FP7-SMARTCITIES-2013
Project number: 609132
http://www.e-balance-project.eu/

e-balance

Deliverable D6.1

Specification of the demonstrators

Editor:	Marcel Geers (Alliander)
Dissemination level: (Confidentiality)	PU
Suggested readers:	Consortium
Version:	1.0
Total number of pages:	108
Keywords:	Bronsbergen, Batalha, Triana, IHP in-lab

Abstract

This deliverable describes the demonstrators in their current physical context, as well as the additions the e-balance project will make at these sites. It also provides detailed insight into how we expect to implement and test the e-balance system on a Use Case basis per demonstrator. Furthermore, a high level description of the current view on the e-balance system is provided, to facilitate a context for the described activities.

The e-balance project has three demonstrators and a supporting simulation environment. Two real-life demonstrators and an in-lab demonstrator are described in this document.

The first demonstrator is situated in the Batalha region in Portugal. The main focus of this demonstrator is on testing the Use Cases concerned with new functionalities from the point of view of the DSO and on checking the impact of these functionalities on the end users.

The second demonstrator is situated at the holiday park Bronsbergen near the town of Zutphen in the Netherlands. The main focus of this demonstrator will be on testing the Use Cases concerned with demand response and side-management, as well as interaction with end-users.

The third demonstrator is located at the premises of IHP in Frankfurt (Oder), Germany. It will consist of a table top emulation of an electricity grid, with all the major components and connections implemented. It allows studying the e-balance system more in-depth, while maintaining a tactile interface.

Disclaimer

The information, documentation and figures available in this deliverable are written by the e-balance partners under EC co-financing (project number: 609132) and does not necessarily reflect the view of the European Commission.

Impressum

[Full project title] Balancing energy production and consumption in energy efficient smart neighbourhoods

[Short project title] e-balance

[Number and title of work-package] WP6 System integration and evaluation
[Document title] Specification of the demonstrators
[Editor: Name, company] Marcel Geers, ALLI

[Work-package leader: Name, company] Augusto Casaca, INOV

Copyright notice

Executive Summary

Three demonstrators divided over three countries are designed to demonstrate the e-balance system. This document describes how the Use Cases and the system architecture combine into a real life system. The e-balance consortium has defined these Use Cases in its deliverable D2.1, which describes the scenarios the e-balance system should be able to cope with and the features the e-balance system will have to provide. This already includes aspects that will be presented as restatements in D2.6. Furthermore, in deliverable D3.1 the architecture for this system has been provided.

This deliverable describes the demonstrators in their current physical context, as well as the additions the e-balance project will make at these sites. It also provides detailed insight into how we expect to implement and test the e-balance system on a Use Case basis per demonstrator. Furthermore, a high level description of the current view on the e-balance system is provided, to facilitate a context for the described activities.

The e-balance project has three demonstrators and a supporting simulation environment. Two real-life demonstrators and an in-lab demonstrator are described in this document.

The first demonstrator is situated in the Batalha region in Portugal. The main focus of this demonstrator is on testing the Use Cases which are concerned with new functionalities from the point of view of the DSO: increasing the quality of service, performing fault and losses analysis, integration and evaluation of micro-generation based on RES, etc. In addition, the grid provided in Batalha supplies the public lighting system. This allows increasing the quality of this specific service for municipalities. It is also an objective to check the impact of these functionalities into the quality of service supplied to the end users. The Batalha demonstrator will utilise the efforts of EDP which is rolling out smart meters in this region. Furthermore, two LV-GMUs with a shared data processing facility will be realised. Also, additional sensors will be placed along the LV grid and public lighting feeders, for increased knowledge about faults and power flows.

The second demonstrator is situated at the holiday park Bronsbergen near the town of Zutphen in the Netherlands. The main focus of this demonstrator will be on testing the Use Cases, which are concerned with demand response and demand side-management, interaction with end-users, studying the benefits of demand side management for micro-grid operation, demand and solar production predictions and neighbourhood power flow analysis. Up to 20 CMUs will be deployed, together with two LV-GMUs and a MV-GMU. These will enable demand side management based on the profile steering mechanism Triana, which will be described in D5.2. In total about 200 connections will be included in the project by a combination of CMUs and predictions.

The third demonstrator is located at the premises of IHP in Frankfurt (Oder), Germany. It will consist of a table top emulation of an electricity grid, with all the major components and connections implemented. It allows studying the e-balance system more in-depth, while maintaining a tactile interface. The in-lab demonstrator facilitates testing of e-balance enabled equipment and intelligent energy devices, before they are rolled out at consumer premises. Furthermore, it also allows the testing of active switching, which is not desirable in the real life demonstrators. The demonstrator will be built up out of modular components, each emulating a part of the physical grid or a connection. Connections can consist out of producers like PV or wind, but also out of energy users like small consumers, prosumers or industry.

List of authors

Company	Author
ALLI	Marcel Geers
INOV	Augusto Casaca, Mário Nunes, António Grilo
IHP	Krzysztof Piotrowski
UTWE	Marco Gerards
CEMOSA	Juan Jacobo Peralta
EDP	Francisco Melo, João Pinto de Almeida, Luís Filipe Gaspar
UMA	Daniel Garrido, Eduardo Cañete, Jaime Chen
EFACEC	Alberto Jorge Bernardo, Paulo Delfim Rodrigues, Nuno Silva, António Carrapatoso, Alberto Rodrigues
LW	Sören Höckner, Henry Schomann
IPI	Pawel Kobylinski

Table of Contents

List of Tables

List of Figures

Abbreviations

AC	Alternating Current
ADC	Analog to Digital Converter
ADSL	Asymmetric Digital Subscriber Line
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BRP	Balance Responsible Party
CAIFI	Customer Average Interruption Frequency Index
CMU	Customer Management Unit
COM	Common Connector
DA	Distributed Automation
DER	Distributed Energy Resource
DER-MU	Distributed Energy Resource Management Unit
DMU	Device Management Unit
DoW	Description of work
DSM	Demand Side Management
DSO	Distribution System Operator
EAN	European Article Number
EC	European Commission
ES	Energy Supplier
ESCO	Energy Service Company
GMU	Grid Management Unit
GSS	Grid Support Service
GUI	Graphical User Interface
GW	Gateway
HV	High Voltage
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IED	Intelligent Energy Device
IP	Internet Protocol
KPI	Key Performance Indicator
LAN	Local Area Network
LV	Low Voltage
LV-FAN	Low Voltage Field Area Network
LVGMU	Low Voltage Grid Management Unit
MAIFI	Momentary Average Interruption Frequency Index
MGCC	Microgrid Central Controller
MV	Medium Voltage
MV-FAN	Medium Voltage Field Area Network
MVFDL	Medium Voltage Fault Detection and Location
MVGMU	Medium Voltage Grid Management Unit
NC	Normally Closed
NO	Normally Open
NPF	Neighbourhood Power Flow
OPF	Optimized Power Flow
PC	Personal Computer
PL	Power line
PLC	Power Line Communications
PS	Primary Substation
PS	Primary Substation
PV	Photovoltaic panel
QoE	Quality-of-Experience
QoS	Quality of Supply
RES	Renewable Energy Sources
RFMesh	Radiofrequency Mesh

RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SM	Smart Meter
SPDT	Single-pole Double Throw
SS	Secondary Substation
TL-GMU	Top Level Grid Management Unit
TSO	Transmission System Operator
UC	Use Case
VOS	Validation of Optimized Solutions
VPN	Virtual Private Network
WLAN	Wireless Local Area Network

1 Introduction

The e-balance project will develop two distinct real life demonstrators, one supporting in-lab demonstrator and also utilise a system simulator. This document specifies the purpose and design of each individual demonstrator. Within this project, the demonstrators are used to integrate, validate and evaluate the work accomplished in the other work packages in a real life environment. The real life demonstrators are located in the Netherlands (Zutphen, holiday park Bronsbergen) and Portugal (Batalha region). The supporting in-lab demonstrator will be located at the premises of IHP in Germany and the simulations will be facilitated by the University of Twente, the Netherlands.

The document is shaped in the following manner:

- Chapter 1 describes the details of the demonstrators pre-e-balance
- Chapter 2 describes the e-balance system from different perspectives
- Chapter 3 describes the research questions consortium partners are interested in
- Chapter 4 describes the demonstrators on a per Use Case basis

The objectives of the three demonstrators aim at covering most of the Use Case's functionalities and the usual electric grid requirements. Also, they will provide a test environment for the integration of e-balance components in a real life complex system. In general terms, different types of technology will be assessed within this context:

- telecommunication technologies, to determine what the best or most practical way for stakeholders to exchange information is,
- additional grid sensors to monitor all the electric grid parameters that allow implementing resilience strategies, and to facillitate new services by the new management units,
- all the required algorithms to operate the system.

The challenge is evident and requires specific information from demonstrators and the coordination of stakeholder and e-balance experts.

During the first stage of the e-balance project, several Use Cases have been described and presented in D2.1. These are based on the main functionalities of a smart-grid and smart-cities. General functionalities include demand response, demand-side management, integration of local production and storage technologies. Furthermore, steps are being taken to extend the project scope to future energy markets.

Each demonstrator focusses at testing some Use Cases and explores specific functionalities. Therefore, there are specific objectives that will be accomplished in each case:

- The Batalha demonstrator aims mainly at testing new services from the point of view of the DSO: increasing the quality of service, fault and losses analysis, integration and evaluation of micro-generation based on RES, etc. In addition, the micro-grid provided in Batalha supplies the public lighting system, what allows increasing the quality of such specific service for municipalities.
- The Bronsbergen demonstrator consists of two MV/LV secondary substations. A part of this grid has previously been operated as a micro-grid. The LV grid has PV on half of the present connections and features a large centralised electrical storage unit. This allows testing of 16 Use Cases related to end-suers (demand response and demand side-management), the micro-grid potential, demand and solar production predictions and neighbourhood power flow analysis, including optimisation and losses calculation. The deployment of ICT and the interaction of the main stakeholders (customers and DSO) will contribute to the validation of the effectiveness of all measures proposed by e-balance and the current approaches of the smart-grid expert community.
- Finally, the in-lab demo in Germany (IHP premises) will be the launching base to test the physical devices and management units that turn the electric grid into a "smart grid" and to test all the options of algorithm effects and limits. Furthermore, it will emulate critical faults and interruptions that cannot be executed in the real life demonstrators for practical reasons. In summary, this final demonstrator will carry out functionalities that cannot be done in real demos and test new sensors, devices and algorithms.

