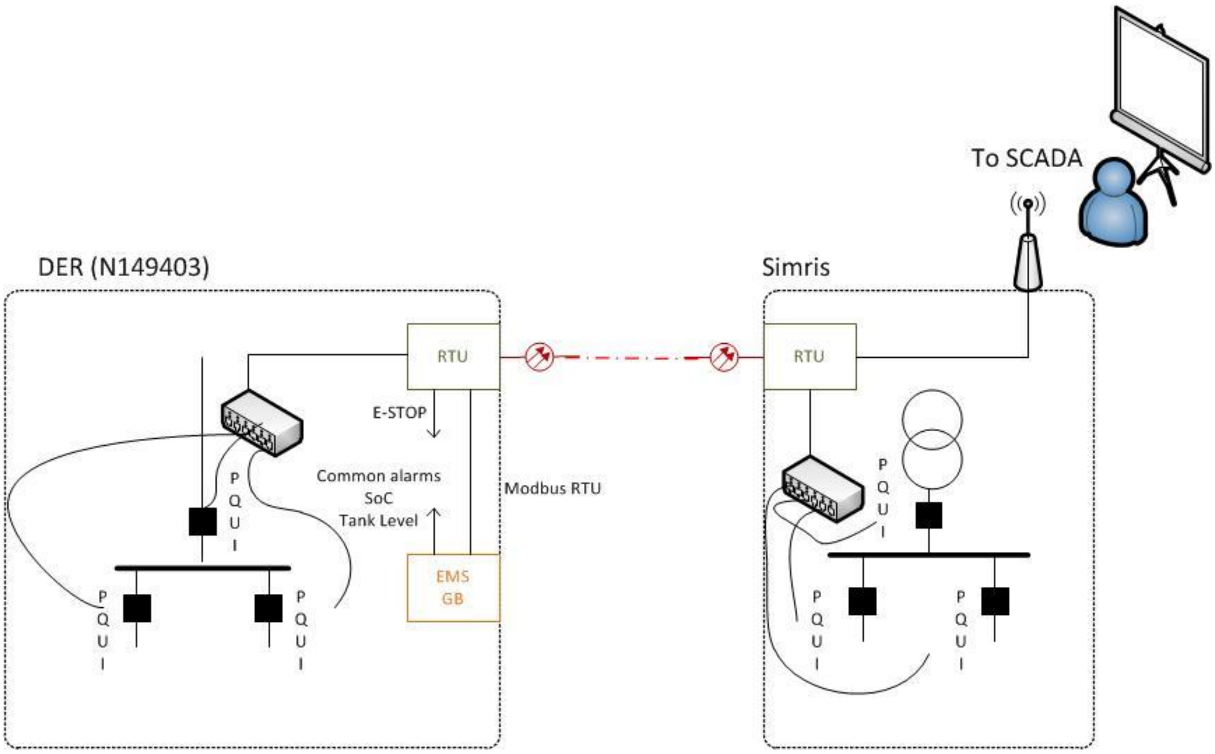


Figure 20: Supervisory Control and Data Acquisition (SCADA)

Furthermore, as the normal amount of information (as mentioned under “Supervisory Control and Data Acquisition” in section 1.2 Grid topology in demo 4B) might not be sufficient in a futuristic grid like the one that is being demonstrated, an interface between the RTU and the EMS was established. The interface of choice was the Modbus RTU protocol, which is a serial interface compliant with the relevant security requirements for interconnecting two critical assets. Through the Modbus RTU interface, some additional key data points were transmitted and an emergency stop function was implemented. The emergency stop function ensures that it is always possible to shut down the system from the SCADA control room, if the system act in an undesired manner. The additional following data points and alarms were successfully transferred from the BESS/EMS to the operational SCADA:

- BESS State of Charge (SoC)
- Backup generator fuel level
- PV, WTG, backup generator, BESS and EMS common alarms

To keep the amount of alarms and signals to a minimum, only common alarms were transmitted to the SCADA to give an indication of which asset is faulty. In theory, it is possible to transmit many data points and to make detailed operation of the EMS possible through the RTU. If a fault occurs, it is possible to conduct a deeper analysis through the remote EMS and BESS HMIs.

3.1.2. Battery Management System (BMS) and BESS Controller

BMS

The BMS monitors each of the 1344 cells arranged in seven racks and calculates both SoC and charge and discharge limits, both of which are communicated to the BESS Local Controller (BLC). The BMS will isolate the battery if these limits are exceeded.

BESS Local Controller

The BLC interfaces towards the BMS system and towards the EMS. In the Simris application, the BLC has only protection automation enabled, meaning that it communicates and receives information from the BMS controller and can shut down the system in case of any issues. There are no microgrid functionalities, only trivial grid connected control functions implemented suggesting that it is possible to establish set-points for active and reactive power.

A more detailed description of the BESS is provided under 3.2 Battery Energy Storage System.

3.1.3. Energy Management System (EMS)

The EMS serves as the main controller in the microgrid control system. It consists of industrial hardware located in the BESS shelter, the DER-substation and in the Simris primary substation. In each location, the EMS has access to relevant information, such as measurements from current and voltage transformers, indication of status from power breakers and disconnectors. In addition, the EMS has direct control over the power breaker at the point of common coupling so that it can command island mode by switching off the breaker when certain requirements are fulfilled.

The RES generation is also controlled by the EMS which can demand the renewable energy sources to be curtailed if the BESS SoC reaches certain levels. During times of high demand and low generation, the EMS can demand the combustion engine driven backup generator to be activated and extend the time in island mode.

The EMS controls the operational mode of the battery system and sets the target voltage and frequency when operating as an island. An overview of the components and their dependencies is illustrated in Figure 21.

3.1.4. Data collection technologies and measuring devices (LMUs/RTUs)

To be able to observe what is taking place inside the LES, measuring systems called Local Measurement Units (LMUs) have been set up in each of the six secondary substations part of the LES. Each LMU collects information at a frequency of 1 Hz about the following parameters:

- Active and reactive power
- Voltage
- Current
- Frequency
- Harmonics

The data collected in the LMUs are then sent via 4G (LTE) to a database. The information from the LMU stored in the database is also used for showing the actual status of the LES live on the project home page.

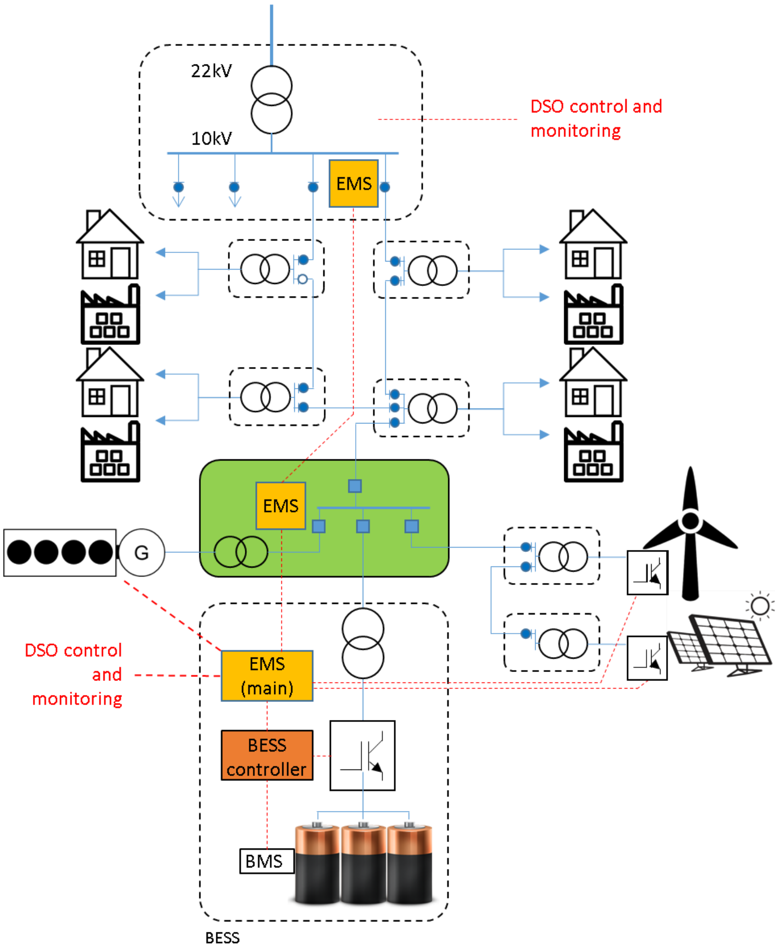


Figure 21: System and component overview in Simris

The EMS can operate in different modes depending on desired function, as have been mentioned previously. The Intentional Island mode is described in detail in the next section and will be omitted here.

Manual

In Manual mode, the assets can be operated and controlled in isolation. Depending on the asset, different parameters are available:

- For the BESS, active and reactive power set-points can be set
- For the PV[1] and WTG, active power set-points can be set
- For the backup generator, the active power as well as the power factor can be set.

The manual mode is most often used for testing and validation purposes.

Virtual Island Mode

In Virtual Island mode, the EMS controls the active and reactive power set-points to the BESS such that a zero exchange over the Point of Common Coupling (PCC) is achieved. It is possible to change the "exchange" set-point over the PCC to any value, within the capabilities of the

[1] The PV-plant is controlled through the SMA Cluster Controller. Only active power is currently controlled through the EMS, but can easily be changed to include reactive power as well if it should become necessary in the future.

battery system and restrictions of the power system, meaning that the microgrid can either consume or inject power to the overlying grid depending on current conditions and state of the grid.

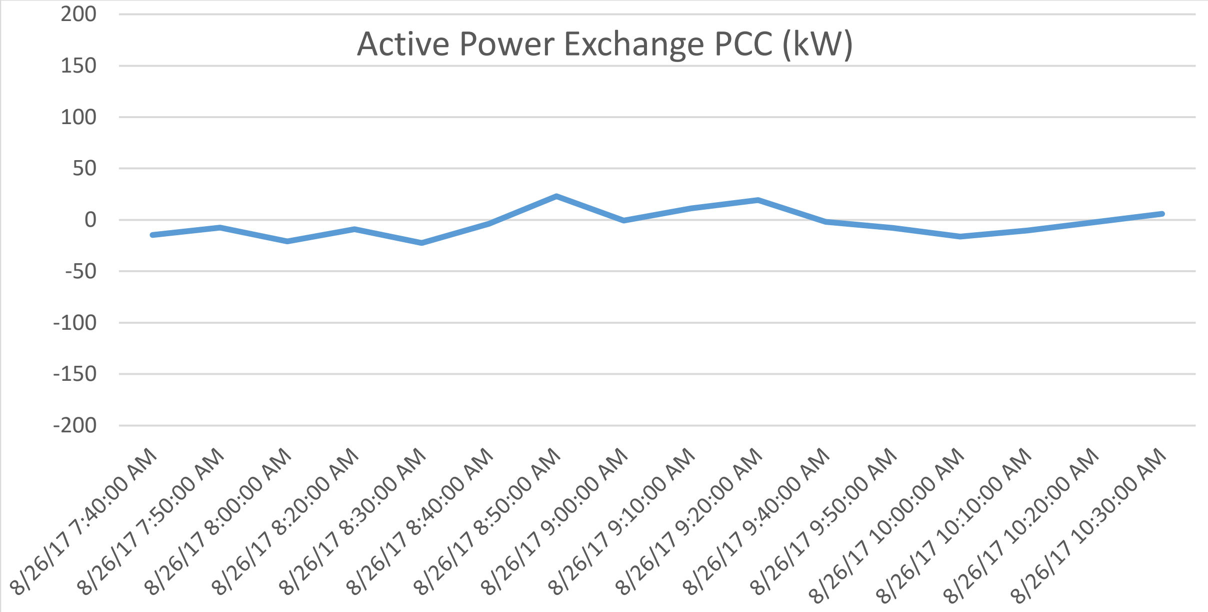


Figure 22: Active Power Exchange over PCC

In Figure 22, Virtual Island operation is illustrated. Because of the limited size of the BESS, the system cannot maintan zero exchange during longer periods of time. Aside from maintaining zero exchange, the microgrid could inject or consume any active or reactive power as have been mentioned previously. This type of ancillary services could prove invaluable in the complex power system that is expexted in the future where peak load hours could be managed with several distributed microgrids provding local balancing as an ancillary service to the overlying grid.

In the same manner, reactive control set points could be set to control voltage profiles. This feature has been tested in the system where the voltage in both DER-substation and Simris primary have been altered with the reactive capabilities of the BESS.

There is no automation implemented for any ancillary service provided to the overlying grid as this was not the main focus of demo 4B. However, it can be implemented by changing the control logics in the EMS since the EMS has access to all relevant measurement transformers. For the scope of the demo it was fully sufficient to test the features manually.

3.2. Battery Energy Storage System

3.2.1. Technology selection and key functions

The BESS was procured as an integrated, containerized system, with one of the key requirements being that the selected supplier had previous experience of integrating batteries and electronics into a similar environment. An initial specification was written and distributed to several system integrators outlining the key requirements and expected sequence of operations, resulting in a variety of responses. Some suppliers would only agree on supplying the battery system if they were to be selected as a supplier of the energy management system as well. These suppliers were discarded as the separation of the BESS from the EMS was considered critical for the project. Offers from other suppliers did not meet the key functionality of seamless transition between grid-connected and islanding mode of operation, requiring either a battery system restart or a tightly coordinated mode change to be able to handle the two distinct operating modes.