2 Description of the demonstrators

2.1 Portugal, Batalha

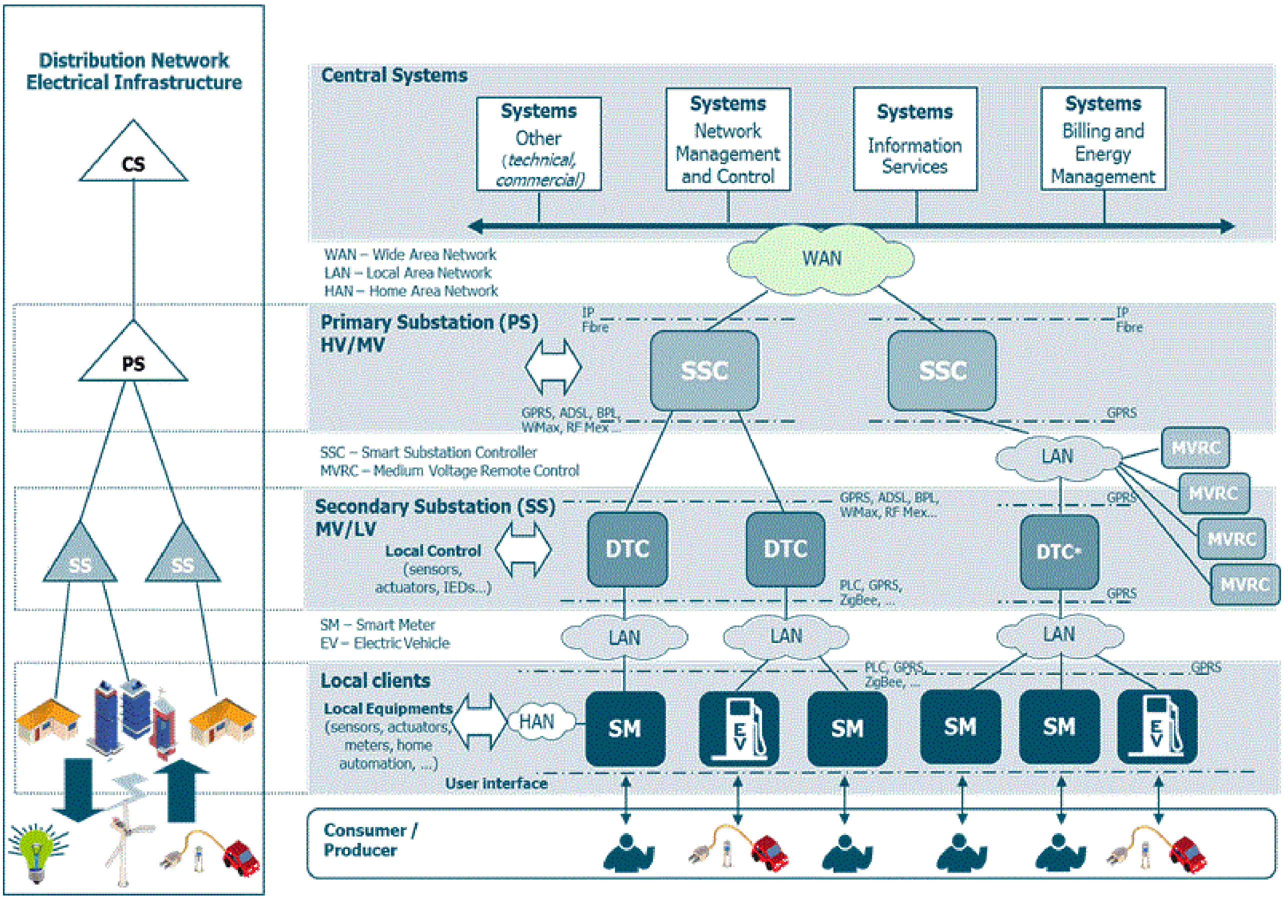

Figure 1: EDP Distribuição's smart grid technical reference architecture

EDP Distribuição's technical reference architecture, Figure 1, was designed in the context of the InovGrid project. This is an R&D and large-scale pilot/ demonstration project, that was launched in 2007 by EDP Distribuição with the support of Portuguese industrial and scientific partners. It focusses on the development of a fully active distribution network with information and intelligent equipment that is capable of automating energy management, thereby improving service quality in terms of decreasing costs and increasing energy efficiency and environmental sustainability. Higher customer involvement is promoted by allowing the customer to access and analyse her consumption with higher detail. Moreover, greater security in supply is ensured, further diversifying renewable energy sources and increasing the capability for distributed generation integration, including micro generation, which becomes more effective and easier to control. Finally, grid renewal and operation becomes easier with the increasing reliability and efficiency due to the increasing effort in automation and tele-control.

The InovGrid project aggregates a set of pilot projects developed in several Portuguese cities with different characteristics. It allows the development of different aspects of the smart grid in different operating conditions. It started with the deployment of a test site in the city of Évora, where a smart grid infrastructure was implemented with 341 data concentrators, 31.300 smart meters and about 54.000 inhabitants involved for testing smart metering functionalities. The InovGrid project platform keeps evolving in terms of functionality, interoperability, security and reach. Seven more test sites are planned for deployment until 2015, which will allow testing of advanced smart grid functionalities, namely Guimarães, São João da Madeira, Lamego, Batalha, Marinha Grande, Alcochete and Ilhas Barreira. Additional 100.000 smart meters will be deployed in these sites.

In the context of InovGrid, an integrated automation pilot will be deployed at the Batalha test site, one of the seven locations already mentioned. It will integrate distributed automation (DA) and advanced metering infrastructure (AMI) components with RF Mesh technology, using the InovGrid architecture. It will cover about 9.000 clients that are distributed by 133 secondary substations in several MV feeders. This location was chosen due to the challenge it poses to increasing quality of service and also due to its dimension.

Implementation of the DA network will enable detection, control and command functionalities in MV and LV networks. In this context, fault current indicators will be installed in 16 new reclosers, six of them are already installed. 27 communicating fault current indicators will be installed in the overhead network with battery backup.

All 133 secondary substations have public lighting circuits. The public lighting management platform will be used to supervise and manage these circuits. This will be accomplished by means of smart alarms that will enable right identification of public lighting status per secondary substation. All secondary substations will be equipped with a smart meter with specific capabilities for public lighting control.

2.1.1 Demonstrator site description (current)

The e-balance demonstrator will be installed in a MV feeder of the São Jorge’ primary substation, situated in the Batalha region and in two secondary substations electrically attached to the same primary substation (normal operation mode). Several e-balance functionalities will be demonstrated using these facilities and related MV and LV grids.
Therefore, some technical details will be described for:

- 1 MV feeder from São Jorge’ primary substation for self-healing Use Cases;
- 2 LV grids attached to MV feeders of São Jorge’ primary substation namely for neighbourhood monitoring Use Cases.

2.1.1.1 Medium Voltage grid model (relevant feeder)

A MV feeder in the Batalha region has been chosen. Main feeder characteristics:

- Distance: 32 km (91% overhead lines)
- # clients: 3900
- Installed capacity: 20.460 kVA
- # secondary substations: 77

Figure 2 gives an overview of the selected MV feeder to validate e-balance self-healing functionalities.

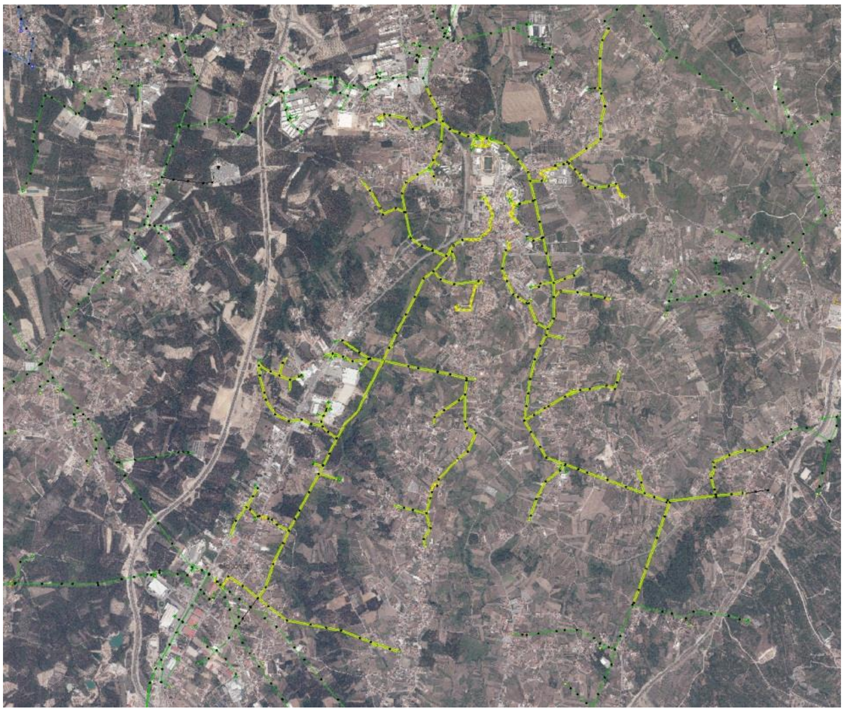

Figure 2: MV feeder (yellow)

2.1.1.2 Low Voltage grid model

Two secondary substations are chosen to demonstrate a selection of the e-balance functionalities. The two secondary substations are in the Batalha region: PT007 and PT019. Their general characteristics are described in Table 1. Figure 3 and Figure 4 give a general overview of the LV grid of SS PT007 and PT019. The individual circuits are described in Annex A.

PT007	PT019
Transformer: 400kVA	Transformer: 250kVA
145 clients (106 monophasic, 39 triphasic)	96 clients (51 monophasic, 45 triphasic)
6 circuits	

Table 1: Generic description of secondary substations PT007 and PT019

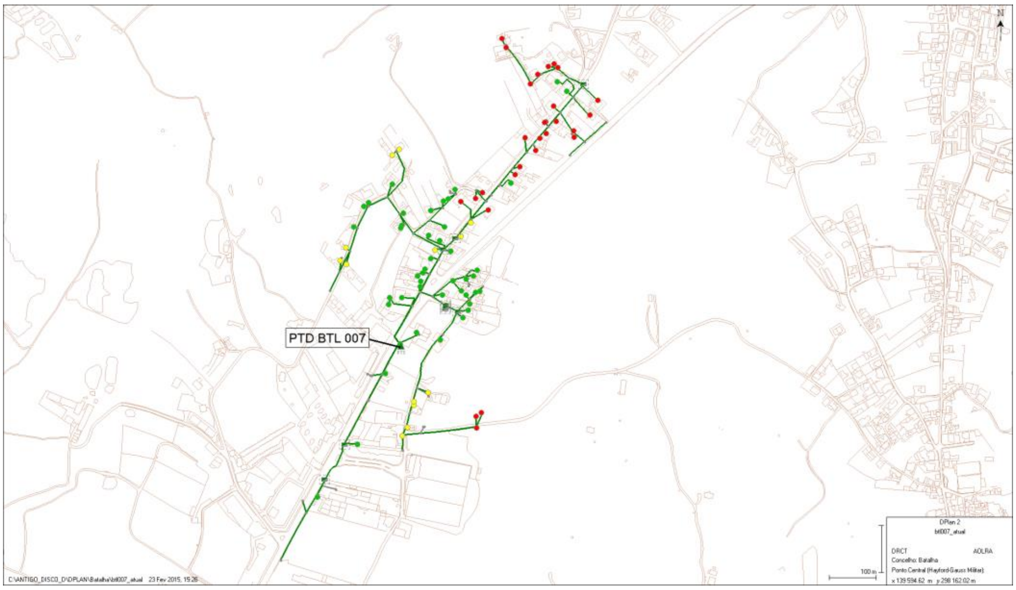

Figure 3 – PT007 (all circuits)

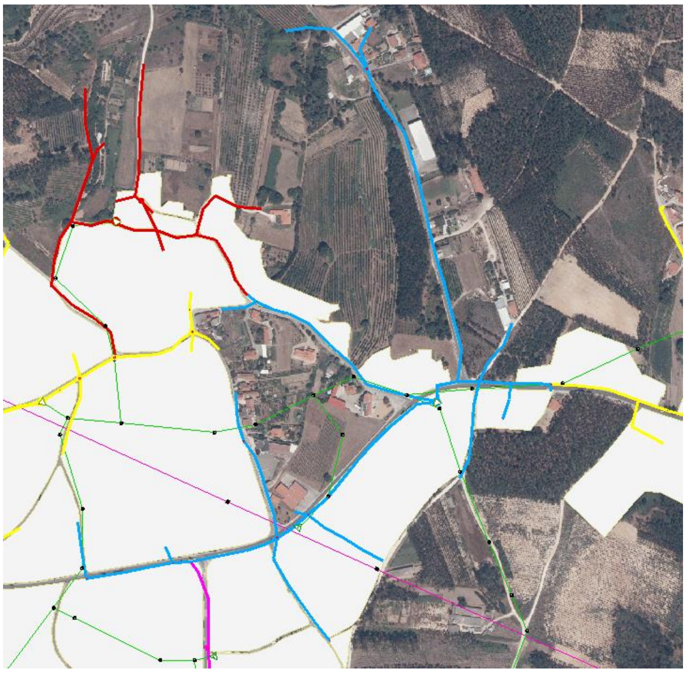

Figure 4: PT019 all circuits (light blue)

2.2 The Netherlands, holiday park Bronsbergen

2.2.1 Demonstrator site description (current)

The holiday park Bronsbergen has been used in several research projects as a demonstration area for energy technologies. During the TF5 project “more microgrids”, a cottage was acquired by Alliander and a large grid-connected storage of 700 kWh was realised, with an effective capacity of 350 kWh due to the nature of the batteries. It has been proven that the local LV grid can be operated as a microgrid. A great number of cottages are equipped with PV panels totalling 315 kWp. As not all roofs are oriented in the same direction, peak production will vary throughout the day.

Another project that has been tested at this demonstrator is VSYNC. This project concerned building a Virtual Synchronous Machine. By using one or more power electronic inverters, it was proven possible to emulate the behaviour of a standard Synchronous Machine. Synchronous machines are the main workhorse in classical powerplants to turn the mechanical energy provided by a thermal process (i.e. the burning of wood or coal) into electricity. This contributes to a stable grid frequency and voltage. This technology can possibly be run in parallel to e-balance, to emulate a commercial “Grid Support Service” (GSS). This GSS can be supplied by the central storage system or optional, currently not installed or foreseen, controllable PV inverters.

2.2.1.1 Medium Voltage grid model (relevant feeders)

The Bronsbergen demonstrator is connected to a medium voltage feeder originating from primary substation Zuthpen. This feeder mainly connects rural agricultural clients, businesses, a hospital and industrial areas. Several normally open switches are available, making grid optimisation a complex matter. The specific feeder is schematically summarised in Figure 46 in Annex B.

2.2.1.2 Low Voltage grid model

The LV grid at Bronsbergen has two separate MV connections at two secondary substations (SS). SS Roelofs powers the majority of the holiday park, shown in Figure 5 by the orange, blue, purple and pink coloured lines. The lines in green are powered by SS Bronsbergenmeer. This part consists of the local congress centre, utility buildings and the remaining cottages.

Figure 5: Aerial photo of the Bronsbergen demonstrator, with a LV-grid overlay. Locations of PV panels indicated by cyan coloured circles

2.2.1.3 Site statistics

A large portion of the cottages in the holiday park Bronsbergen is permanently inhabited. Figure 6 shows the consumption histogram of the connections at this LV grid. For a long time, PV and consumption were separated connections at this site. Hence, the influence of PV production is not visible in these statistics.

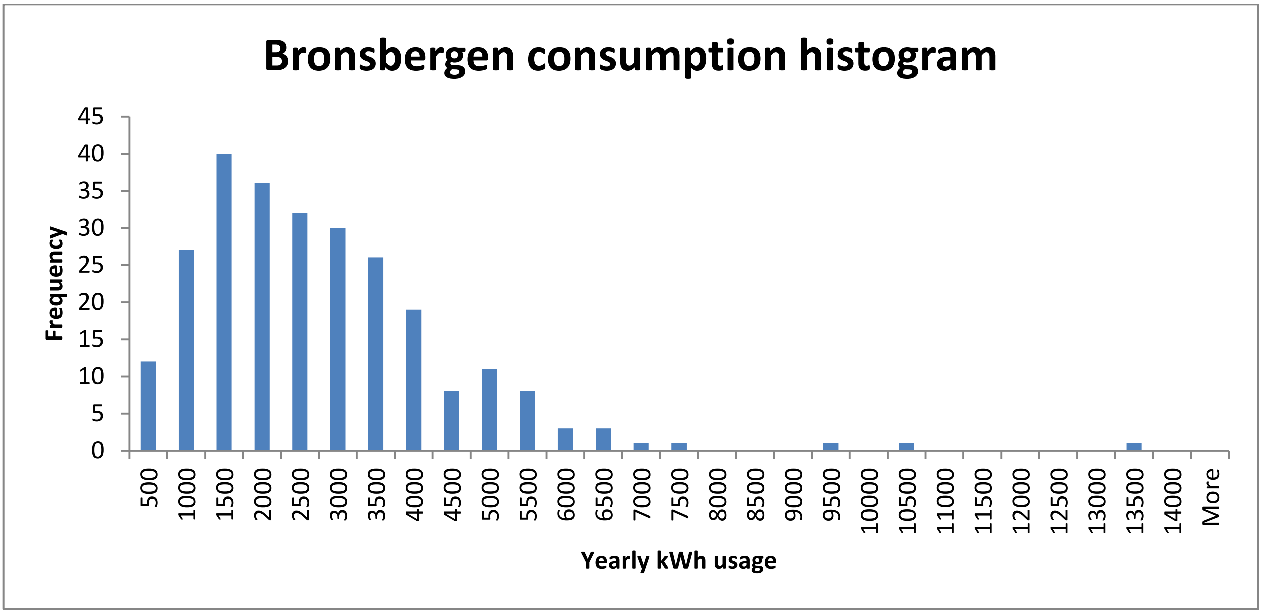

Figure 6: Yearly consumption histogram comprising all customers at Bronsbergen

Other specific site statistics include:

- 208 cottages in total, of which 92 with solar panels installed during construction
- The 92 cottages have a combined production of 315 kWp (at install date, currently the degradation is unmeasured). These 92 cottages have the following PV installations:
  - 56 installations of ≈ 2,6 kWp
  - 35 installations of ≈ 4,6 kWp
  - 1 installation of ≈ 7,1 kWp
- Several cottage owners have installed solar panels on cottages that did not have them before. The specifications of these installations are not fully known at the time of writing. These are additional to the previously mentioned 92.
- Conference centre is also equipped with solar panels and a heat pump. The details of these are not known yet.
- 90 kW net peak loading of the transformer at SS Roelofs

2.3 Germany, in-lab IHP

The in-lab demonstrator is to be located at the IHP lab in Frankfurt (Oder), Germany. The aim of this demonstrator is to show the features of the e-balance system on a grid model in small scale. Thus, it has similar features as the simulation provided by UTwente. The difference is that the in-lab demonstrator uses an implementation of the algorithms on physical devices and real energy flows occurs. This kind of demonstrator can be seen as a model on-the-table and a physical interaction with the system is possible. This includes for instance cutting some power line or provoking a short-circuit, e.g., due to a fallen tree. Such extreme test cases are not desirable in the real demonstrators due to the involvement of real customers (no intentional energy delivery interruptions are allowed) as well as due to possibly high costs of such experiments.

Another kind of physical interaction that is planned, is the inclusion of real appliances that may be included as part of the emulated grid. The plan is to obtain some smart home appliances and create a household in our laboratory that is connected with the in-lab demonstrator and is thus also controlled and monitored by the e-balance system.

The in-lab demonstrator is to be realised with a modular approach. It consists of several kinds of building blocks representing parts of the energy grid. These blocks also include their corresponding e-balance system management units, as well as sensors and actuators. Connecting these building blocks allows creating a diversity of grid configurations and thus allows the implementation of a diversity of test scenarios. Due to this flexibility, the in-lab demonstrator is not limited to a single energy grid model or topology and allows for instance creating a model of each of the real life demonstrators. The only constraint on the scalability is the available area (the size of the table) and the number of available building blocks of each kind. To overcome this issue, in some cases for instance, if the number of households is too large, several households may be represented by a single block. This will emulate the consumption and production of these households as a sum. In this case, however, the emulation of the energy flow between each household is limited and virtual.

2.3.1 Demonstrator description

The building blocks represent the real elements in the energy grid, with the voltages and currents scaled down. The in-lab demonstrator building blocks are visualised in Figure 7. The blocks are described in detail in Annex C and more briefly as follows:

- Primary Substation block – includes the energy source. It is realized as a block powered by 230V AC and delivering 48V AC that represents the MV level in our settings.
- Secondary Substation block – realised as a transformer that converts the 48V AC into 24V AC that represent the LV level in our settings.
- Transmission lines block – represents the connections in the grid in both LV and MV. The physical connection can be opened representing a damaged transmission line in the emulated grid.
- Switch block – allows creating dynamic grid topologies. Realized as a relay controlled by the respective management unit. Depending on the configuration may be normally open or closed.
- Consumer block – this general and configurable block represents all possible energy production and consumption sites that can be connected to the LV and MV grid. Thus, depending on the profile the block is programmed with, it may be a simple energy consumer at LV, a prosumer, energy storage at LV or MV, large energy consumer or producer at MV, or any kind of DER at LV or MV. The consumer block will indeed inject energy into the grid if configured so. Thus, it shall be possible to run part of the emulated grid in islanded mode. Additionally, the customer block can be equipped with different communication modules that allow interaction with real non-standardised smart appliances. It can also represent several production and/or consumption sites connected to a single point in the grid combining their consumption and production.

All the building blocks are equipped with the required sensors and management units. Thus, the process of building the grid topology to be emulated consists of three steps:

- Physical (electrical) connection of the building blocks,
- Logical connection of the e-balance components (sensors, actuators and management units) to match the desired grid topology,

- Configuration of the desired behaviour of the customer blocks – uploading the energy profiles.

There is no final specific topology and configuration defined for the in-lab demonstrator. The best suitable layout will be defined in the course of developing the control algorithms, in order to expose the most attractive and desirable evaluation conditions.

The user interaction with the in-lab demonstrator will be possible via the graphical interface realised as a separate device (tablet or PC) connectable to any of the management units. It presents the state of this unit and the control options.

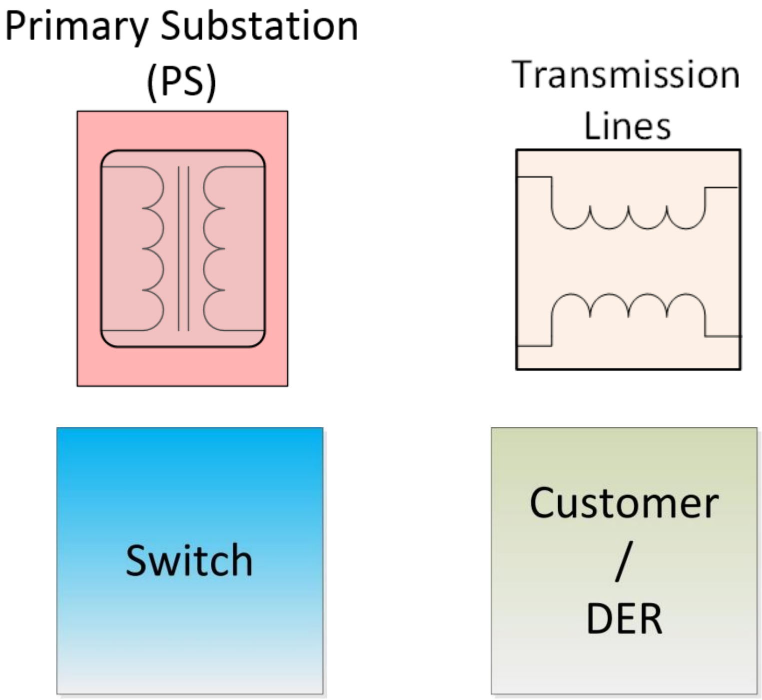

Figure 7: in-lab demonstrator building blocks

2.3.2 Technical details of the demonstrator realisation

The in-lab demonstrator provides a much larger flexibility for the definition of the technical specification compared to the two real life demonstrators. This is mainly due to the smaller number of constraints caused by the specific deployment. Thus, several technical details defined in the following subsections are given as a set of possible solutions.

2.3.2.1 Hardware and software platform

The intention is that the in-lab demonstrator will be based on the nodes developed at the IHP (see Figure 8). These nodes are based on the MSP430 and on the ARM Cortex M3 microcontrollers and are equipped with three radio modules for inter-node communication. The hardware platform is extendable and additional hardware blocks can be easily attached to the main processing and communication board as required. One of the additional boards we developed is an ADC board allowing measuring the electrical parameters with 24-bit resolution, what makes it perfectly suited for energy related measurements. The IHP nodes are compact in size, while providing a rich feature set, which simplifies the development of the in-lab demo building blocks.