The key technologies used in the package (battery supplier, PCS supplier, transformer supplier) were not specified, only that the system should be functionally compliant. However, E.ON also engaged directly with both battery suppliers and PCS suppliers to understand the unit capabilities and limitations.

The power requirement was set to be of comparable size to the peak consumption at Simris at around 800kW. This power results in the BESS being larger than any individual renewable generation source. A higher power rating would have increased the confidence in the capability of the battery to manage the voltage within the microgrid, and Enercon advised that a minimum battery size should be 2MW to guarantee stable operation of the WTG.

The requirement on the battery for providing the capability of seamlessly changing between grid-connected and islanded mode, without changing battery system operational mode, constituted the main area of uncertainty regarding this solution as only a few suppliers were able to guarantee this capability. Alternative solutions were to accept a temporary outage while the battery system shut down, changed modes and re-started or to install a semiconductor switch at the point of network connection, giving a clean, high speed disconnection to allow the battery system to change modes.

The energy for the BESS was selected based on maximum amount that could be purchased within the budget constraints at the time.

The final BESS selected for DEMO 4B is characterised by a rated power of 800kW, an energy capacity of 332kWh and includes PCS functions allowing the islanding.

3.2.2. System features

The BESS includes three key control components controlling the system operation:

1) BMS, responsible for SoC estimations and enforcing battery system limits
2) PCS inverter control, responsible for the high-speed switching of the electronics to manage the different operating modes
3) Battery system controller, supplied by Loccioni. This includes a state machine for different operating modes and manages transitions between states.

A summary of the key components is shown in Figure 23.

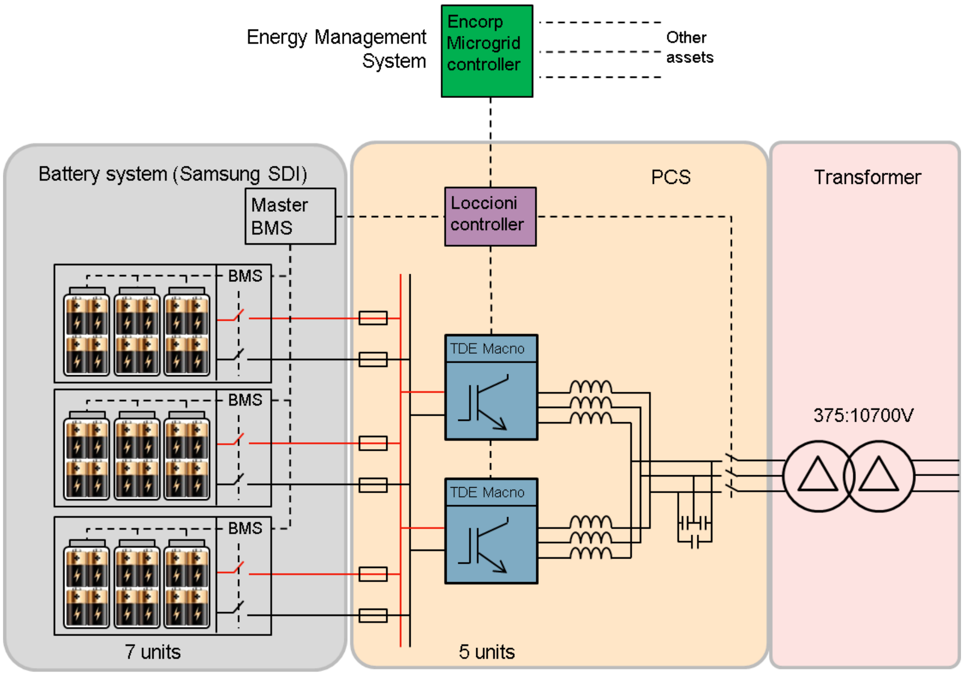


Figure 23: Overview of BESS components

The Loccioni control system state flow diagram is shown in Figure 24.

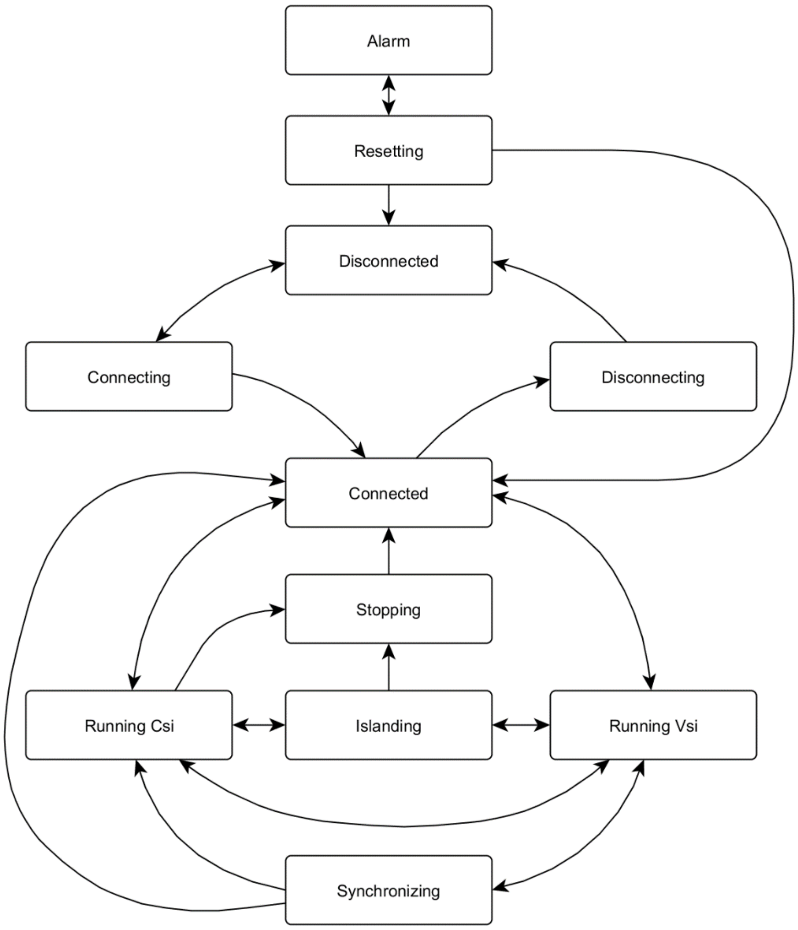


Figure 24: BESS state controller

The different states are requested by the EMS, and the Loccioni controller then implements the mode to the PCS. This hierarchical control structure allows the high-speed operation to be managed at a local level (inverter switching at 2.5kHz), the Loccioni controller controlling the local interfaces and operating modes, and the EMS managing the system demands at around 1Hz communication update.

Should a fault occur when the system is islanded mode, the BESS is able to provide the necessary short circuit current that the system needs to trip the protection devices and recover to normal mode without causing a black out as shown in Figure 25 where the voltage level is stabilized within 200 ms.

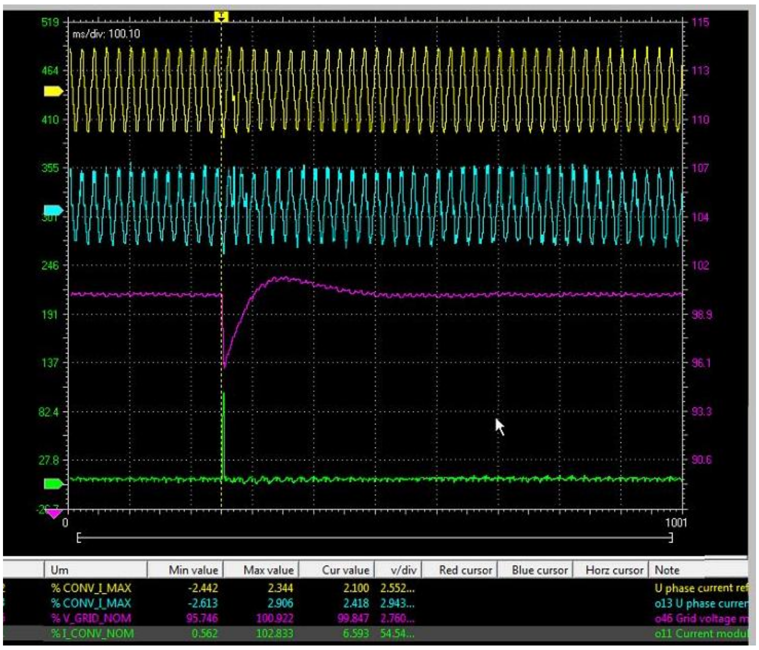


Figure 25: Voltage during short circuit testing

3.2.3. Islanding

The PCS controller running in Voltage-source-inverter mode operates in droop for both power as a function of frequency and reactive power as a function of voltage and allows the BESS to seamlessly transition between grid-connected and islanded operating modes.

To island the system, the EMS measures the real and reactive power across the point of network connection and sets the voltage and frequency targets for the battery system such that the real and reactive power are near zero. The system is then ready to be islanded and the EMS demands the circuit breaker to open. The battery system does not change operating mode, but becomes responsible for managing the island voltage and frequency. The EMS updates the voltage and frequency targets when islanded to maintain a constant 10.7kV/50Hz as these will vary along the BESS droop curves with changing active and reactive power. However, the control in the EMS is relatively slow, such that a power imbalance allows the frequency and voltage to transiently change before being trimmed back.

To reconnect to the grid, the EMS controls the voltage and frequency to match the grid voltage and frequency, synchronizing the systems. Once within prescribed limits, the EMS closes the circuit breaker.

The system was first islanded with customers in December 2017. Figure 26 shows the frequency variation during the backup generator starting and a WTG trip on the 13th of December 2017.

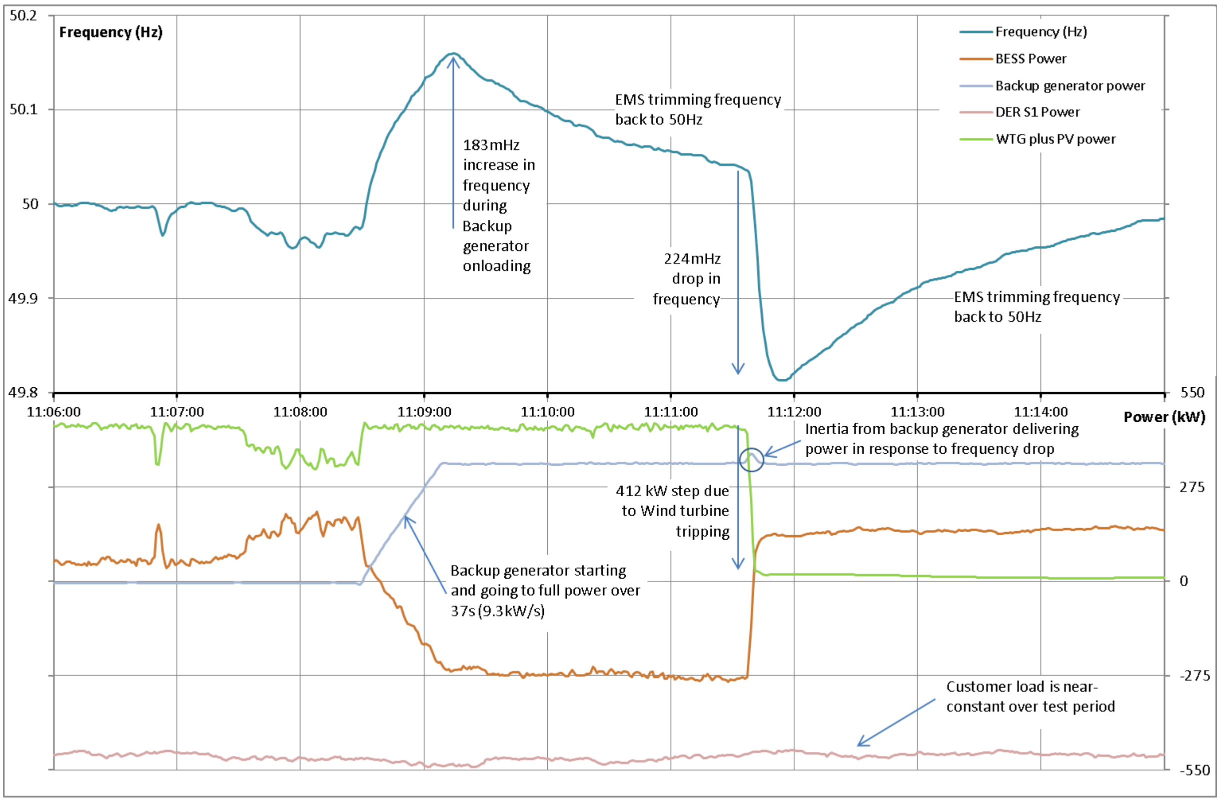


Figure 26: Frequency and powers during backup generator starting and wind turbine tripping

Longer term testing comparing the voltage, frequency and total harmonic distortion (THD) of the system when islanded to the same parameters for the local Nordic power system shows that the LES had better power quality when islanded than it would have had when grid-connected. Figure 27, Figure 29 and Figure 28 show the comparison for islanding testing on the 12th of April 2018, where the system was islanded 08:00 – 20:00. In all cases, the results from the LES when in island mode of operation are displayed the upper trace and the Nordic power system are presented in the lower trace.