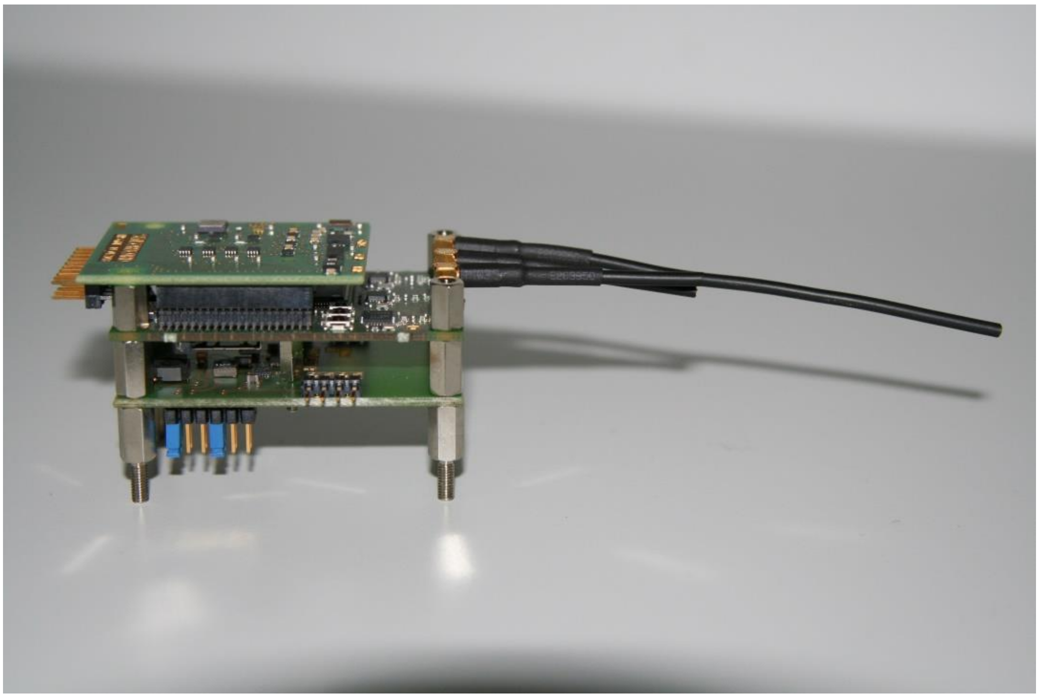

Figure 8: the IHP sensor node

The IHP nodes are used for implementing sensor and actuators, for implementing the management units we plan to use an embedded PC that allows us to use exactly the same energy management software as used in the two real world demonstrators. We will reuse the same implementation of the software modules to be used in the real life demonstrators.

The hardware to be used for the management units will be equivalent to the BeagleBone Black[1] or the Raspberry Pi[2] embedded PC, i.e., a small size low power ARM based system running the Linux operating system. It is also compatible with the CMU hardware platform provided by Lesswire for the real life demonstrators.

The software platform on the IHP nodes is IHP own simple operating system implemented in the C programming language. We plan to implement the software modules required for the involved devices, as defined by the e-balance system specification for this platform.

2.3.2.2 Communication technologies

The IHP nodes provides three radio modules for the inter node communication. These modules allow implementing any kind of software protocols in the 868 MHz and in the 2.4 GHz bands and also allow using the ZigBee protocol in the 2.4 GHz band. Additional radio modules can be attached to the main board as well, if necessary.

Furthermore, the embedded PC hardware, like BeagleBone Black or Raspberry Pi provides also the possibility to communicate over Ethernet. Thus, the communication possibilities are plentiful.

We intend to define the protocols to be used in the in-lab demonstrator for the different parts of the network to reflect the technologies that may be applied in a real deployment. We also intend to provide configuration possibilities that allow for instance tuning and monitoring the features of the communication, like the data rate.

For the communication with the real sensors and smart appliances we intend to use Z-Wave and ZigBee modules. We have chosen these two protocols due to the availability of devices that use them.

---

[1] http://beagleboard.org

[2] http://www.raspberrypi.org

3 The e-balance experience

This chapter will describe the user experience of the e-balance system. Project and partner related details will be presented in chapter 5**.**

3.1 Energy user/producer customer interaction

The primary focus of the e-balance system is on the end-user. The focus of the Bronsbergen demonstrator will not only be on the technical performance of the hierarchy, but also on the residences of the cottages at this site. It is important to realise however, that an end-user of the e-balance system does not have to be a single person. It can be a group of people, but also something more abstract such as a commercial company or an electric vehicle charging point.

3.1.1 The first encounter

The first physical encounter of the customer with the e-balance system, will be through the Customer Management Unit (CMU). This is a device provided by the project to the user, which allows him to be able to interact with the project in a technical sense. It will function as energy manager, data hub and (tele)communication portal. The CMU is a box with electronics, which will *(most likely)* be placed at the distribution cabinet of the customer's house / residence / cottage.

An installation manual (paper or digital) will explain the subsequent physical installation of the CMU.

The CMU will be connected to the Smart Meter via a local port (P1 in the Netherlands) for local data analysis purposes (Use Case #7 and #8). It may be connected to the local LAN via a direct connection or via WLAN. This connection will be used to acquire additional information for data analysis purposes. After the initial physical connectivity has been realised, other devices that need to be connected directly can be attached.

3.1.2 The initial configuration

After the CMU device has been installed, some initial configuration has to be applied. A browser enabled device can be used to connect to a LAN IP address to bring the CMU GUI forward. Information regarding contracted capacity and prices need to be entered, it must be based on the energy contract. The pre-mentioned data should be supplied by the user for now, programmed locally by means of an energy bill.

After configuring the essentials, the user is requested to select an energy usage strategy (UC#1, UC#5). First, a selection is made on the kind of participation that is desired. Pre-programmed participation strategies are:

1. "Own energy first!": maximise local consumption
    a. Local energy balancing, with grid and e-balance fall-back option
    b. Local energy balancing, but without supplying flexibility to the grid, just information
    c. Local energy balancing, without communication (CMU only)
2. "e-balance Mode": full e-balance participation
3. "Remote Control Mode": aggregator in control

Next, the user will be requested to provide an additional set of preferences. The e-balance energy management system has the ability to send out a priority signal[3] in order to prevent critical grid failure or disconnection. The CMU will use a different set of customer defined strategies in case these energy delivery limitations occur (UC#2). It is likely that this will involve comfort decreasing choices. Hence, this needs to be made very clear to the user, so that choices are well thought through. Whereas compliance will be rewarded, non-compliance could ultimately result in disconnection of the user (in case the Smart Meter, Market Model and legal framework allow this) or disconnection of the entire local grid (feeder), in order to maintain stability of the rest of the grid. Currently, only the latter option is possible in the Netherlands as current and future Smart Meter generations no longer have a remotely operable switch installed in the Netherlands.

---

[3] The methods to prevent critical grid failure are currently under debate and development within the consortium. These will be presented in deliverable D5.2. The text related to this is thus subject to change.

If the user has connected a DER like a set of PV panels, typical system characteristics can be provided to the system, such as azimuth, kWp, roof angle etc.

At this point in time, the user has specified all the technical boundary conditions of the system. The system will however also create data. The user will get the option[4] to read the *(local)* privacy regulations, to understand their rights. With this (new) awareness, choices are presented to share or withhold data for specific purposes and services (UC#8).

The complete system from a user perspective is depicted in Figure 9.

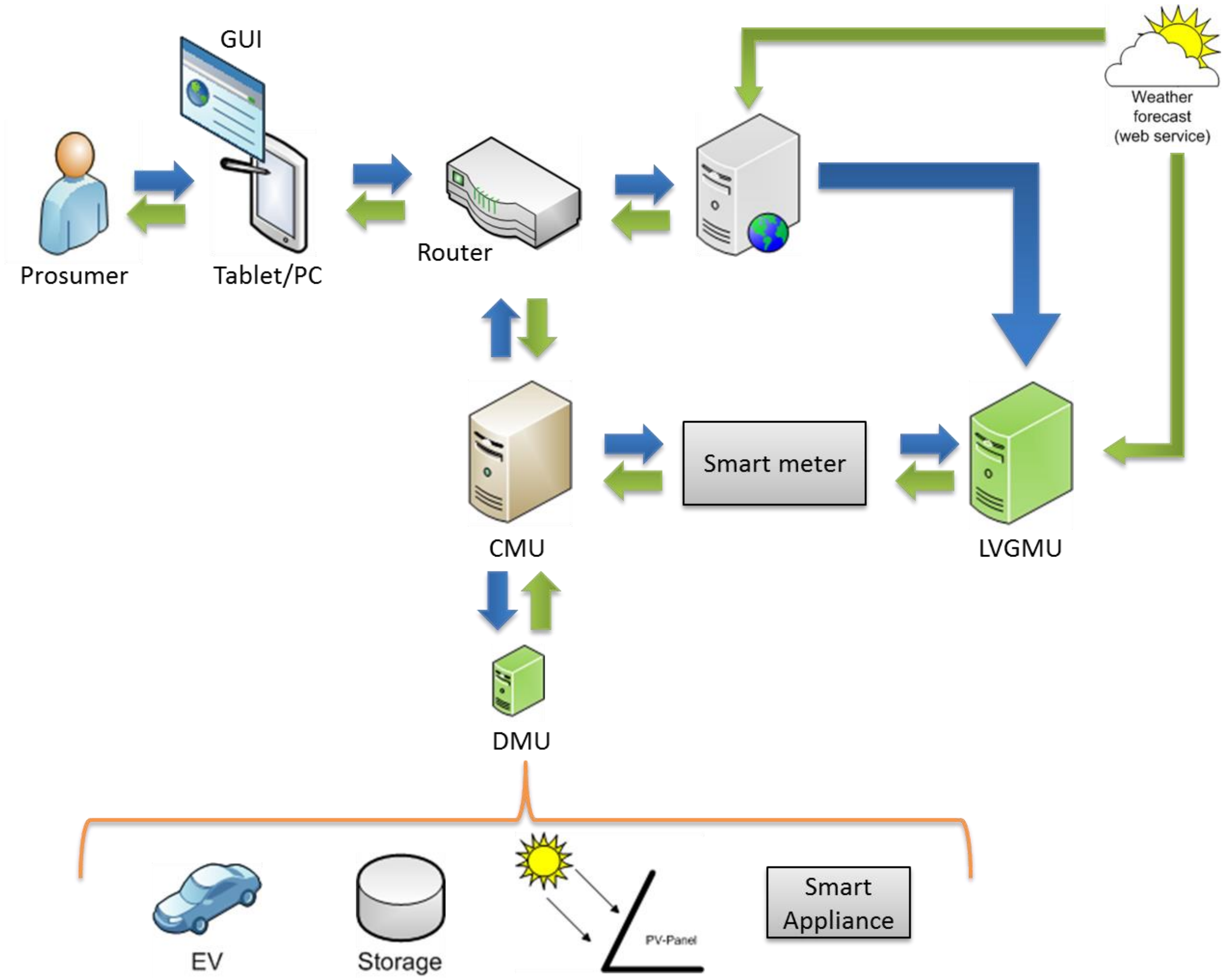

Figure 9: The e-balance system from a user perspective

3.1.3 Customer interface for better efficiency and interaction

After the initial technical installation and configuration, the system is ready for use. After a certain amount of operational time has passed, the system will have acquired sufficient data to provide feedback on the user's energy usage (UC#7). A division can be made into feedback regarding energy efficiency and interaction.

Feedback regarding energy management can for example consist out of the following aggregations:

- Overview of used/produced kWh on a 15 minute or hourly basis for a period of one selected day
- Overview of used/produced kWh on a daily basis for one week or month
- Overview of weekly energy usage/production
- Overview of monthly energy usage/production
- Overview of yearly energy usage/production
- Subdivision of above overviews based on device specific measurements, if available.
- Comparison with externally acquired reference

---

[4] The option to read relevant privacy information is under debate.

Besides energy usage feedback, the system will also provide feedback regarding e-balance specific features. An analysis of the energy usage can result in advice about the settings chosen in 3.1.2. It will indicate how much money can be saved or what the benefits for society have been or would have been if another option is chosen. This way the user is assisted in making a better decision on how to use the e-balance system. Also, the system will indicate how well the user succeeded in helping system performance. Statistical data from the balancing methods can be presented for example. Also, the amount of money earned or missed by the current behaviour is indicated.

3.2 Energy balancing

The actual energy balancing performed by the e-balance system affects all stakeholders. Although it is one and the same system, the stakeholder experience and interests will differ.

3.2.1 End-user / consumer

The end-user of the e-balance system will have a CMU to predict, monitor and control their energy usage and or production. The CMU will gather all desired energy usage of Intelligent Energy Devices (IEDs) in the shape of power profiles (UC#9). An example of an IED can be a Smart washing machine which will communicate the expected power demand, based on the chosen washing program and specified end-time for the program to be completed. Also, regular appliances can be made smart by adding a smart plug in between the device and the power socket. This plug will act as negotiation device with the CMU (UC10). It is important to realise that a PV installation and energy storage devices can also be made intelligent.

Subsequently, the power profiles are combined with a prediction of the energy usage of all the other devices connected to the local installation. The resulting aggregated profile will be communicated to the DSO. This will be repeated every 15 minutes; sending out the predicted aggregated power profile for the next 24 hours.

The DSO may respond with a general request to reduce or increase the energy exchange with the grid in either direction (usage or feed-in) for each of the 15 minute intervals. The CMU will negotiate with the IEDs to determine to which extent it is possible to comply with the general DSO request. A measure is determined by the CMU that indicates how well it can assist the DSO. This single number is communicated back to the DSO, which will then inform the CMU whether the newly negotiated power profile should be followed or the originally sent profile.

3.2.2 DSO

The DSO will provide and maintain the e-balance infrastructure. It will facilitate the controlled balancing of energy, provide information and access to the energy market and assist all stakeholders.

In the low voltage grid, the most important component of the e-balance infrastructure will be the Low Voltage Grid Management Unit (LV-GMU). The LV-GMU will request every connected CMU to send out a power profile with a 15 minute interval and covering a total timespan of 24 hours. It is likely that not every connection to the low voltage grid will be equipped with a CMU. Hence, the LV-GMU will have to make a prediction of the energy exchange at these points of connection. The predictions and communicated CMU power profiles are summed to form a “neighbourhood profile”. This profile represents the unadjusted expected power usage for the next 24 hours.

The newly formed neighbourhood profile will be compared with a pre-programmed “desired profile”. This profile represents a default setting at first and can for example be a completely flat profile. The absolute value of this profile is subject to research. The desired profile will be influenced by local grid limitations and requests from other management units. During or after the negotiation phase, the LV-GMU will perform a technical “sanity check” by using the supplied profile as input for an electrical *load flow*. This is a calculation that will show whether grid components will be overloaded and grid voltages remain within grid code limits.

The result of the comparison will be a power profile, indicating at which times there will be an energy shortage or surplus and how large this will be. The CMUs will respond with a single number how well they are capable of assisting in solving the shortage or consuming the surplus. The LV-GMU will rank these responses and select the CMUs that together can reduce the difference profile the most efficient.

All remaining difference profiles are communicated by a group of LV-GMUs upwards to the Medium Voltage Grid Management Unit (MV-GMU). The MV-GMU will go through a similar process as described above. On the one hand, the energy exchange of medium voltage connections without a management unit will be predicted and this prediction is combined with the difference profiles acquired from the LV-GMUs. An additional iterative negotiation round is started, during which it is determined whether a LV-GMU can solve the remaining difference of other LV-GMUs. This is done by adjusting the LV-GMU's "desired profile" to the difference profile sent out by the MV-GMU.

Any remaining differences after these negotiations will be communicated upwards to the Top Level Grid Management Unit (TL-GMU). This TL-GMU will balance amongst MV-GMUs and typically also with large centralised power plants and the grid connections with neighbouring regions (interconnectors).

It is important to note that conceptually speaking, the centralised power plants will be reduced to an imbalance functionality and that the transport grid will only be used when Distributed Energy Resources (DER) are insufficient to deliver the desired power in a region. In practise, with the currently low amounts of DER in most regions and low flexibility of loads and generators, centralised power plants will remain to have a peak and base load functionality.

3.2.3 Energy supplier / Aggregator / Balance Responsible Parties

The view of the energy supplier, aggregator or balance responsible party roles on the e-balance system greatly depend on the chosen market model and regulatory framework. All these roles are depending on political and social decisions, resulting in the market conditions applicable. In this paragraph several options are described in case a BRP role is present in the market.

Currently, the (Dutch) energy market uses the concept of "Balance Responsible Parties" (BRPs). Typically, a large energy producer is a BRP. It is thus their responsibility that enough power is produced or imported to balance power demand. Currently, the demand of most of the customers is predicted by using knowledge of anonymised historical data, combined with statistics. Deviations to this prediction will cause an imbalance on the energy grid. This imbalance is solved technically under the control of the TSO. Afterwards, in a process called reconciliation, the measured energy usage is compared with the original planning of the accompanying BRPs. The BRP responsible for the imbalance will pay the associated imbalance price, which is typically much higher than longer term trading prices.

It is thus in the interest of the BRPs to know accurately what amount of energy their customers are going to exchange with the grid, in order to reduce the amount of energy that needs to be bought on the imbalance market.

Currently, not many control possibilities exist for BRPs to influence the consumer behaviour with respect to energy usage or production. The facilities of the e-balance system will change this. Several routes for influencing the customer's energy exchange can be envisioned. The energy supplier or aggregator can offer flexibility at their customers towards BRPs as a service.

As a different approach, in case a BRP has a monopoly in a certain region, the "desired profile" of the MV-GMU and LV-GMU can be adjusted to get the desired effect of a balanced portfolio. This will however not be the case in a liberalised energy market. Hence, it is more likely that the BRP will have some control over the degrees of freedom a CMU has to comply with the LV-GMU's request to aid in balancing. In other words, the BRP might want customers to reduce energy consumption or increase production in order to compensate for the lack of production elsewhere, thus forcing a better energy availability elsewhere. The customer's CMU will in such a case not aid the DSO by complying with the LV-GMU's request, but instead or additionally comply to the BRP's request. As such, the BRP and DSO will both provide incentives to influence the behaviour of the customer, but not necessarily the same.

3.4 Neighbourhood monitoring

Inherent to a demand side management system like e-balance, is the increase in information regarding the (expected) power flows on the Medium Voltage (MV) and Low Voltage (LV) grids. This information can be aggregated to aid several stakeholders. This section describes some of the uses of this data for different stakeholders.

3.4.1 DSO

The most obvious use of energy and power flow data is by the DSO. The DSO will have a detailed overview of the loading of every grid component (UC#13). This enables the DSO to build up a detailed historical overview, to facilitate future grid planning and operational activities (UC#15, UC#17, UC#27, UC#28). For example, a more reliable lifetime analysis (aging of components) can be performed and possible congestion can be predicted based on much more accurate data This also enables the prevention of faults caused by overloading or too high voltages (UC#24).

By knowing the power flows more accurately, energy losses can be determined with greater certainty, allowing for better grid optimisation (UC#21). A detailed analysis of DER feed-in (UC#14) gives the possibility to account for future weather variations, to be sure that possible grid congestion does not remain hidden.

The addition of sensors and smarter use of data will enable faster detection of faults and fraud. This will enable the DSO to reduce the amount of time customers have to spend without energy in case of a fault (UC#22, UC#23, UC#29, UC#30). Also, detection of possible fraud occurrences in the neighbourhood households will reduce the risk of higher costs for society related to the use of electrical energy. By using the right algorithms to compare measurements from the household smart meters and from sensors placed in the grid (UC20), discrepancies caused by fraud and faulty administration can be detected.

3.4.2 Regulator

In a liberalised market, the energy regulator needs objective measurements to determine how well a DSO is performing. By having access to more detailed Quality of Supply (QoS) information (UC#18) and the amount of energy losses (UC#21), some of the most important technical criteria for judging the performance of a DSO are provided. Due to its hierarchical architecture, the e-balance system can retrieve and aggregate the QoS information from every layer in the grid.

3.4.3 Regional and local authorities and social housing associations

Insight in (anonymised) local energy usage, provides authorities or housing associations insight in the energy efficiency of the region or assets under their control. This enables them to make informed decisions on where to invest in energy saving measures, such as renovation and isolation of buildings.

3.4.4 Commercial parties

(Anonymised) energy usage and production data, but also the amount of CMU penetration can give insight into more directed marketing campaigns.

3.5 Data handling

According to European Directives (95/46/EC and 2002/58/EC), any information from customers must be protected and anonymised from the moment the data leaves their domain. This requires that the information management systems handling customers' data must implement measures to control and hide data that allows locating or capturing the users' behaviour and privacy. However, according to the project approach, only basic information needs to be processed to balance the energy grid. Data will thus only be used for the purpose it is shared/supplied for and deleted when this purpose is fulfilled.

Data aggregations will only be made available as open data when no direct trace back to individuals can be made.

Measures are taken to ensure data is only supplied to authorised stakeholders by means of data labelling and encryption methods.

3.6 Medium Voltage

During a fault in the electricity grid, customers of the grid operator will experience a temporary lack of voltage and thus energy supply. The regulator uses the total amount of outage minutes in a year as one of the criteria to evaluate the performance of the grid operator.

Typically, a Medium Voltage (MV) grid is built in a mazed configuration, meaning that several circular connection topologies are present. However, the grid is operated in a radial fashion, which means that energy is supplied only via a single route to a secondary substation.

The number of outage minutes can be reduced by shortening the time that is needed to restore the energy supply to as much connections as possible. To accomplish this, several techniques can be implemented. Within the e-balance project, the presence of several levels of management units will make it easier to identify the location of a fault. Two different approaches are considered.

1. Augmenting the management units with remotely operable switches and sensors will result in the possibility of quick isolation of a fault, resulting in short outage times.
2. By utilising the local production and a grid-frequency control facility, it is possible to operate a secondary substation in “islanding mode”. Providing a stable energy supply, without a connection to the MV grid. The balancing functionality of the e-balance system is expected to reduce the capabilities and dimensions of the grid-frequency control facility. Furthermore, by combining several adjacent secondary substations, the amount of possible flexibility will increase, influencing the needed fast response control capabilities (UC#11).

4 Research questions

The partners expect to have the following questions answered by the end of the project, based on the results gathered from the demonstrators.

Alliander:

- Which CMU strategy is favoured by customers?
- Which CMU strategy works best autonomously?
- What data rates are required for the system to function?
- What kind of control power and energy reserve do I need in a microgrid in case DSM is available via the e-balance methodology?
- How well do simulations and practise match?
- How well does the prediction of load and generation match reality?
- What is the effect of balancing on the lifetime of transformers according to IEC 60076-7?
- What is the customer's view on DSM?
- How well does a central control of PV inverters perform, with the aggregator role in mind?
- Will the voltage quality improve with the balancing system active?

IHP:

- How well does the proposed security and privacy solution work, what is the overhead, what could be improved?
- What does the actual communication look like, what is the required amount of data to be exchanged for managing the system, what is the benefit of the hierarchical architecture and the fractal-like approach?

University of Twente:

- How well do our balancing algorithms work in the Bronsbergen field test?
- What is the influence of balancing on the voltages / VUF (Voltage Unbalance Factor) at the end of feeder?
- How much flexibility are users willing to give to the system?
- How much flexibility can the e-balance system use in Bronsbergen?
- To what extent can simulations be used to predict what happens in the demonstrator?
- Are the network models accurate?
- Is it possible to use less accurate predictions and still achieve a good performance?

CEMOSA:

- How much additional energy consumption constitutes the e-balance technology at household level?
- Do users find interesting using the e-balance application?
- Do grid operators (DSO, energy supplier, aggregator…) think e-balance system improves their services?

University of Málaga:

- Is the user willing to use the system (how much degree of interaction is reasonable for the user)?
- Is the system feasible in terms of usability, ease of use? What things can be improved based on user feedback?

INOV:

- What is the performance of sensor mesh network solutions, using the ISM 868 MHz band and IoT protocols, for measuring quality of supply, detecting fraud detection and fault location, determining losses and implementing fault prevention?
- Compare the results of the e-balance solution with other solutions that DSOs are implementing in the grid and evaluate possible synergies.

EDP:

- How do the benefits of e-balance, from the DSO perspective (grid optimisation, loss reduction, better quality of service), compare with the cost of sensor and ICT dissemination?
- What are the maintenance requirements of ICT, sensors and other equipment to be installed along LV and MV networks?
- How can the DSO justify those investments (capex) and also the extra maintenance costs (opex), so that they can be accepted by the regulator?
- How to guarantee that the configuration of MV and LV networks and also the phase of prosumers are permanently updated in real-time to support the execution of the algorithms?
- What main changes in regulation can be suggested to the regulator in conclusion of the demonstration of the benefits of e-balance to the system?
- What are the most effective ways of influencing prosumers in being flexible? And which of them could be tolerated by the regulator?