Figure 27: THD when islanded

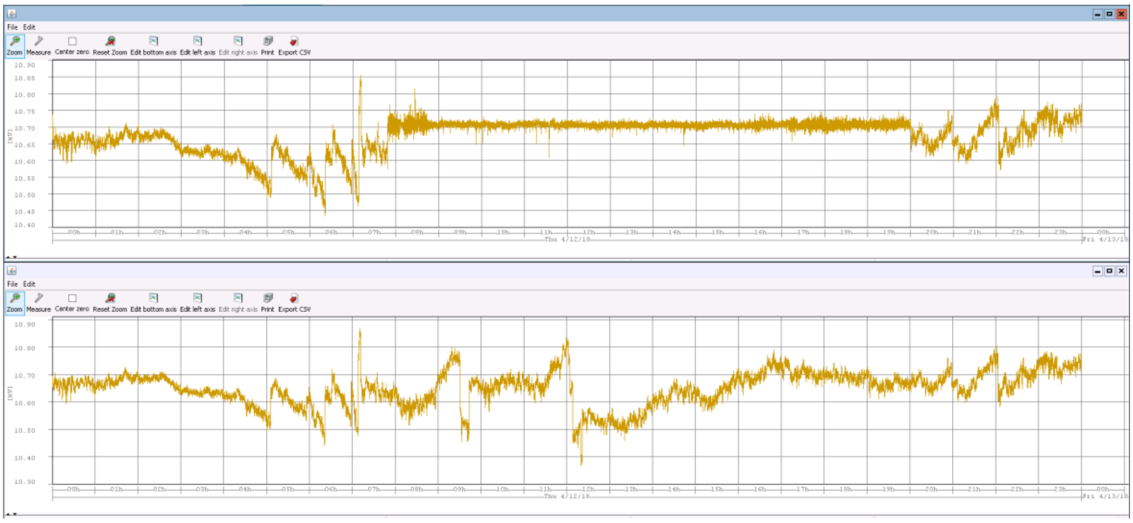


Figure 28: Voltage when islanded

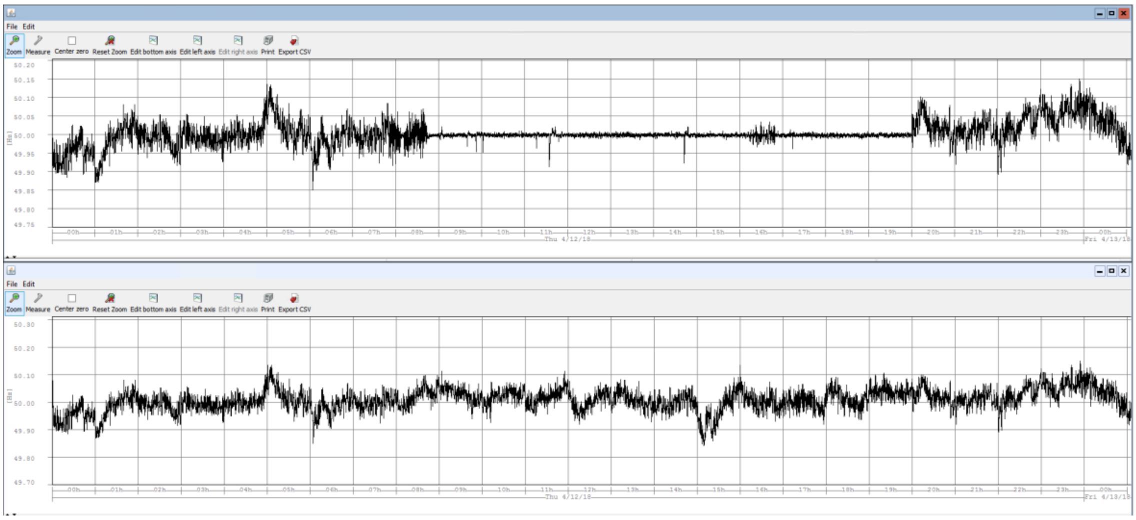


Figure 29: Frequency when islanded

3.3. Design and simulation of control algorithms

The focus of this section is placed on the design, implementation and evaluation of advanced control algorithms for microgrid energy management. The objective of this research is to find a solution on how to distribute the power flows such that power demand and generation are balanced and operating mode dependent objectives are achieved. In Figure 30 a high-level energy system schematic is displayed.

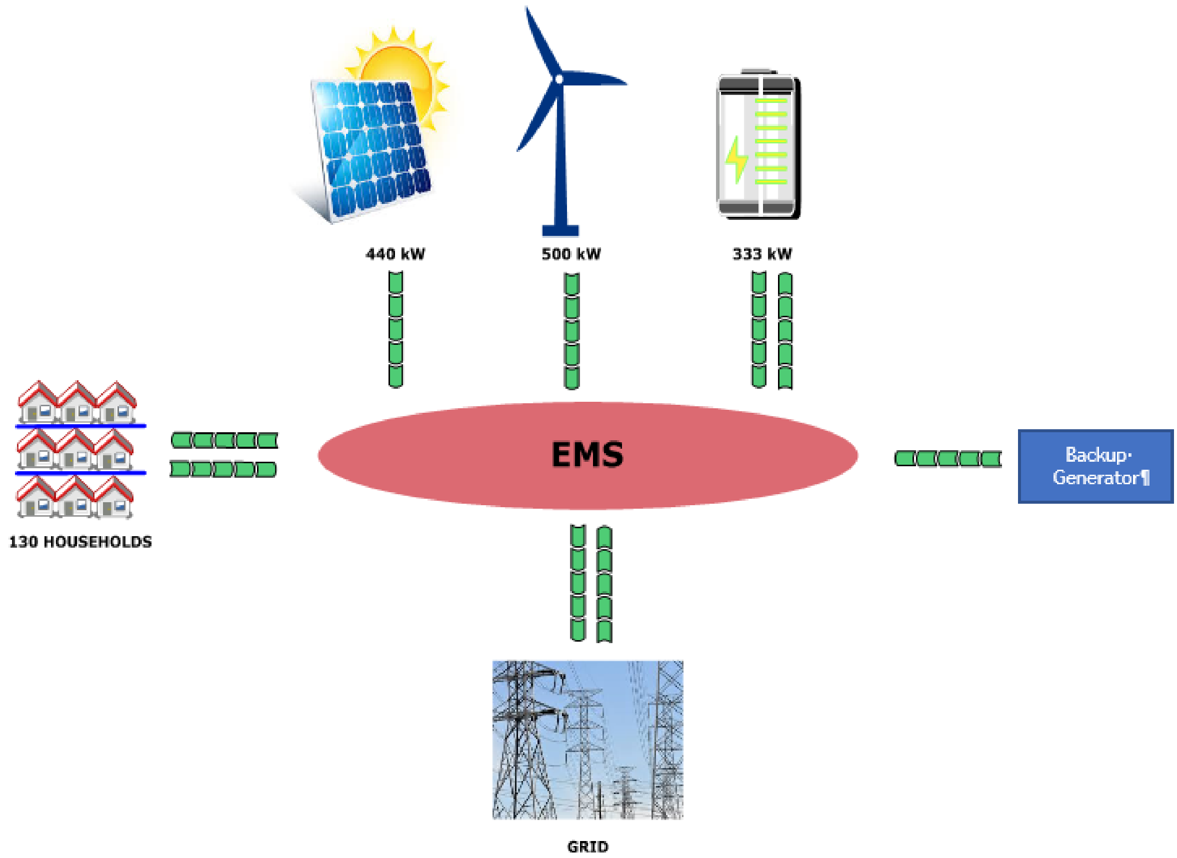


Figure 30: High level energy system schematic

To holistically solve this problem, model predictive control (MPC) has been applied to optimize microgrid operation for (1) grid-connected, (2) virtual island and (3) intentional islanded mode. In general, the main idea of MPC-based control is to employ a simplified mathematical model of the system to be controlled, and, to predict the behaviour of the system over a finite prediction horizon (i.e. a finite time interval). According to the predicted system behaviour, the control actions are determined such that a performance index is minimized and all operational constraints are satisfied over the complete prediction horizon.

In the model, microgrid optimization is conducted by a centralized MPC scheme. A favourable model for optimization is to look at economics as the solvable function such as operational cost minimization and set the mode of operation as a constraint. As a prerequisite, the controller requires knowledge about the current system state, i.e., the SoC of the main battery as well as the residential batteries, and, the expected load and generation profile. If utility costs are to be minimized, energy prices must be known as well.

An MPC is an advanced control technique for multivariable control problems, which use an internal model of a system to generate predictions of the system's future behaviour. The designed MPC finds an optimal plan for running the assets for each time step over the prediction horizon starting at the current time step. The optimization is based on predictions of the upcoming demand, production from renewable energy sources and predictions for the state of the system. For the optimization, only the first control input is implemented, and subsequently the time horizon is shifted by one-time steps. At the next time step, the new state of the system is measured or estimated, and a new minimization is performed whilst considering the new information. This is shown in Figure 31.

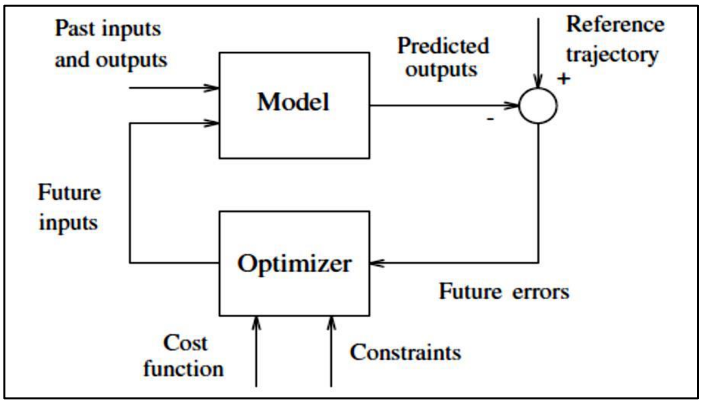


Figure 31: Simplified MPC scheme

The remaining part of the system model is given by equality constraints reflecting the power balance. As already indicated, the cost function and the constraints are related to the prevailing microgrid mode. Therefore, the following paragraphs will briefly give an overview of the costs to be minimized along with the related constraints for every operating mode.

In **virtual island mode**, the only objective is to minimize power exchange with the utility grid. Particularly, power is only provided to the utility grid if renewables would have to be curtailed otherwise and power is consumed from the utility grid if internal generation and storage cannot satisfy the demand. This objective translates into a cost function, which penalizes the absolute value of the power flow from and to the utility grid respectively. To formulate such an objective, a mixed-integer formulation is required. To satisfy operational constraints, main and residential battery SoC and power are constrained. Moreover, curtailment of regenerative energy resources is limited to zero and is as such not a viable option in virtual island mode.

In **grid-connected mode**, the main aim of the control scheme is to minimize operational costs. In a first approach, this is achieved by minimizing the purchase of electricity from the utility grid while maximizing the re-selling of electricity to the grid, taking into account the electricity price at all points in time. At the same time the cost of batteries and the profit-loss from RES curtailment is also considered.
A later approach might also consider indirect costs that e.g. relate to maintenance costs in case of leveraging storage units.

In **islanded mode**, the main objective is to ensure that no power exchange with the utility grid is required. As such, at times of positive power discrepancies, the power demand needs to be accommodated by solely harnessing microgrid DERs. At times of positive power discrepancies, curtailment of renewables might be required if the energy cannot be stored in the battery. For this operating mode, the backup generator must be included into the system model, which results in additional control inputs that specify whether the generator is turned on or off (binary variables) and how much power it provides to the microgrid (continuous variable). This step has not yet been conducted and is part of ongoing work. In islanded mode, fuel consumption is the only monetary cost that needs to be minimised, thus being the only part of the cost function. Operational constraints are extended such that power exchange with the grid is constrained to be zero.

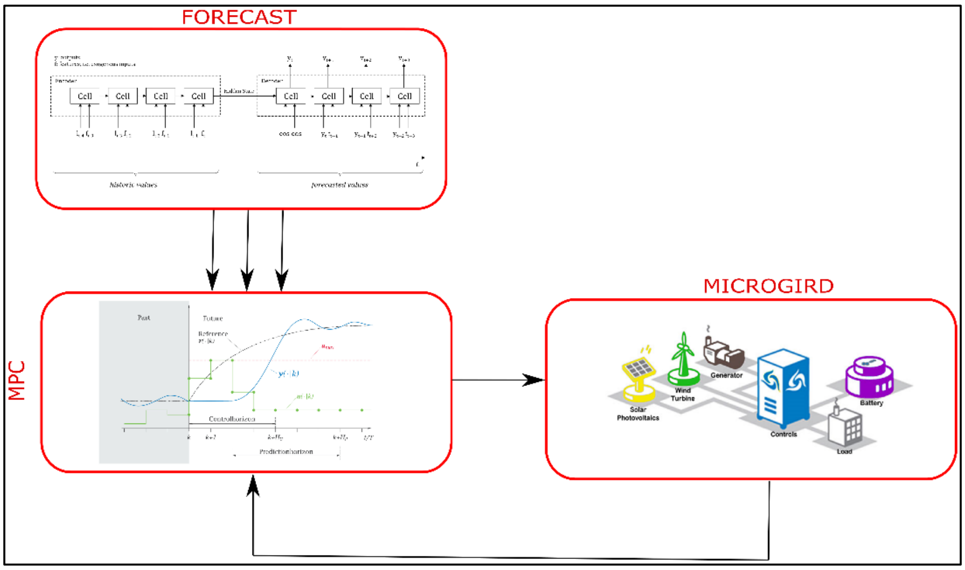


Figure 32: MPC control interaction with other modules

Until now, these modes have been considered independently. As part of future work, it needs to be analysed how a transition between modes can be realised – either as part of the MPC-based control scheme or through a high-level decision algorithm. Generally, the formulation as an optimisation problem allows to reconfigure the MPC cost and constraints online based on the microgrid mode such that only a single controller unit is required for power distribution instead of designing separate controllers for every microgrid mode.

The solution outlined above is considered to be implemented as part of the ICONICS EMS. From an architectural viewpoint, ICONICS EMS needs to receive the battery SoC from the households and the main battery, the current residential load and PV power as well as the microgrid's PV and wind power. At every sampling step, the MPC-based energy management provides the battery power and breaker power set points to ENCORP while the power set points of the residential batteries are directly distributed to the households.

The main advantage of applying an MPC-based control concept can be seen in a holistic optimization of the microgrid. In general, while a heuristics-based approach makes leverage of expert knowledge, it is mostly not capable to achieve the global optimum in terms of (monetary) costs. With the capability of predicting the future behaviour of the microgrid given an appropriate estimate of expected generation and demand, MPC is expected to significantly improve system operation (evaluations are subject of ongoing work). In grid connected mode, the overall operating cost might be significantly lower compared to a heuristics-based approach. In virtual island mode, the required power from the utility grid can be further reduced while in islanded mode a lower fuel consumption of backup generator can be achieved by avoiding any curtailment of renewables.

As the MPC bases its operation on forecasts regarding demand, PV and wind production, algorithms to provide these forecasts are needed to enhance MPC capabilities. Forecasting for the developed MPC is done by using neural networks and relevant machine learning techniques. They aim at identifying patterns in historical data and extrapolating these into the future, thus deriving a forecast for the relevant time-series. The approach constitutes a multivariate regression, as the forecasts are based on externally generated inputs, e.g., weather forecasts, day and date information, etc., for each of the forecasted time step.
Recurrent neural networks are especially capable of capturing time-series dynamics, as they possess cyclic self-feeding connections utilized to model the dependencies of one time-step with regards to the previous time-steps (see Figure 33).

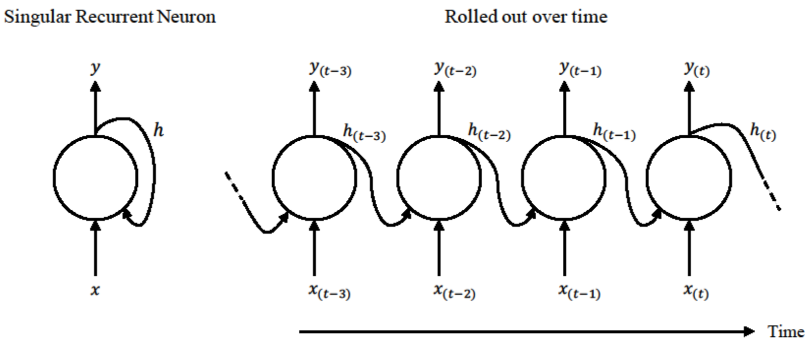


Figure 33: Simplified explanation of LSTM concept

So-called Long Short-Term Memory (LSTM) cells further provide memory vectors to store and access information from previous time-steps depending on exogenous input variables.

The employed forecasting algorithms use LSTM cells in an encoder-decoder set-up to derive forecasts for future demands, PV and wind productions. The encoder, as depicted in Figure 33, serves to encode the historic time steps of the time-series. It further ensures that the memory vectors, referred to as hidden state, are up to date to derive the first forecasted time step within the decoder part of the forecasting algorithm.

The forecasting horizon can be set to arbitrary lengths and use desired sample rates to provide flexibility with respect to the specifications set by the MPC. First results show that the envisioned neural network architecture is capable of producing forecasting accuracies of 90 percent and above on available open source load, wind and PV data sets. The next steps will focus on improving these results and applying the algorithms for Simris specific data.

To compare the MPC model an instantaneous minimisation of the energy exchange between the microgrid and the main grid has been performed. The instantaneous minimization optimises each time step without taking predictions of future scenarios into considerations and uses only the data available in each time step, i.e., current measurements, similar to the current mode of operation in Simris. The results show that the MPC approach outperforms instantaneous minimisation in the key aspects of maximising the use of RES as well as the minimisation of energy exchange with the main grid. The results also show that MPC is able to lower the peak power exchange between the main grid and the micro grid.

3.4. Demand Side Response

3.4.1. PV and battery system

PV and battery system offers customers an opportunity to be more self-reliant and reduce the feed-in from the grid. PV panels produce energy when the sun is shining and the battery allow the excess energy to be stored. At a later point in time, when the load demand exceeds the power supply, the battery is discharged allowing the stored energy to be utilised for important grid balancing services. As the market penetration for this solution is increasing and due to the versatility of the battery it is expected to become a vital part of the future energy system.

The main concern regarding the battery is how much flexibility it will be able to provide. At a brief glance the battery seems to be a great source of flexibility for the electricity grid. However, when the LES is characterised by an excess of energy, due to high power generation in the central PV-power plant, the batteries are likely to be filled up by the household solar power generation alone since the residential PV would also provide max output. Hence, there might be little additional storage capacity left to utilize for grid balancing services through DSR. Likewise, during days of energy deficit in the system, due to lack of solar power production, it is unlikely that the residential batteries has stored energy that can be used to support the grid. Therefore, this trial can serve to provide valuable insights into the real potential of residential PV and battery system as a means of providing flexibility to an LES.

Control Strategy

To evaluate to most appropriate way to manage the batteries, two control strategies will be implemented and tested. Both strategies employ the state of charge of the main battery as the governing variable in their control functions. One of the strategies is based on residential *battery power control* and the other residential *battery energy control*. Every five minutes the setpoint will be sent from the DSR platform to each battery.

The first approach is to demand the battery to charge at maximum power when the main battery is at a high state of charge and to discharge at maximum power when the main battery is at a low state of charge, as shown in Figure 34. In this case, the lower and upper limits are controllable parameters in the DSR platform, i.e. at what SoC charge and discharge takes place.

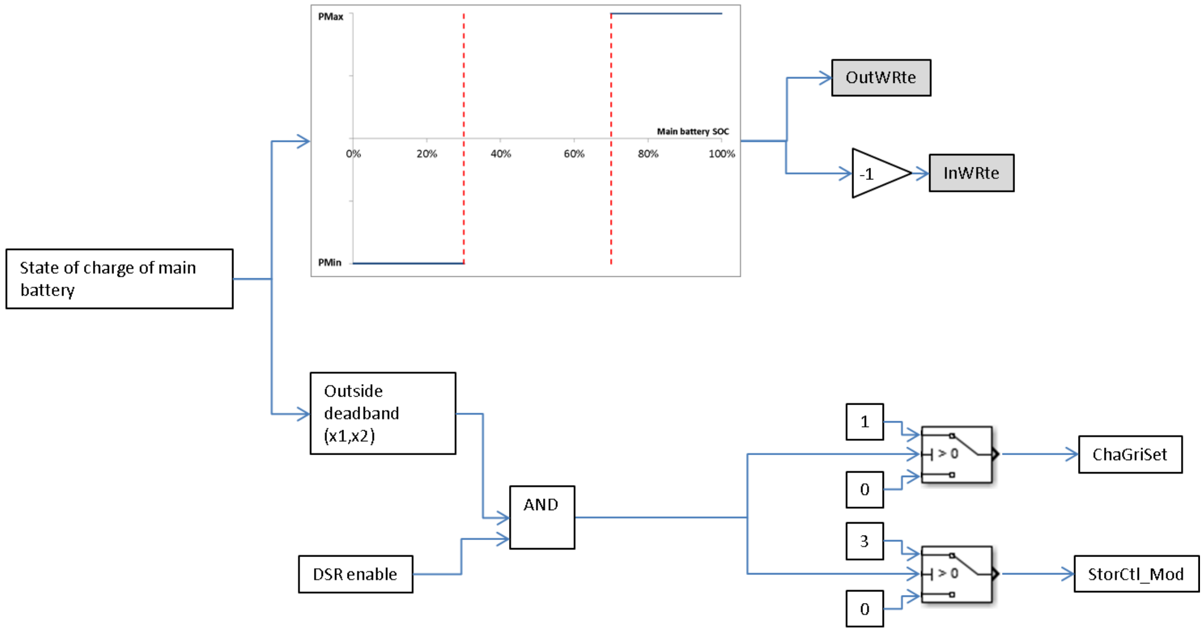


Figure 34: Residential battery power control

The second approach aims to control the state of charge of the residential batteries to match the state of charge of the residential batteries to the state of charge of the main battery. In this case, there will be a lookup table to equate the state of charge of the main battery to a target state of charge of the residential battery. The power demanded to the residential battery will then be set such that after five minutes the residential batteries are as close as possible to the target state of charge, as shown in Figure 35.
Within the DSR platform, the lookup table and dead band parameters are soft coded, meaning they are easily changed without making changes to the source code. Note, one set of parameters shall apply to all residential battery systems.

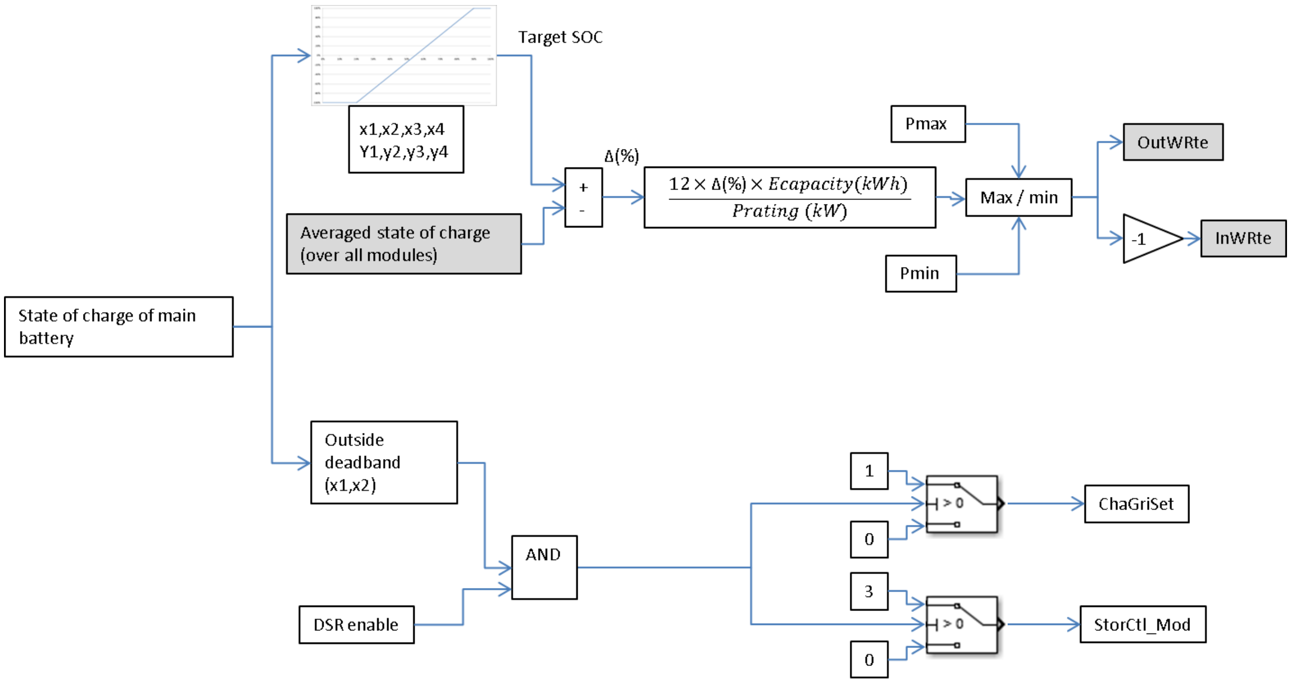


Figure 35: Residential battery energy control

Communication

To supervise and control the PV and battery system a communication line needs to be established. In Fronius installations the communication controller is embedded in the inverter (Symo). This inverter is locally connected to a PV and battery system. The remote access is setup in a twofold way, which is the Solar Web access and the Modbus access.

The Solar Web access provides customers with read-only metering data from the inverter, PV and battery. Fronius provides a “Solar Web API” to retrieve data from an external server like the DSR-System implemented for use case three the protocol is based on REST. In the diagram below, see Figure 36,the communication line is displayed in blue colour.