EFACEC:

- How will e-balance concept impact on the Quality of Service and on the Power Quality KPIs?
- At what extent, thinking globally and acting locally will be aligned with the e-balance implementation, as it is being designed, implemented and deployed according to a fractal paradigm?
- How do balancing and monitoring algorithms go along together, facing mutual grid status and circumstances, towards flexibility, grid operation and quality of service?
- At what extent (not only technical, but also economic) LV grids monitoring will become cost effective? What added value will DSO such as Alliander and EDP achieve?
- What will be the social impact of e-balance?
- How people (all human stakeholders) will drive the outcome of e-balance? What could they expect from e-balance?
- And after e-balance, what could be the next step?

5 E-balance roll-out project details

5.1 Portugal, Batalha

The main focus of the Batalha demonstrator will be on new functionalities from the point of view of the DSO:

- Increasing Quality of Service (QoS)
- Impact analysis of QoS improvement
- Fault and losses analysis
- Integration and evaluation of micro-generation
- Public lighting resilience

5.1.1 Implementation of e-balance at the Batalha demonstrator

The following 12 Use Cases will be demonstrated at the Batalha demonstrator.

Use case #	Title
	Neighbourhood monitoring
13	Neighbourhood power flows
14	DER power flows (restated)
15	Optimized power flow
17	Validation of optimized solutions (restated)
18	Quality of supply measurement
20	Fraud detection
21	Losses calculation
22	LV fault detection and location
23	Public lighting faults and fused luminaires detection and location (restated)
24	Fault prevention (LV)
	Smart Medium Voltage Grid
29	MV fault detection and location
30	Automatic grid service restoration - self-healing (MV)

Table 2: Use Cases assigned to the Batalha demonstrator

5.1.2 Technical site additions by the e-balance project

Several components will be added to the demonstrator by the e-balance project, compared to the description provided in chapter 2.1. Within brackets, the main responsible consortium partner is indicated.

- LV-GMU (Efacec)

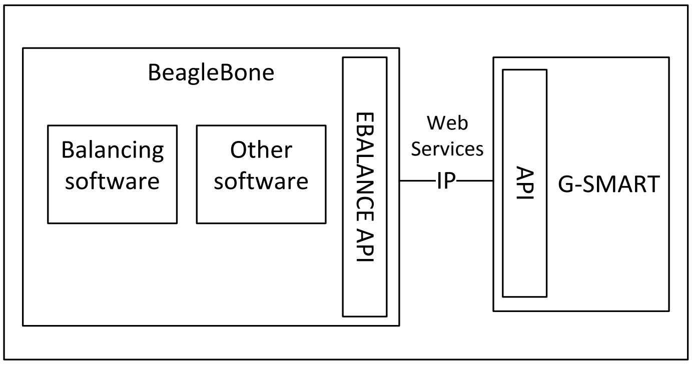

Figure 10: Efacec's "G-smart" hardware solution to be extended with additional to be developed software on BeagleBone hardware for e-balance functionality.

- MV-GMU (Efacec) (integration within the São Jorge primary substation control systems, located in Batalha)
- DER-MU (INOV)
- LV sensors (INOV)

5.1.3 System validation

The e-balance system will need to be tested and monitored on a technical and conceptual level. The technical level involves the correct operation of hardware, software and telecommunication. The conceptual validation concerns the system as a whole. This section describes this validation for the Batalha demonstrator based on the Use Cases presented in Table 2.

5.1.3.1 UC #13: Neighbourhood power flows

Objective: The main goal is to get a macro view of power flows along the feeders, based on telemetry, and using state estimation algorithms to mitigate the impact of telemetry inconsistencies and unknown values. Aggregated Power Flows are provided, based on telemetry and on State Estimation.

Description: The Neighbourhood Power Flows (NPF) module provides a synchronous and accurate characterization of the LV grid operation state, in order to identify potential problems occurring in the LV grid (e.g. voltage limit violation, congestion). It ensures a synchronous snapshot of the LV grid conditions, able to deal with the distinct characteristics of LV grids, namely:

1. LV grids are usually operated under unbalanced conditions.
2. LV grids are usually operated with radial topology.
3. LV grids have usually a high number of nodes when compared to the number of measurement devices.
4. Insufficient data for LV grid modelling.

The state estimation algorithm determines the grid state based on real time measurements provided by LV sensors and by householder smart meters. It also uses other relevant information from historic and forecasted load and generation data. In order to ensure system observability, the module generates a set of pseudo-measurements. Additionally, the module performs also without depending on LV grid modelling or depending on real-time and pseudo measurements available.

Architecture components involved in the demonstrator

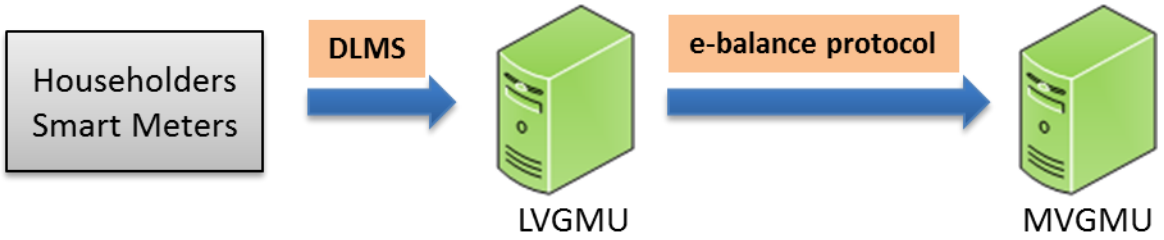

Figure 11: Use Case #13: involved architecture components at Batalha demonstrator

The involved architecture components are: LV–GMU, LV grid sensors and Smart Meters, as visualised in Figure 11.

The LV sensors will measure the power demand and other grid measurements in each phase and will transmit those measurements to the LV-GMU. Where applicable, smart meters will also measure the power exchange at the connection with the LV grid. LV grid sensors provide real time measurement data. The algorithm that combines real time measurements with forecasted data, providing the NPF outcome, performs in the LV-GMU.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Neighbourhood LV feeders topology setup.	The configured topology is turned into active mode.	Internal to the LV-GMU		Topology startup indication (ok, failure) at LVGMU.
2	Alarm of current or voltage threshold detected in the sensors placed along the LV grid segments.	When the current is above a threshold (independently of its severity) or the voltage is below or above a threshold (independently of its severity), an alarm message is originated.	Spontaneous current or voltage alarm events from LV sensor to LV-GMU	event	LV-GMU displays the received alarm.
3	Periodic report of current or voltage measurements from the sensors placed along the LV grid segments.	The sensors placed in the LV feeder periodically transmit the current and voltage measurements to the LV-GMU.	Sensor to the LV-GMU, upon request	Periodic read	LV-GMU displays the received measurements.
4	The algorithm forecasts load demand and generation values at each node, by using historical data, providing pseudo-measurements.	An algorithm running in the LV-GMU, performs load and generation forecasts, by using historical data. Pseudo-measurements populate the internal database for NPF use.	Internal to the LV-GMU		LV-GMU displays the forecasted values.
5	The algorithm combines the forecasted pseudo-measurements with the former real time measurements.	The algorithm running in the LV-GMU combines all data, while providing an accurate LV grid segments observability.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node.

Table 3: Events and Actions for UC #13

Test procedures in the demonstrator

1. Select a particular feeder.
2. Gather and evaluate all real time measurements from LV grid sensors.
3. Compute and evaluate all forecasted data from smart meters, including from DER assets.
4. The LV-GMU combines all available data, providing NPF outcome.
5. Assessment of the NPF outcome under the real conditions.
6. Assessment of the NPF details related to the DER assets.

5.1.3.2 UC #14: Distributed Energy Resources (DER) power flows

Objective: The main goal is to get details of the aggregated Power Flows, specifically considering DER and load assets. This Use Case uses the outcome of Use Case #13.

Description: The outcome of the Neighbourhood Power Flows (NPF) module is used so that a more detailed LV grid observability is provided, comprising the role of DER assets, comprising renewable generation, storage and flexible or conventional loads.

The state estimation algorithm – described for Use Case # 13 – details the role of DER assets, while describing how they impact on the power flow values within the LV grid segments that constitute feeders.

Architecture components involved in the demonstrator

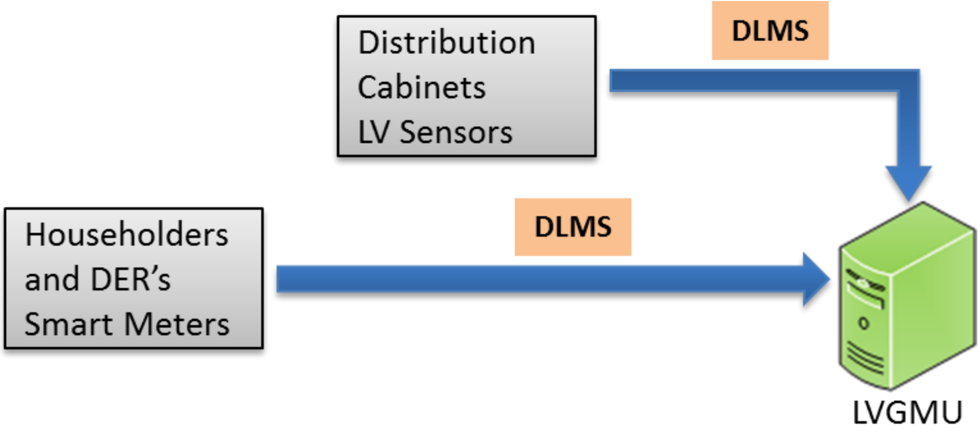

Figure 12: Use Case #14: involved architecture components at Batalha demonstrator

The involved architecture components are: LV–GMU, LV grid sensors and Smart Meters as visualised in Figure 12.

Smart meters are placed in the LV feeder, comprising also DER assets. They will measure the power demand and other grid measurements in each phase and will transmit those measurements to the LV-GMU. LV grid sensors provide real time measurement data. The algorithm that combines real time measurements with forecasted data, providing the NPF outcome, runs in the LV-GMU.

Test procedures in the demonstrator

1. Select a particular feeder.
2. Gather and evaluate all real time measurements from LV grid sensors.
3. Compute and evaluate all forecasted data from smart meters.
4. The LV-GMU combines all available data, providing NPF outcome.
5. Assessment of the NPF outcome under the real conditions.

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1 (as in UC # 13)	Neighbourhood LV feeders topology setup	The configured topology is turned into active mode.	Internal to the LV-GMU		Topology startup indication (ok, failure) at LVGMU.
2 (as in UC # 13)	Alarm of current or voltage threshold detected in the sensors placed along the LV grid segments.	When the current is above a threshold (independently of its severity) or the voltage is below or above a threshold (independently of its severity), an alarm message is originated.	Spontaneous current or voltage alarm events from LV sensor to LV-GMU	event	LV-GMU displays the received alarm.
3 (as in UC # 13)	Periodic report of current or voltage measurements from the sensors placed along the LV grid segments.	The sensors placed in the LV feeder periodically transmit the current and voltage measurements to the LV-GMU.	Sensor to the LV-GMU, upon request	Periodic read	LV-GMU displays the received measurements.
4 (as in UC # 13)	The algorithm forecasts load demand and generation values at each node, by using historical data, providing pseudo-measurements.	An algorithm running in the LV-GMU, performs load and generation forecasts, by using historical data. Pseudo-measurements populate the internal database for NPF use.	Internal to the LV-GMU		LV-GMU displays the forecasted values.
5 (as in UC # 13)	The algorithm combines the forecasted pseudo-measurements with the former real time measurements.	The algorithm running in the LV-GMU combines all data, while providing an accurate LV grid segments observability.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node.
6	The algorithm details each of the aggregated power flows, coping with all DER assets within the LV grid segments that comprise the feeders	The algorithm running in the LV-GMU provides an accurate LV grid segments observability, comprising all DER assets.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node, also comprising the details for all DER assets.

Table 4: Events and Actions for UC #14

5.1.3.3 UC #15: Optimized power flow

Objective: The main goal is to propose optimized MV grid topologies aiming at minimizing losses while keeping technical conditions of the grid within safety and operational limits, which enables the active integration of Distributed Energy Resources (DER).