The second communication line is used to send control signals to the inverter and thus must be secured to prevent unauthorized access. The protocol for this purpose is Modbus-TCP, which runs in a VPN (Virtual Private Network). The VPN technology selected to meet the requirements OpenVPN, implying that a corresponding router supporting OpenVPN is needed on premise. To initiate communication, the router establishes the VPN connection to the DSR-system as a first step. Secondly, a remote-control access can be performed, if Modbus access is enabled on the inverter side and access for the IP-Address of the DSR system is allowed. This second communication line is coloured in orange for the VPN and green for the Modbus, which is outlined in Figure 36.

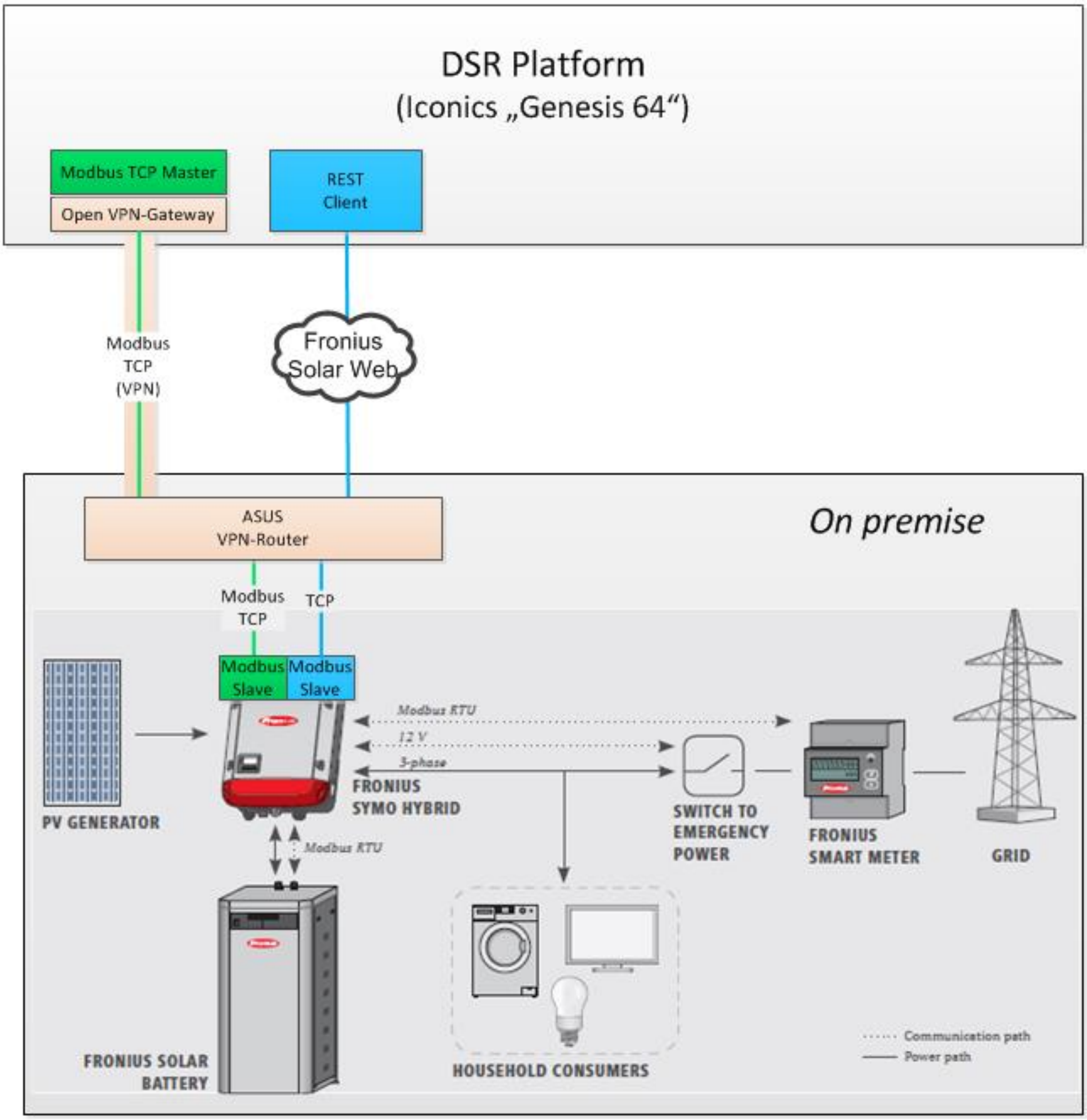


Figure 36: Fronius Communication Interface

3.4.2. Heat Pumps

Electrical heat pumps are a common source of heating for Swedish households and is a major electricity consumer relative to other appliances in a residence. In Sweden, around 60 percent of the total household energy consumption is allocated to meet heating demands. In addition, due to the thermal inertia of buildings it is possible to turn a heat pump off for a long period of time without the indoor temperature dropping more than 1°C from the initial temperature. For these reasons electrical heat pumps offer an opportunity to help stabilising the grid. An estimation of the overall Swedish flexibility potential in heat pumps is in the size of gigawatts, thus providing an excellent foundation for scalability.

Heat pumps can provide both negative and positive flexibility since it is possible to both increase and decrease heat demand. However, the available flexibility is largely dependent on the outdoor temperature as represented in Table 2. The specific temperatures are dependent on the heat pump technology utilised and other factors such as wind, sun, heat generation from internal electrical load and people. Hence, it should be noted that Table 2 merely provides a general overview.

Table 2: Flexibility potential based on outdoor temperature

Outdoor temperature	Flexibility potential
> 15°C	No flexibility
0°C	Increase/decrease heat demand
< -15°C	Decrease heat demand

In warm weather there is a theoretical potential for flexibility but as temperature exceeds 15°C, the heat pump is often turned off as there is enough heat to keep a comfortable indoor climate. At colder temperatures, around 15°C and below, the heat pump most likely operates at maximum capacity, unless the heat pump is over dimensioned, and therefore it is only possible to decrease the power output. In-between, it is possible to both increase and decrease the demand. How much in either direction depends on the outdoor temperature.

Nibe

The heating power is set by the flow temperature in the radiator system. The heat pump does not control the power (kW) setpoint, only the flow temperature. The power in kW is normally not actually measured or calculated in heat pumps. The heating power can be translated to electrical power depending on product characteristics and heating system design parameters such as COP.

Rather than a signal based on power in kW, the DSR platform creates a steering signal in percentage, based on the main battery state of charge in a range between 100 percent (maximum power increase) and -100 percent (maximum power decrease). To ensure that customer comfort is maintained, a boundary control is implemented, disabling DSR control if the indoor temperature deviates ±1°C from the customer set indoor temperature. The heat pump control signal process is outlined in Figure 37.

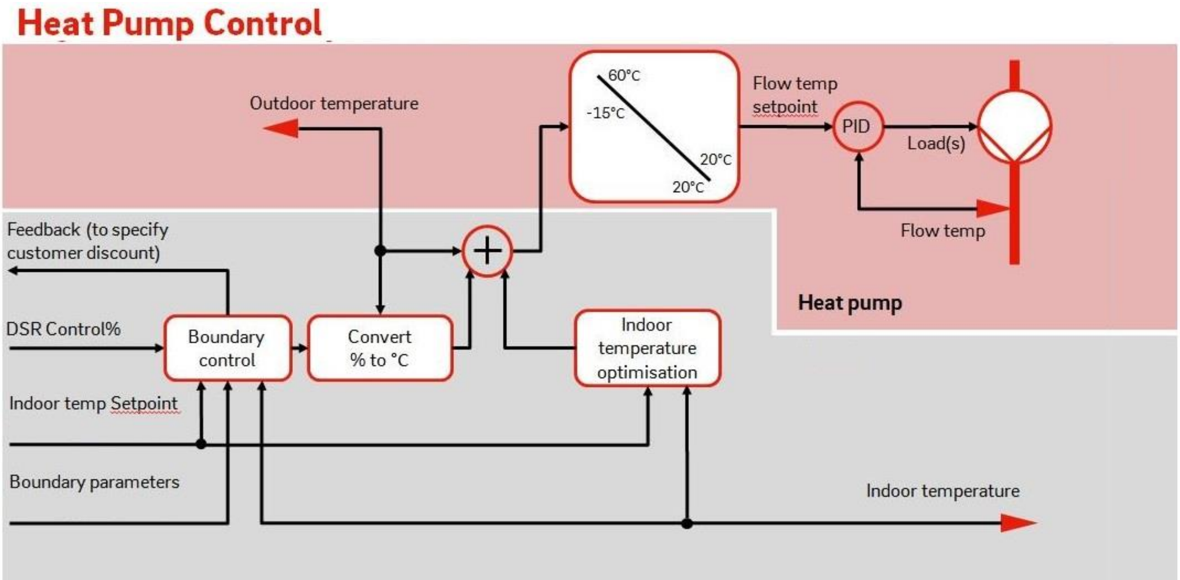


Figure 37: DSR control signal process chart for heat pumps

To create a flow temperature offset, the outdoor temperature (T) is evaluated in relation to design variables in the heat pump system. These variables are described in more detail in Table 3.

Table 3: Explanation of heat pump variables in the system

Available parameters	Comment
max_flow_temp	This value refers to the maximum flow temperature, which is heat pump dependent.
min_flow_temp	This value refers to the minimum value of flow temperature (if reached this will be equal to the current indoor temperature as the heat pump turns of).
max_out_temp	This is the maximum design outdoor temperature value (low outdoor temperature) at which the flow temperature reaches the 'max_flow_temp'. This is the state where the heat pump will run at 100% and can therefore not be increased, it can however be decreased if the room temperature is within the boundary.
min_out_temp	This is the minimum design outdoor temperature value (high outdoor temperature) at which the temperature reaches the 'max_flow_temp'. This is the state where the heat pump normally stops heating and no increase or decrease is possible.

An overview of the process is described in Figure 38, where the temperature (T) is evaluated against either min_out_temp or max_out_temp, creating a temperature delta, depending on if the outside weather is warm or cold. Since max_flow_temp, min_flow_temp, max_out_temp and min_out_temp are all static variables based on the heat pump design their relation creates a constant which is multiplied by the temperature delta and the requested level of DSR control.

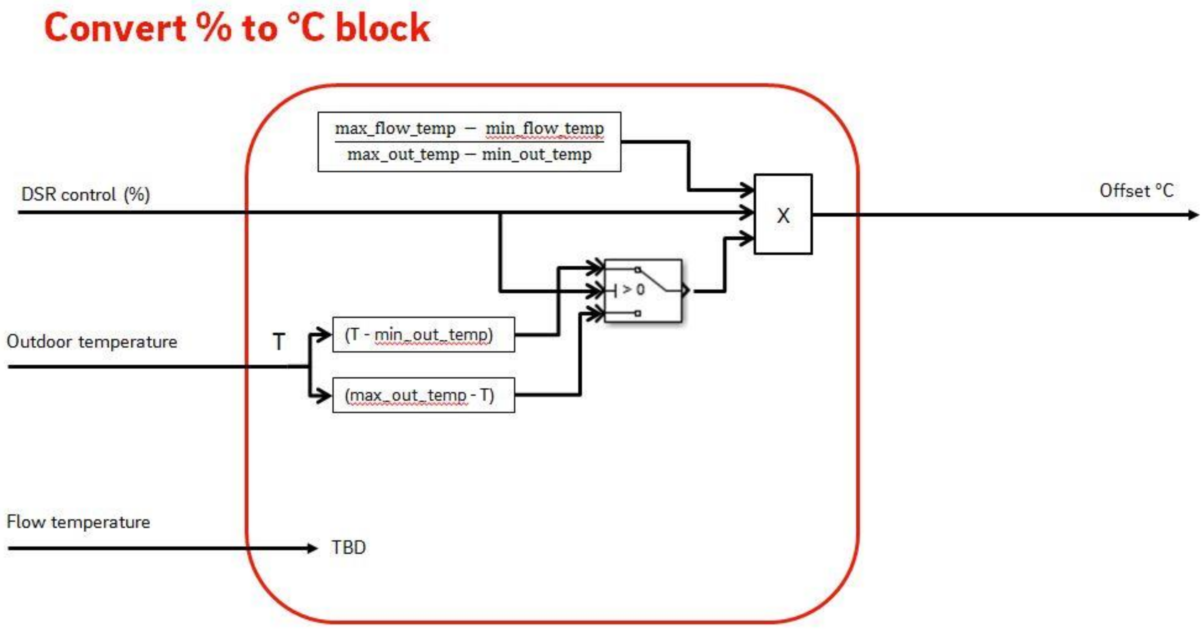


Figure 38: DSR control signal conversion to flow temperature offset

The signal will be uniform across the heat pumps, meaning the same signal will be sent to all devices. The signal is sent from the DSR platform to the heat pumps via an API set up by Nibe, specifically to allow customers monitor and remotely steer their heat pumps through their home network, see Figure 39.

Figure 39: Communication path from DSR platform to the Nibe heat pump

The data points collected through the API are:

- Room temperature (°C)
- Outdoor temperature (°C)
- Hot water temperature (°C)
- Flow temperature (°C)
- Return temperature (°C)
- Heat medium flow (°C)

Ngenic

Old heat pumps will be steered using a product called Ngenic Tune from the Swedish company Ngenic. The product is already being marketed to customers as a means to improve indoor comfort and possibly reducing heat energy consumption. The Ngenic Tune comprise three parts; an indoor temperature and light intensity sensor, a gateway and an outdoor temperature control device (installed inside the house).

Most Swedish heat pumps calculate energy requirements by only taking the delta of indoor and outdoor temperature. Hence, savings can be made by also including the influx of light and the house's thermodynamics, which is calculated using machine learning algorithms. The heat pumps connected via Ngenic Tune will not be accessed by E.ON individually but rather Ngenic acts as an aggregator via their cloud and manage the dispatch of each unit. The DSR platform sends the DSR control signal to Ngenic's own backend system, which in turn translates the signal to match their own algorithms and then forward the control to each Ngenic Tune via the home routers. *Note that E.ON does not have any specific insight into the control algorithms used by Ngenic.*
The Ngenic tune relays a temperature set point to the outdoor temperature control device, which emulates the usual outdoor temperature signal to heat pump, telling the heat pump that the outdoor temperature is different than it actually is, as represented in Figure 40. When utilizing the flexibility of the heat pump comfort boundaries are set to ±1°C to keep a high customer comfort.

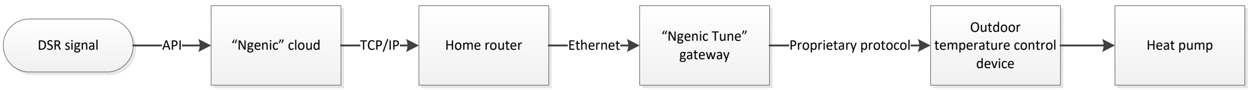


Figure 40: Communication path from DSR platform to Ngenic controlled devices

Data collected from the Ngenic devices are:

- Sensor temperature (°C)
- Sensor target temperature (°C)
- Sensor Light (Lux)
- Outdoor controller temperature (°C)
- Outdoor controller, control value (°C)

3.4.3. Hot Tap Water Boiler

Water heaters offer a cheap opportunity to increase the flexibility in the household. Since the energy is stored as heat and cannot be converted back to electricity it is however less versatile than a battery. During excess production in the LES, the water tanks can be heated reducing the need to heat water at other times such as when the system has a deficit of energy. There is also the option to stop the hot tap water boilers from heating as usual. Since the heating patterns of a boiler tends to be sporadic, the actual flexibility potential is reduced. There is also a risk of negatively impact customer comfort, by lacking hot water when needed, this is not taken into consideration within the project and remote control will only manage heating water during excess power generation.

The water heaters are accessed by a product called "Bobbie" from the Bulgarian company "MClimate".

The "Bobbie" device has been developed to generate energy savings by minimising the amount of excess heat in the hot tap water boiler. By monitoring the household consumption patterns, the overlying DRS platform will know when and how much water will be consumed and will minimise the tanks heat losses by pre-heating it just in time. For this purpose, temperature measurements to the inlet and outlet pipes of the water tank are necessary. The "Bobbie" device will receive steering signals from the DSR platform using smart meter technology and thus the water tanks will be managed by setting the heating in on/off mode.

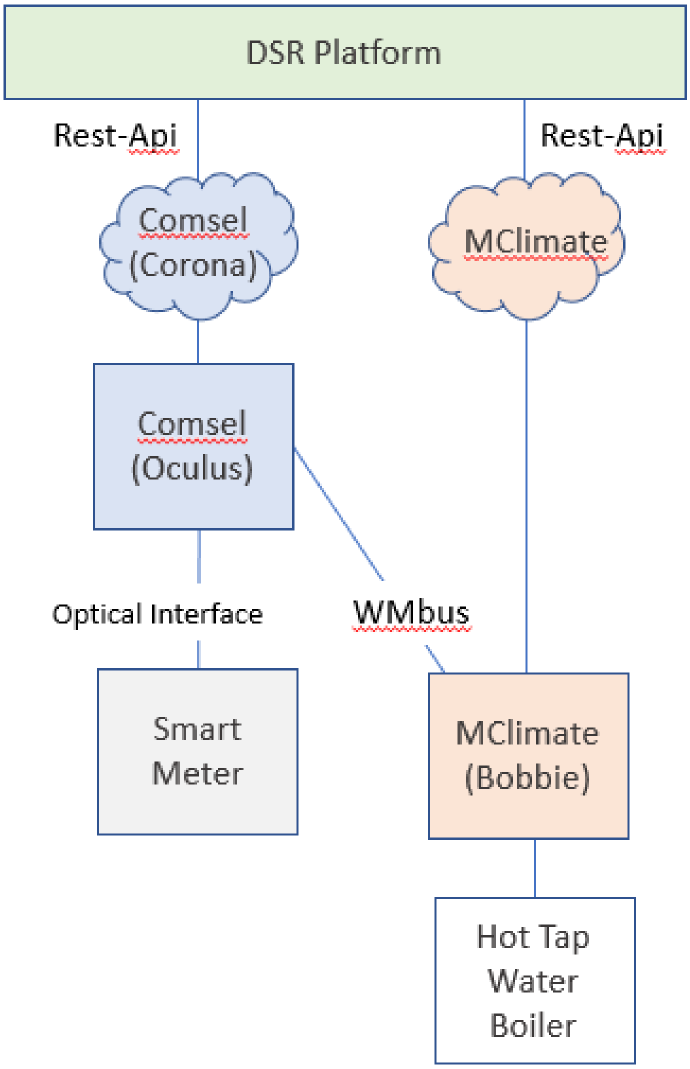


Figure 41: Communication to Bobbie-device

The main requirement is to connect to the Bobbie device. This is realised by using the Occulus from Comsel, which provides a WMBus (Wireless MBus) interface through which the Bobbie device can be reached. In addition, the Oculus device needs to fulfil its main task, which encompasses reading smart meter data by the optical interface. In the communication diagram in Figure 41: Communication to Bobbie-devicetwo cloud system are shown. Via the

Comsel-cloud the smart meter data is received and the steering signal to the Bobbie device is sent. Through the MClimate interface, additional meter data from the hot tap water boiler, acquired by the Bobbie, like temperatures (temp-in, temp-out) and boiler voltage are collected.

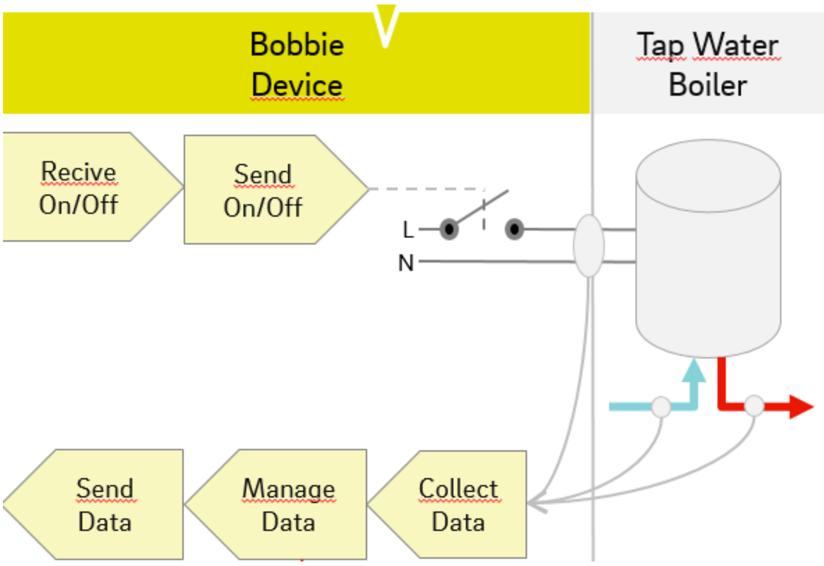


Figure 42: Bobbie-device, collecting data

The boiler voltage is utilized as a feedback signal to verity the switching. The temperatures are a necessary input for the flexibility calculation. The flexibility information could also be offered by the MClimate cloud. This is part of the commissioning process and will be decided later.

3.4.4. Electric Vehicles

Transport has a large environmental and climate impact. For this reason, electrification of vehicles has recently become a clear focus for key players of automotive and energy industries, who are dedicated to developing innovative solutions to address these difficulties. A substantial increase in the number of circulating Electric Vehicles (EVs) is foreseen in medium and long terms, bringing both challenges and opportunities for DSOs to integrate related technologies to modern electric systems.
Within this context, a steerable EVSE is planned to be integrated in Demo 4B, while connected to the Demand Side Response system installed herein. The deployment of this innovative solution has a dual objective: 1) increase public awareness around innovative solutions featuring e-mobility and smart energy systems in the future energy landscape, by advertising proposed solution through marketing activities and material; 2) showcase EVs as source of flexibility to support the penetration of renewable energy, by controlling the EVSE current output in response to the fluctuating balancing requirements of the system.
To achieve both objectives, the Chago Media EVSE model by ENSTO has been selected as preferable hardware asset (see Figure 43) for the implementation of the solution.

Figure 43: Overall look and dimensions of ENSTO Chago Media EVSE

The general description of the use case/technical requirements can be summarised as below, where two different conditions apply:

1. The EVSE should act as a commercial charging station for most time, during normal operation when the LES is connected to the main grid.

2. During test periods (islanding mode), DSR platform sends periodic steering signals to the EVSE through back-end, limiting the amount of energy the charging station is providing to connected EV over time. Two control options for the use case during test periods are proposed below: a simple ON/OFF control capability, depending on the real-time LES Battery state of charge; a current charging limitation control, as function of a discrete number of the real-time LES Battery SOC intervals.

For condition 2. the proposed alternatives will be chosen in accordance to the capability of both the DSR system and back-end API. Such options are described as follows:

Control Option #1 – ON/OFF logic control
During testing mode, if the EV car needs charging up to a target final EV battery state of charge (either 100% or pre-set value):

- No charging current flow if LES battery SOC is less than X%
- Maximum allowable charging current if LES battery SOC is equal or greater than X%

The control module (embedded in the DSR) receives a signal from the Iconics system, which depends on main battery State of Charge (SOC) received from the EMS system. This signal reflects the real-time state of charge at any given point of time, and is the compared to a threshold value (eg. 40%). The control module outputs a binary steering signal towards the back-end API, demanding to switch either ON or OFF the charging process. Once the back-

end system receives the signal, it shall apply the requested condition and send back an acknowledgement signal (ACK). If the connected EV has reached the final target state, then the EVSE shall be automatically switched OFF. The cycle time between the DSR platform and the backend should be 5 minutes.
A basic concept sketch of communication set-up and parameters is provided in Figure 44.

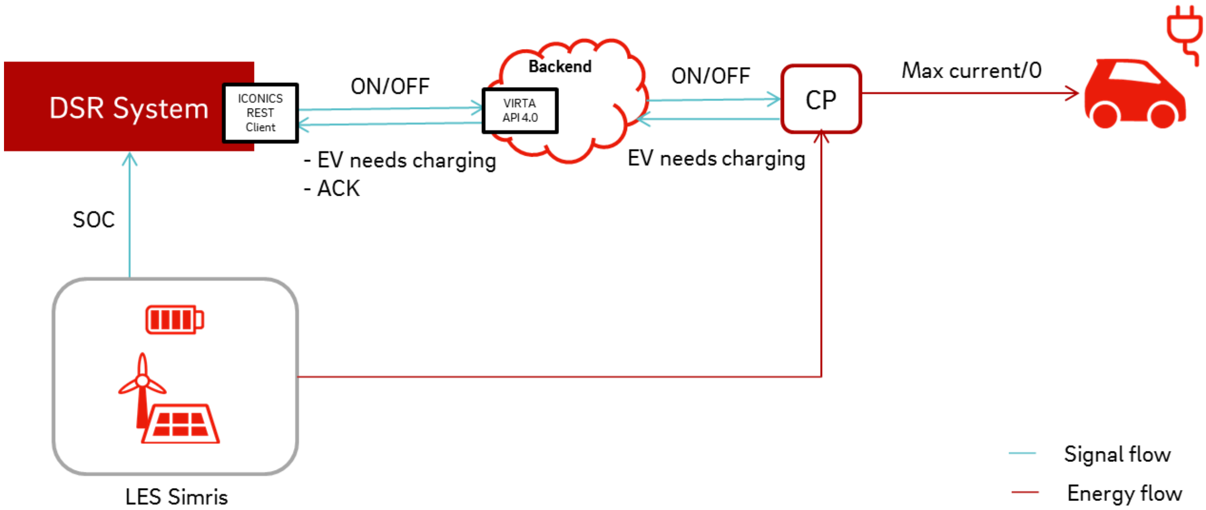


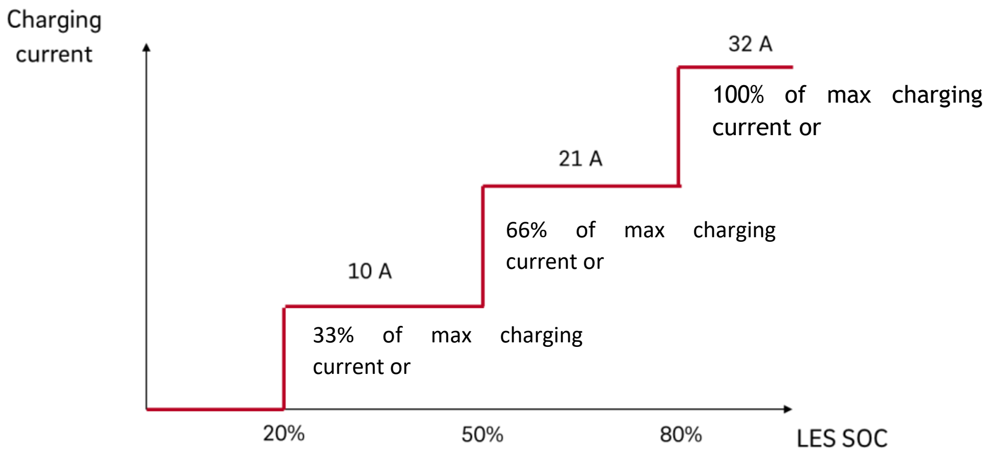
Figure 44: Communication set-up for EV chargers