Description: The e-balance Optimized Power Flow (OPF) module is a core grid control and monitoring application and its main objective is to determine the optimal MV grid topology, which minimizes distribution network operation costs while minimizing the sum of active power not supplied. The OPF also provides the optimal states for transformers and capacitor bank taps – as control order suggestions – and the coordination with DER units, so that other applications could drive the respective response by primary substation transformers and capacitor banks.

The results obtained by this module must comply with operational constraints such as equipment operating limits, system security limits and radial operation of the network.

The OPF calculations can be integrated with different modes of operation namely:

- Preventive / advisory mode
    - Improving the efficiency of MV operation by minimizing the active power losses of the system or avoiding possible congestion or voltage problems
- Corrective mode
    - Dealing with the effective occurrence of voltage violations, feeders' congestion, excessive active power losses, faults, thus suggesting remedy actions to overcome the grid incidents).

Architecture components involved in the demonstrator

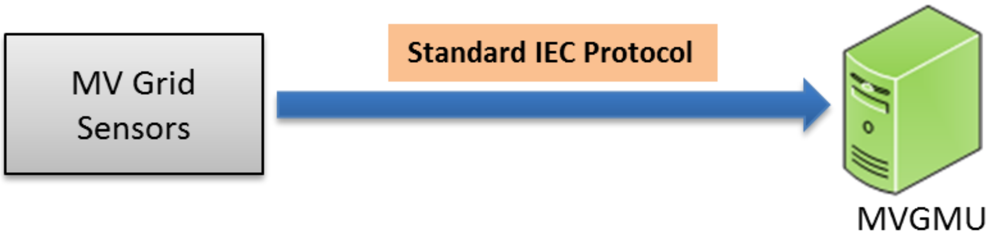

Figure 13: Use Case #15: involved architecture components at Batalha demonstrator

The involved architecture components are: MVGMU and MV grid sensors as visualised in Figure 13.

The deployment of remotely controlled reconfiguration devices in Medium Voltage (MV) distribution grids along with increased network monitoring equipment enables the implementation of new optimal network applications, aiming at improving the efficiency and reliability of distribution systems and minimizing operating costs.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	MV losses calculation by the power flow application.	The application processes data from MV sensing devices and determines energy losses within energy grid assets.	MV grid sensors data to the MV-GMU	Read, upon request or event as an alarm	MV grid losses are presented at the MVGMU GUI.
2	Proposal of a new grid topology for improvement.	The application assesses the grid condition and proposes switching actions for grid topology improvement, coping with grid safety and operational criteria.	Internal to the MVGMU		MVGMU displays the proposed switching actions for grid topology improvement; This switching actions need to be validated by a duly user – out of the scope of this Use Case.
3	Once one or several of the following grid incidents occur (voltage violations, feeders' congestion, excessive active power losses, faults), the application assesses possible remedy actions by proposing new topology arrangements for grid improvement.	The application detects grid incidents and proposes remedy switching actions for grid topology recovery from the identified incidents, coping with grid safety and operational criteria.	Internal to the MVGMU		MVGMU displays the proposed remedy switching actions for grid topology recovery; This switching actions need to be validated by a duly user – out of the scope of this Use Case.

Table 5: Events and Actions for UC #15

Test procedures in the demonstrator

1. Select a set of several MV feeders, able to be reconfigured (remotely or manually).
2. Gather and evaluate all real time measurements from MV grid sensors.
3. Compute and evaluate the losses, while assessing multiple topology options for improvement.
4. Assess grid incidents, while assessing multiple topology options for recovery from incidents.
5. When applicable, the MVGMU presents a list of candidate improving/remedy switching action, so that they could be assessed by a duly user, aiming at improving the grid.

5.1.3.4 UC #17: Validation of optimized solutions

Objective: The main goal is to validate in a study environment all proposed grid topologies and generation set-points, aiming at being applied in the real world. This Use Case takes into consideration the outcome of Use Cases #15 and 16. Since Use Case #16 will not be demonstrated, the objective of Use Case #17 will be restricted and will cope only with the validation in a study environment of all proposed grid topologies, aiming at being applied in the real world.

Description: The e-balance's Validation of Optimized Solutions (VOS) module is responsible for implementing and validating the optimal reconfiguration solution for the MV network determined by the OPF module. The outcome of Use Case #15 corresponds to the output of the OPF module, which finds the best topology which minimizes the active power losses considering the actual state of the distribution network under study, as well as suggesting transformer and capacitor bank tap changing control orders.

The solution found will have to comply with the operation constraints of the distribution network, so that the solution found is always feasible.

The VOS module is responsible for determining an automated reconfiguration sequence, ensuring the security of the distribution network during the sequence steps.

Architecture components involved in the demonstrator

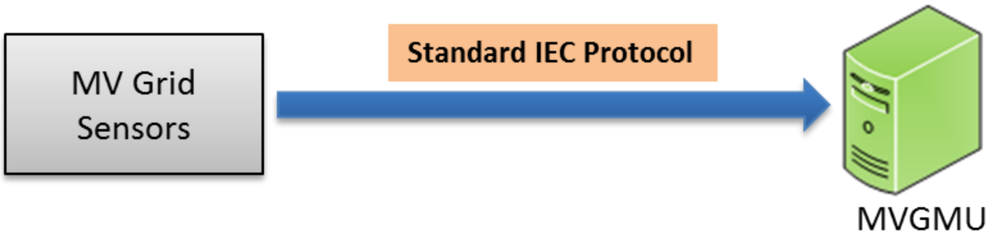

Figure 14 Use Case #17: involved architecture components at Batalha demonstrator

The involved architecture component are: MVGMU and MV grid sensors as visualised in Figure 14.

As a result of the preliminary proposal of new optimal network topologies aiming at improving the efficiency and reliability of the MV distribution grid, performed by the MVGMU's OPF module, a duly user will be able to use MVGMU's VOS module to validate those proposals while defining the requested switching orders, coping with grid security and operational criteria (as a result of real time data collected from MV grid sensors), thus implementing or correcting the suggested network topology.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	The module processes the optimal MV grid topology proposal.	The application processes topology data in the form of an optimal MV grid topology (switching actions), using the outcome of the OPF module.	Internal to the MVGMU		
2	The application assesses the proposed mode.	The module checks whether the proposal refers to preventive / advisory mode or to corrective mode.	Internal to the MVGMU		MVGMU displays the proposed mode, namely if the proposal aims at anticipating any potential grid incidents, or if it aims at correcting any identified grid constraints impacting QoS.
3	Validation of the proposed topology solution by the OPF module.	The module checks if the proposed topology solution (switching actions) by the OPF module is valid for losses minimization, considering the current grid operational conditions.	MV sensors provide data to the MVGMU; Internal to the MVGMU.	Read, upon request or event as an alarm	MVGMU displays the result of the validation process.
4	Validation of the grid normal operation.	The module checks if there are no pending faults yet to be located and isolated.	Internal to the MVGMU		MVGMU displays the result of the validation process.
5	Definition of the reconfiguration sequence.	Definition of the switching order reconfiguration sequence, considering the nature of the switching equipment, their ability for remote control, their grid placement and their typical use.	Internal to the MVGMU		MVGMU displays the reconfiguration sequence, by presenting the list of switching orders.

Table 6: Events and Actions for UC #17

Test procedures in the demonstrator

1. Select a set of several MV feeders, able to be reconfigured (remotely or manually).
2. Gather and evaluate all real time measurements from MV grid sensors.
3. Compute and evaluate the losses, while assessing multiple topology proposals (options) for grid improvement.
4. Assess grid incidents, while assessing multiple topology options for recovery from incidents.
5. When applicable, the MVGMU presents a list of candidate improving/remedy switching orders, so that they could be assessed by a duly user, aiming at improving the grid performance.

5.1.3.5 UC #18: Quality of Supply Measurement

Objective: The e-balance management system processes information from neighbourhood households and determines the quality of service Key Performance Indicators (KPIs), according to the data retrieved from the smart meters.

Description:

This LV-GMU requires periodic data retrieval from smart meters aiming at measuring the technical quality of supply metrics. Based on this information the LV-GMU will analyze and calculate the defined KPI. Namely, the LV-GMU shall receive the information on the number and duration of supply interruptions of each customer and/or each feeder, allowing the calculation of service quality standards and corresponding service level agreements. The LV-GMU shall receive the information on defined service quality events, and perform the processing of this information for the purpose of reporting. The KPI for QoS and for QoE are aligned with regulatory and grid operator parameters. They may comprise: e.g QoS (MAIFI, CAIFI, SAIDI, etc.) and QoE (voltage limits violations).

Architecture components involved in the demonstrator

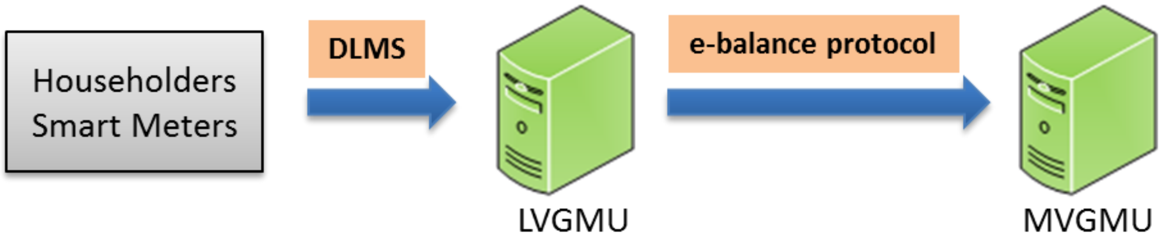

Figure 15: Use Case #18: involved architecture components at Batalha demonstrator

The involved architecture components are: MV-GMU, LV–GMU and Smart meters as visualised in Figure 15.

The Smart meters are located at each customer’s premises.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Read service quality data and voltage quantities	LV-GMU reads service quality data and voltage quantities from smart meters	Data from smart meters to LV-GMU, by exception or upon request	read, event	
2	Determining KPIs	LV-GMU calculates KPIs based on the retrieved service quality data and voltage quantities.	Internal to LV-GMU		LV-GMU shows KPIs in the GUI
3	MV-GMU notification	LV-GMU sends KPIs to MV-GMU	LV-GMU to MV-GMU	Periodic	MV-GMU shows KPIs in the GUI

Table 7: Events and Actions for UC #18

Test procedures in the demonstrator

1. LV-GMU reads energy quality related information from smart meters.
2. LV-GMU determines KPIs based on the received information from smart meters. Their values can be verified on the GUI.
3. LV-GMU sends KPIs to the MV-GMU. Their values can be verified on the GUI.

5.1.3.6 UC #20: Fraud Detection

Objective: Detection of fraud occurrences in the neighbourhood distribution grid.

Description: This Use Case receives periodical energy metering, with the adequate level of accuracy, from the householders' smart meters and also from smart meters placed at street/aerial distribution cabinets on selected feeders. Algorithms will compare aggregated energy values with the energy values measured at each street/aerial distribution cabinet and at the secondary substation LV bus-bar, thus estimating possible fraud occurrences in the neighbourhood distribution grid.

Architecture components involved in the demonstrator

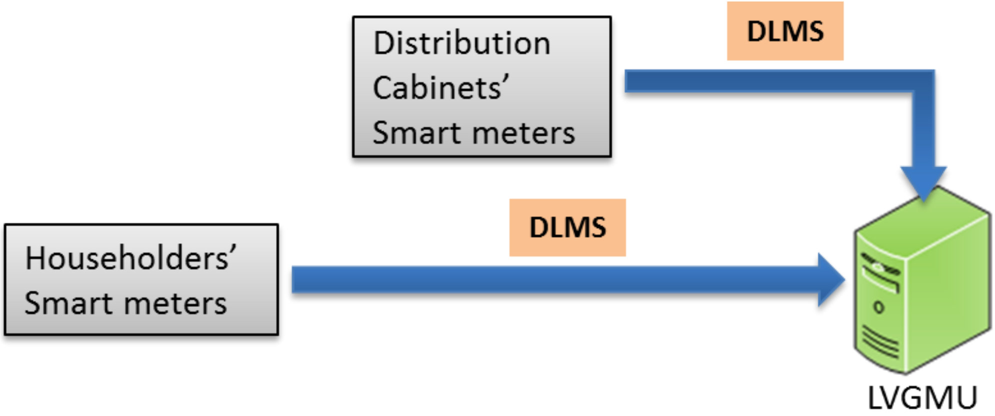

Figure 16: Use Case #20: involved architecture components at Batalha demonstrator

The involved architecture components are: LV–GMU and Smart Meters as visualised in Figure 16.