Control Option #2 - Discrete interval logic control
During testing mode, if the EV car needs charging up to a target final EV battery state of charge (either 100% or pre-set value), the charging current is expressed as function of a discrete number of LES battery SOC intervals:

Below, an example with 4 ranges is provided:

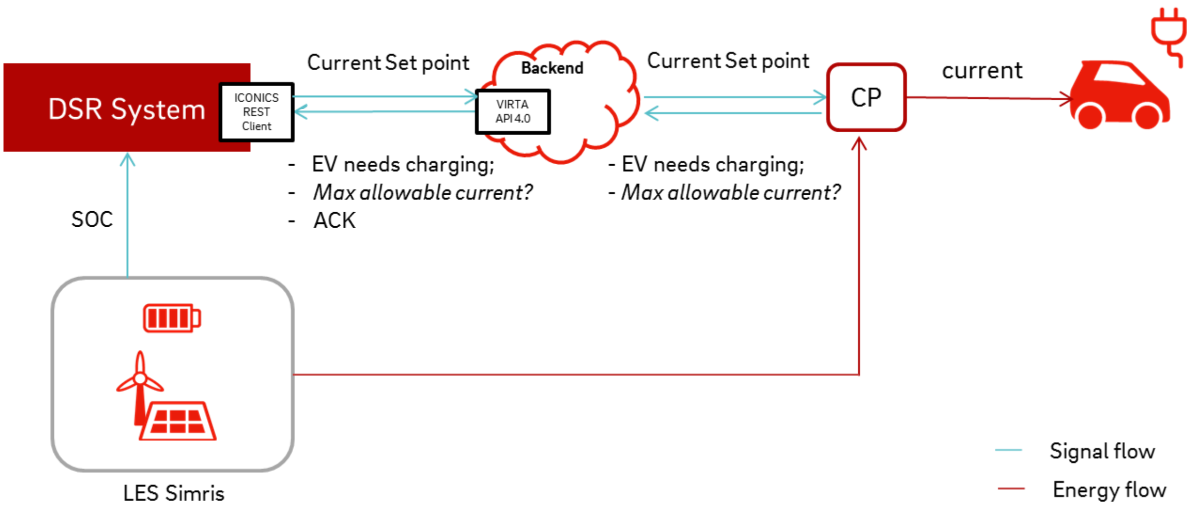
- No charging current (0 A) if SOC is less than 20%;
- 33% max charging current (or 10 A) charging current if SOC is less than 50% and greater or equal to 20%;
- 66% max charging current (or 21 A) charging current if SOC is less than 80% and greater or equal to 50%;
- max charging current (or 32 A) if micro-grid battery SOC is equal or greater than 80%

A graphical view of the control logic for the abovementioned example is shown below:



The control module (embedded in the DSR) receives a signal from the Iconics system which depends on main battery State of Charge (SOC) received from the EMS system. This signal reflects the real-time state of charge at any given point of time. The control module compares this signal and outputs a charging current set point towards the back-end API, demanding to change the value of the charging current as established for the given range interval. Once the back-end system receives this signal, it shall apply the requested condition and send back an acknowledgement signal (ACK). If the connected EV has reached the final target state, then the EVSE shall be automatically switched OFF. The cycle time between the DSR platform and the backend should be 5 minutes.

A basic concept sketch of communication set-up and parameters is provided:



3.4.5. DSR Platform

An indicative architecture of a generic DSR is shown in Figure 45 consisting of three system layers. At the bottom the process level contains the hardware, which manages the onsite management. The connectivity layer is the heart of the LES Simris project, it is the central DSR platform that connects the assets with the steering signals and the external services in the top layer, such as forecasting services and potential marketplaces.

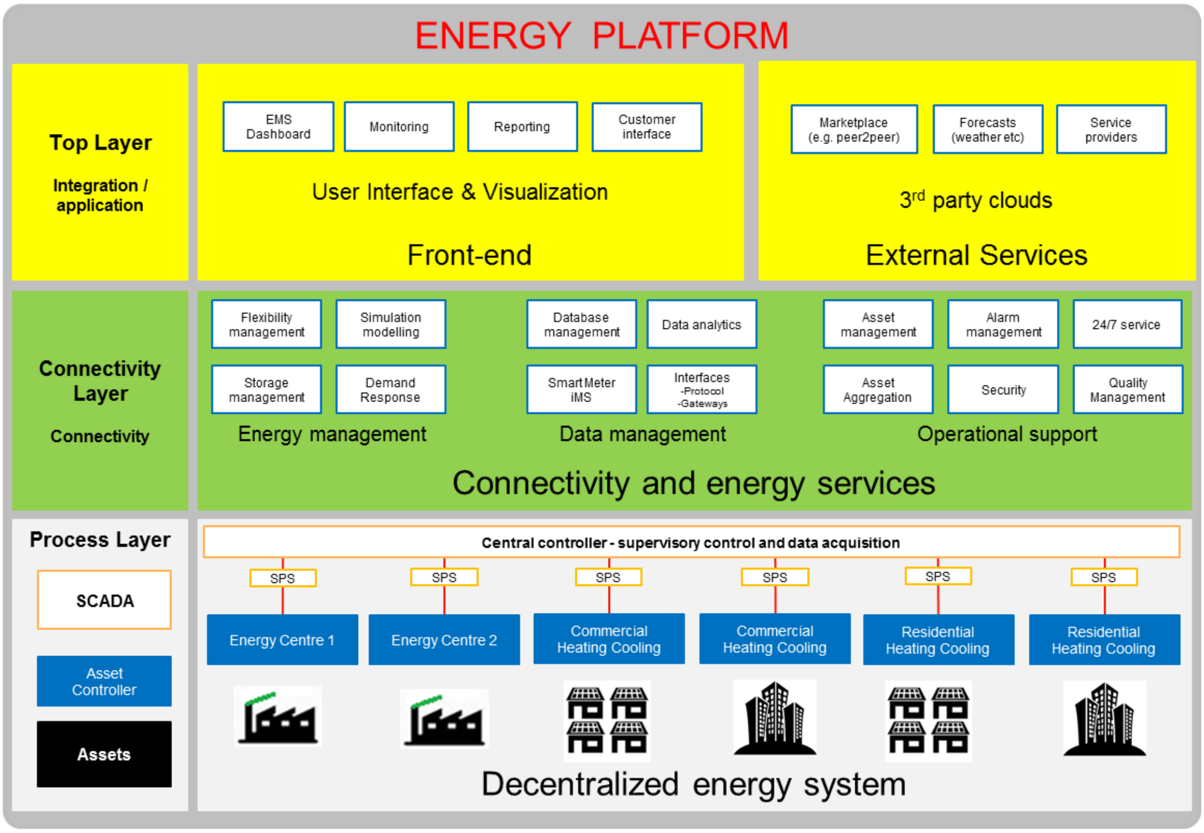


Figure 45: Indicative architecture of E.ON's EMS concept

The idea of a generic DSR is applied in the following system design. For the connectivity layer the software is based on a SCADA (supervisory control and data acquisition) software, an industry standard. The system provides the following functions:

- Deliver a real time - data platform for monitoring and control
- Provide control loops to optimize energy usage in the local energy system and by this generate profit
- Offer real time connectivity to assets and external platforms
- Provide open connectivity to extend services to system operator and flexibility marketplaces
- Simplify Integration of new assets types to expand asset base
- Visualise key performance indicators, monitor energy consumption, steering signals and user interaction

These functionalities had to be customized within project setup.

The following diagram shows the main components of the demand side response system. The micro grid controller manages the onsite generation assets. The intelligence module focuses on the use of smart algorithms to increase the flexibility potential in the system and the peer-to-peer module will increase customer participation through community engagement and visualisation. The DSR platform will tie these modules together with the assets at customer households and manage the overall control.

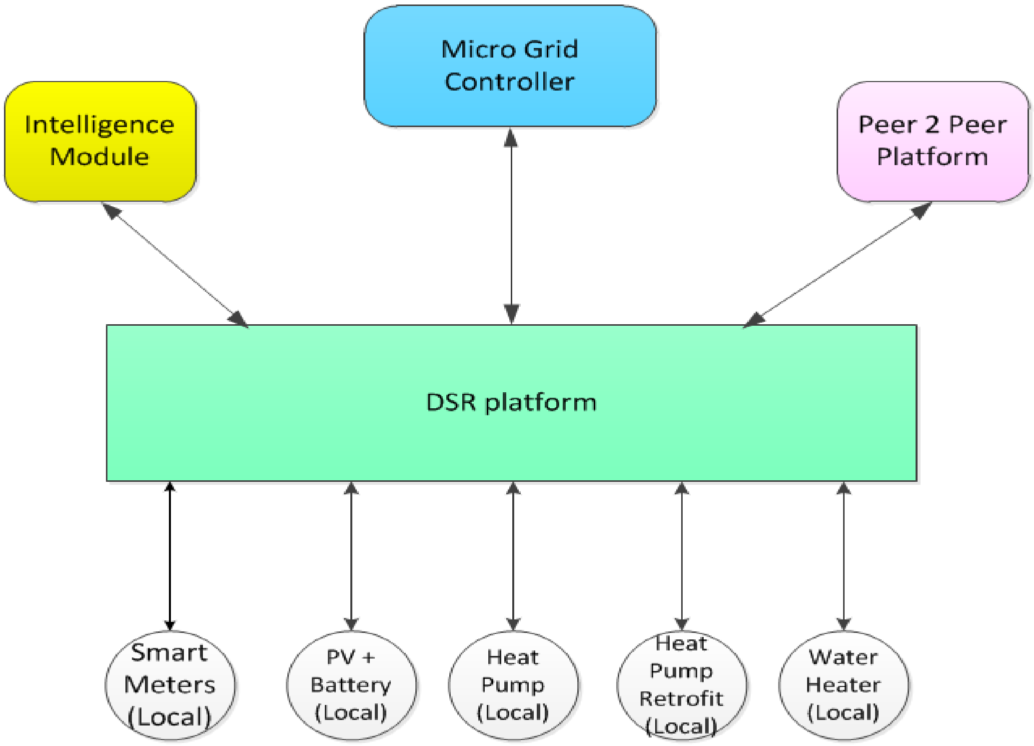


Figure 46: High Level System Overview

With a couple of exceptions, the assets will be connected to the DSR platform with cloud to cloud communication using REST API. REST API is becoming the de facto standard for web service application communication and is widely supported. Other communication protocols used are Modbus TCP and Modbus, both of which are also commonly used. A detailed overview of the system architecture is presented in appendix A. The mentioned interfaces are not aligned with the stringent requirements of smart grid communication standards, designed for immediate reaction times and extended security requirements.

For each asset the interface security and data privacy are checked. The solutions provided by the suppliers will be verified according to E.ON internal standards and the overall European requirements. Additionally, the data models for each asset needs to be evaluated and conformed in the DSR platform.

3.4.6. Local Energy Market

To elicit active customer participation, a Local Energy Market platform is being developed. The platform contains a user interface (see Figure 47, Figure 48 and Figure 49) where each individual customer can view their consumption, autarky level, flexibility and support provided to the LES and the earnings for participation.

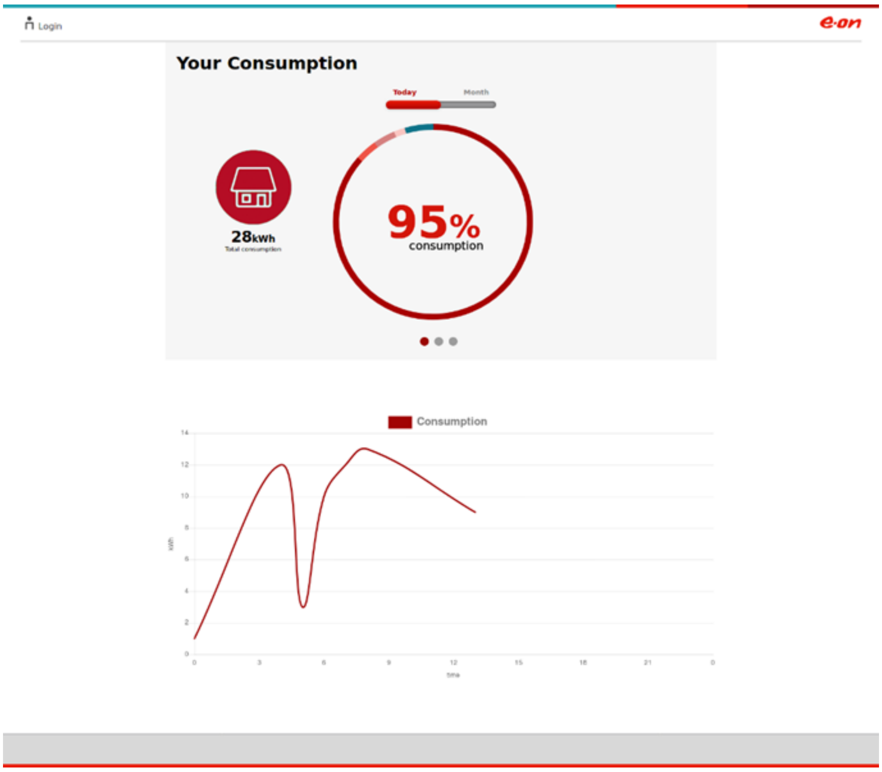


Figure 47: Screenshot of customer consumption overview

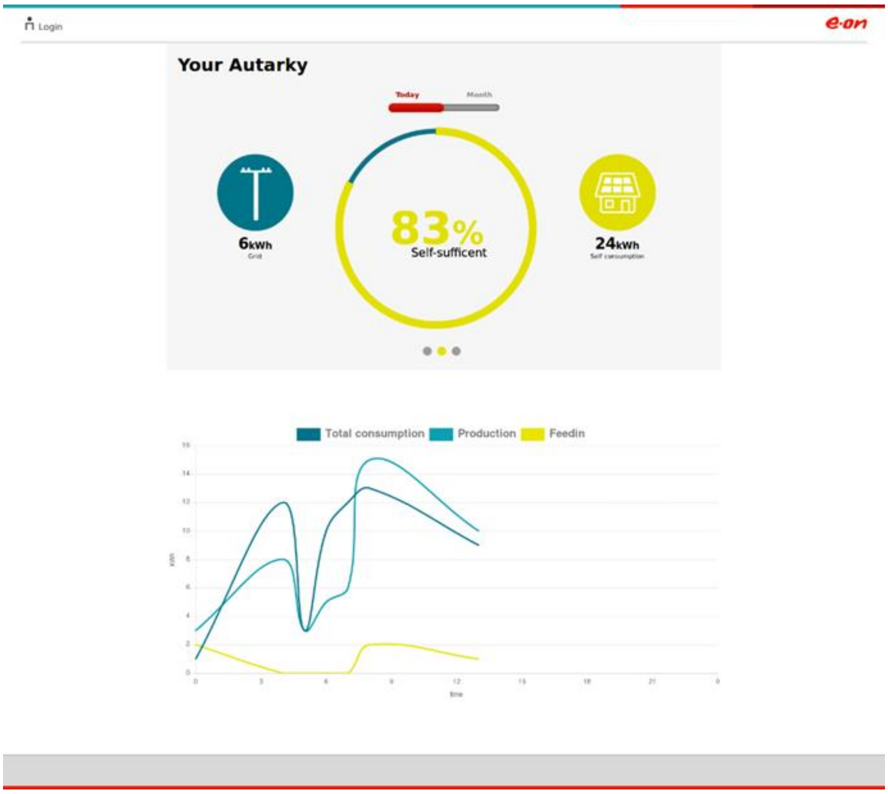


Figure 48: Screenshot of customer autarky level

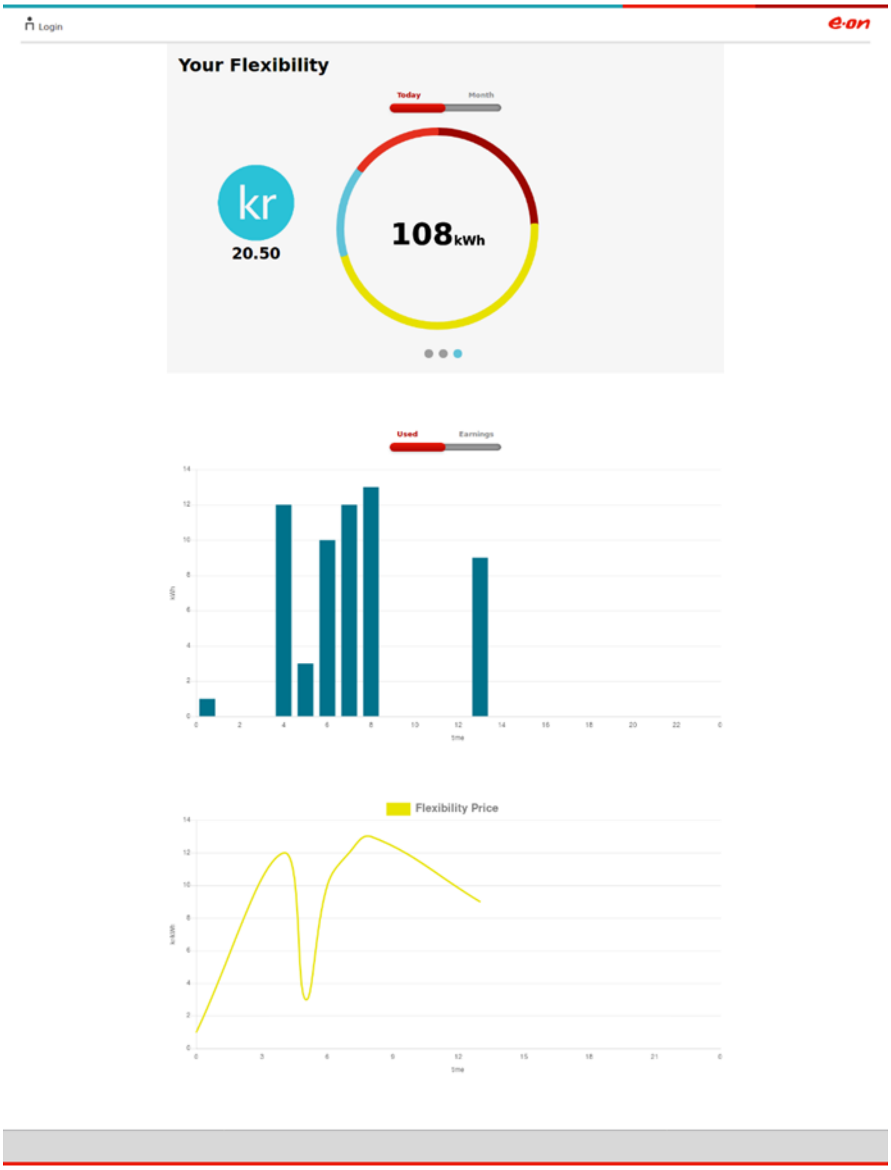


Figure 49: Screenshot of customer flexibility overview including flexibility price

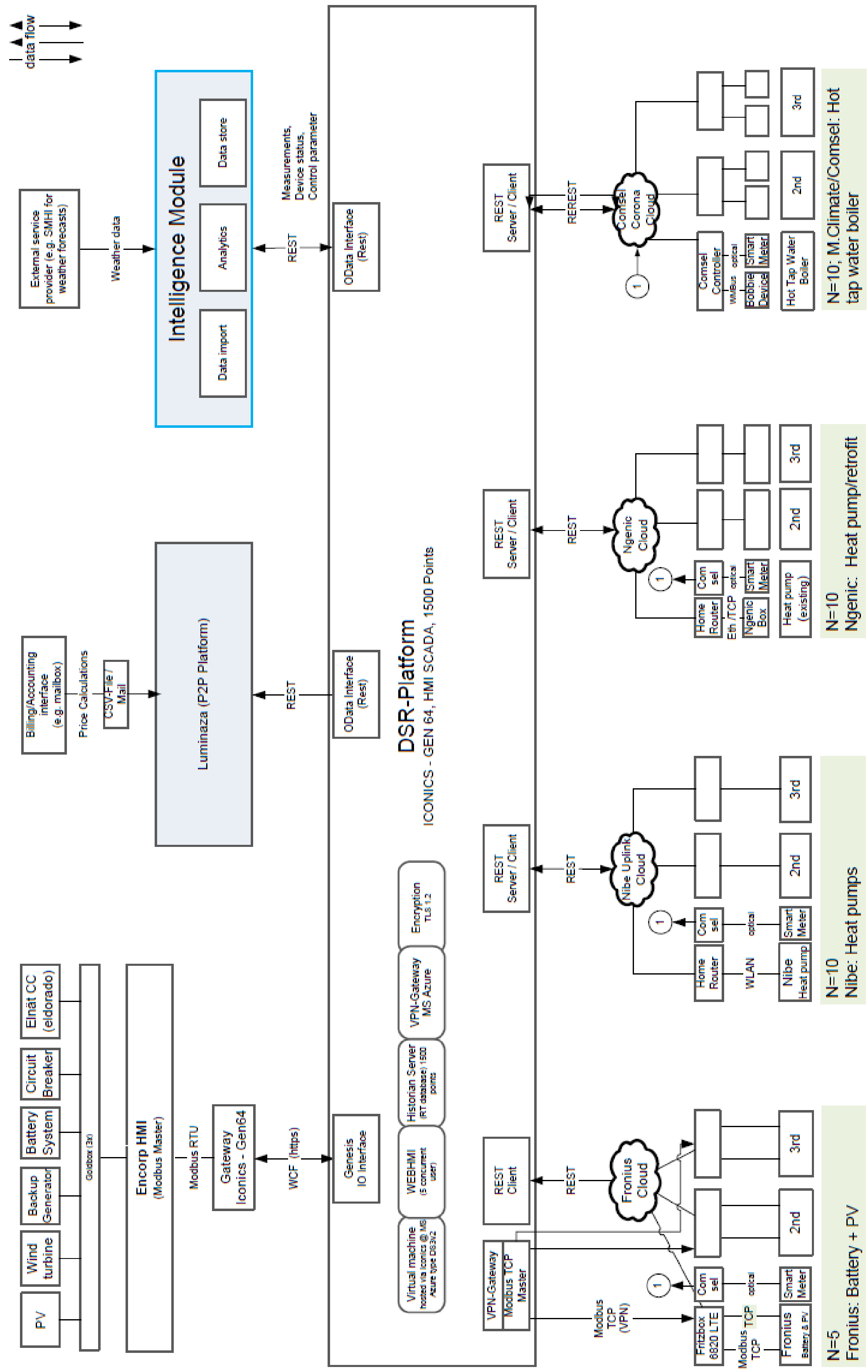
Active customers receive a fixed monthly compensation and a variable monetary compensation per kWh based on the alternative costs of curtailing RES and importing electricity from the main grid. An active customer is defined as a household with equipment that is steerable by E.ON.

The development of the platform has been divided in phases. The first version of the Local Energy Market platform contains the aforementioned simple market mechanisms and allows the customer to have an initial interaction to these type of customer empowering tools.

For the second phase of the platform development, advanced steering mechanism of distributed flexibility resources and flexibility value models are being developed. In this regard, learnings in deliverables D8.9 and D8.10, which addresses EU-wide regulations and rules concerning building local energy marketplace/platform and commercialization of end-customers flexibility respectively, have been taken into consideration to elaborate the scope of the local market and to enable peer-to-peer interactions. The customer behaviors are monitored through the site interaction but also in the form of interviews to understand if any customer perception is changed through the course of the project. Ideally customer input will also be taken into consideration when further developing the local market concept.

Like the other modules in the overall system the Local Energy Market platform is a separate module provided by an additional company, Lumenaza, in order to increase scalability and replicability. The platform is connected to the DSR platform through the ICONICS O-data interface, their standardized API for data communication between web services. A data model have been developed by E.ON with the intention of reusing it for future projects.

APPENDIX A


data flow
External service provider (e.g. SMHI for weather forecasts)
Weather data
Intelligence Module
Data import
Analytics
Data store
Measurements, Device status, Control parameter
REST
Billing/Accounting interface (e.g. mailbox)
Price Calculations
CSV-File / Mail
Luminaza (P2P Platform)
PV
Wind turbine
Backup Generator
Battery System
Circuit Breaker
Elnät CC (eldorado)
Goldbox (3x)
Encorp HMI (Modbus Master)
Modbus RTU
Gateway Iconics - Gen64
WCF (https)
Genesis IO Interface
OData Interface (Rest)
DSR-Platform
ICONICS - GEN 64, HMI SCADA, 1500 Points
Virtual machine
WEBHMI
Historian Server
VPN-Gateway MS Azure
Encryption TLS 1.2
VPN-Gateway Modbus TCP Master
REST Client
REST Server / Client
Modbus TCP (VPN)
Fronius Cloud
Nibe Uplink Cloud
Ngenic Cloud
Comsel Corona Cloud
Fritzbox 6820 LTE
Com sel
Home Router
Eth / TCP
WLAN
optical
Modbus TCP
Fronius Battery & PV
Smart Meter
Nibe Heat pump
Ngenic Box
Heat pump (existing)
Comsel Controller
Bobbie Device
Hot Tap Water Boiler
2nd
3rd
N=5
Fronius: Battery + PV
N=10
Nibe: Heat pumps
N=10
Ngenic: Heat pump/retrofit
N=10; M.Climate/Comsel: Hot tap water boiler

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