Smart Meters are placed in selected LV feeder distribution cabinets. They will measure the consumption of energy in each phase and will transmit energy metering data to the LV-GMU. Moreover, other Smart Meters are located at consumer premises (householders) and transmit energy metering data as well. The algorithm to detect frauds runs centrally at the LV-GMU.

Events and Actions:

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Energy metering from smart meters located in the feeder (householders and/or distribution cabinets).	LV-GMU periodically requests energy metering data from each smart meter.	Metering data from SM to LV-GMU, upon request	Read	LV-GMU displays the received metering data.
2	The algorithm determines the possible existence of energy consumption fraud in the feeder segment.	An algorithm running in the LV-GMU, based on the metering data received from householders' SMs and from street/aerial distribution cabinets' SM, determines a possible fraud in the energy consumption in the feeder.	Internal to the LV-GMU		LV-GMU displays the occurrence of frauds.

Table 8: Events and Actions for UC #20

Test procedures in the demonstrator

1. A set of SMs is selected for each feeder, comprising customers (householders) and distribution cabinets.
2. Establish the period of polling metering data from the SM.
3. Check if the energy consumption in the feeder matches the aggregated metering data from smart meters within the feeder.
4. Simulate a fraud in the feeder and check that it is detected by the LV-GMU.

5.1.3.7 UC #21: Losses calculation

Objective: Comparison of the theoretical and real energy losses in a feeder.

Description: In this Use Case the theoretical losses along a feeder will be estimated and the real losses in the same feeder are evaluated based on measurements made by sensors placed in the feeder.

Architecture components involved in the demonstrator

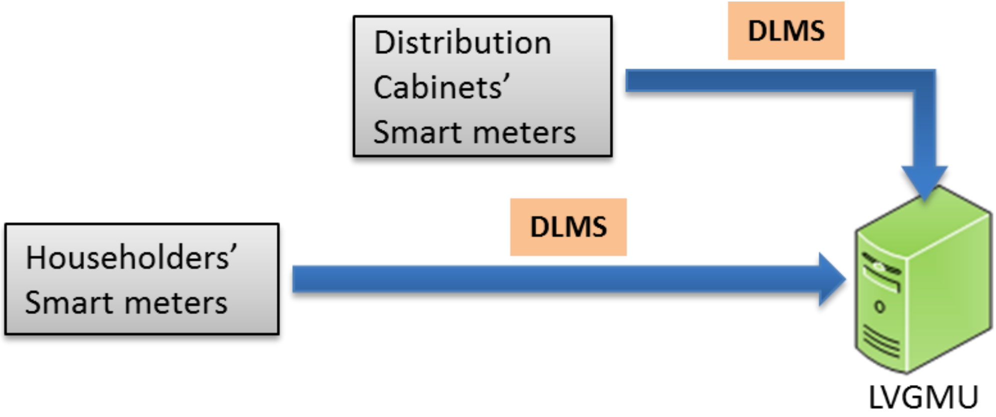

Figure 17: Use Case #21: involved architecture components at Batalha demonstrator

Smart meters are placed in the LV feeder and at the customers as visualised in Figure 17. They will measure the consumption of energy in each phase and will transmit the measurement to the LV-GMU. The algorithm that evaluates theoretical energy losses and compares with the real energy losses runs in the LV-GMU.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Energy measurement from sensors placed in the feeder.	The sensors placed in the feeder periodically transmit the energy measurement to the LV-GMU.	Sensor to the LV-GMU	Periodic	LV-GMU displays the received measurements.
2	Algorithm calculates losses based on the retrieved data.	An algorithm running in the LV-GMU, calculates the real energy losses based on the retrieved data.	Internal to the LV-GMU		LV-GMU displays the real energy losses.
3	A comparison is done between the theoretical and real energy losses.	The algorithm running in the LV-GMU does this comparison.	Internal to the LV-GMU		LV-GMU displays the comparison of theoretical and real energy losses.

Table 9: Events and Actions for UC #21

Test procedures in the demonstrator

1. Select a particular feeder.
2. Evaluate its theoretical energy losses.
3. Make periodic energy measurements from sensors.
4. The LV-GMU compares the theoretical with the real energy losses values.
5. The LV-GMU compares the theoretical with the real energy losses values.

5.1.3.8 UC #22: LV fault detection and location

Objective: Detection and awareness of faults in low voltage electrical distribution grids, followed by determination of their location.

Description: This Use Case requires the use of sensor devices (LV sensors to be deployed along the LV feeders and smart meters already deployed at householders), able to detect transient phenomena in the grid, while being able to detect fault events. As a result, those sensor devices (sensors) will send alarm events to the LV-GMU. This Use Case will identify the phase and feeder segment in which the fault occurred. By adding additional sensors along the LV feeders, the fault can be located with more accuracy.

Architecture components involved in the demonstrator

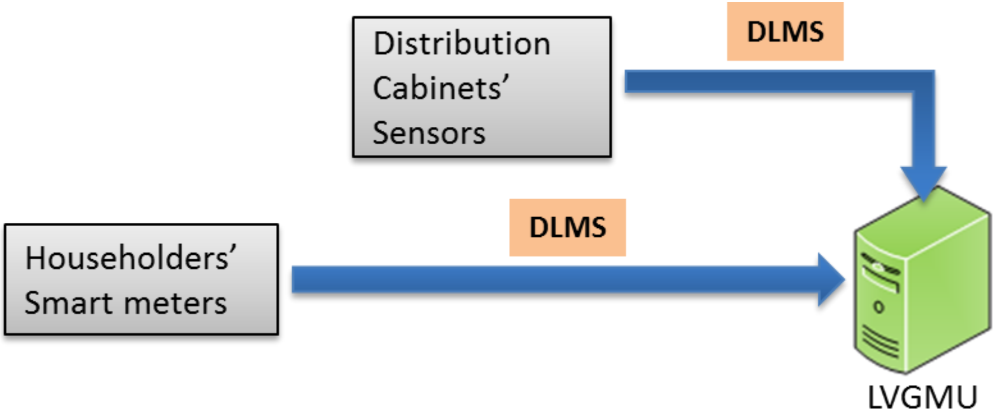

Figure 18: Use Case #22: involved architecture components at Batalha demonstrator

The involved architecture components are: LV –GMU, tri-phase sensors and Smart Meters as visualised in Figure 18.

The tri-phase sensors are placed in the LV feeder. They will measure the current and voltage in each phase and will originate an alarm when the thresholds for current or voltage are reached. The Smart Meters are located at consumer premises. Those communicating by RF MESH contribute to narrow the fault location algorithm, by issuing "last gasp" messages upon severe fault occurrences. Those communicating by PLC PRIME, will only keep on responding to poll requests by the LV-GMU, if they are placed in a healthy LV grid segment, meaning that those which do not respond to poll requests by the LV-GMU, are placed in a faulty LV grid segment. The algorithm to detect faults and their location runs centrally in the LV-GMU, using data from LV grid sensors, as well as using "last gasp" messages from RF MESH enabled Smart Meters, and also by polling PLC PRIME enabled Smart Meters.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Alarm of current or voltage threshold reached in the sensor.	When the current is above a fault limit threshold or the voltage is below a low voltage limit threshold, an alarm message is originated.	Spontaneous fault alarm event from LV sensor to LV-GMU	event	LV-GMU displays the received alarm.
2	Fault detection algorithm checks for additional fault alarm notifications.	The algorithm activates a timer to allow other sensors to report any alarm event, if applicable.	Internal to the LV-GMU		LV-GMU displays the received alarm.
3	Determining the persistence of the fault.	LV-GMU polls the most distant sensor in fault to check the continuation of the fault condition. If the sensor replies with its status, stating that the voltage and current measurements are normal, it means that the fault was transitory. If it doesn't, it means the fault is persistent.	Event data from sensor to LV-GMU, upon request	Read	
4	Determining the location of the potential faulty LV grid segments.	Based on the status and measurements retrieved from the sensors, the LV-GMU can determine the location of the fault, by assessing the faulty events versus its own LV grid topology representation, determining the downstream LV grid segments that might have contributed to the fault.	LV-GMU to sensor	Read	LV-GMU displays the location of the main faulty LV grid segments.
5	Determining the exact location of the faulty LV grid segments.	If the potential faulty LV grid segments comprise RF Mesh enabled Smart Meters, the LV-GMU checks for any "last gasp" messages reported by Smart Meters placed along all potential faulty LV grid segments, one segment at a time; those that have reported a "last gasp" message, state which specific faulty LV grid segment they belong to. Alternatively, if the potential faulty LV grid segments comprise PLC PRIME enabled Smart Meters, the LV-GMU polls the upstream Smart Meters placed along all potential faulty LV grid segments, one segment at a time; those that do not reply – within a certain timeframe or within a certain number of retries – state which specific faulty LV grid segment they belong to.	Internal to the LV-GMU.		Display the exact location of the LV grid faulty segment.
6	MV-GMU notification	LV-GMU notifies the MV-GMU about the location of the fault	LV-GMU to MV-GMU	Event	Display alarm notification and fault location.

Table 10: Events and Actions for UC #22

Test procedures in the demonstrator

1. A current alarm is simulated in a certain node. This can be done by lowering the threshold of the current alarm below the normal value so that a customer is not affected.
2. Check the detection and location of the fault through visualization of the algorithm steps and visualization of messages in the GUI of the LV-GMU.
3. A voltage alarm is simulated in a certain node. This can be done by raising the threshold of the voltage alarm below the normal value so that a customer is not affected.
4. Check the detection and location of the fault through visualization of the algorithm steps and visualization of messages in the GUI of the LV-GMU.
5. Simulate more than one current and voltage alarms simultaneously.
6. Simulate blown-up fuses, by removing them from the LV grid cabinets within a period less than 3 minutes, to avoid affecting the grid system operator KPIs.
7. Check the detection and location of the faults through visualization of the algorithm steps and visualization of messages in the GUI of the LV-GMU.

5.1.3.9 UC #23: Public lighting fault and fused luminaires detection and location

Objective: Detection and location of Public Lighting (PL) faults and of fused or faulty public luminaires.

Description: The occurrence of faults in public lighting segments is similar to those described in UC #22. Besides PL faults, this Use Case also addresses the detection and location of faulty or fused luminaires. It considers two different types of public lighting luminaire faults: i) Timetable mismatch, and ii) assessment of the possible occurrence of one or more light bulb (luminaire) blow up incidents, which may occur in different segments of the same public lighting feeder, thus detecting such incidents while locating the corresponding faults.

Architecture components involved in the demonstrator

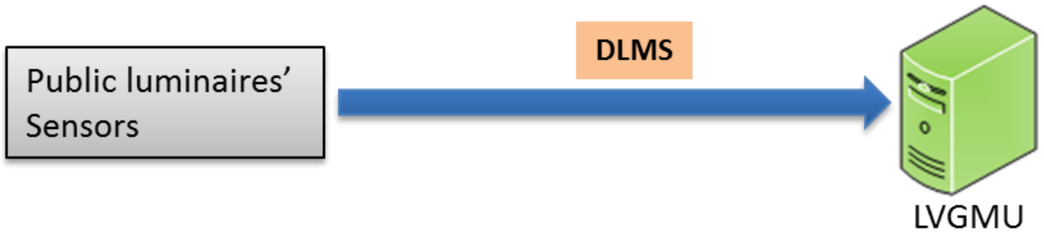

Figure 19: Use Case #23: involved architecture components at Batalha demonstrator

The involved architecture components are: LV –GMU, sensors and public luminaires as visualised in Figure 19.

The impedance of each segment is initially measured in order to calibrate the algorithm. The calibration process also comprises the topology notion of the PL feeder, namely by stating the number and type (impedance) of each luminaire, within each PL segment (a PL segment is comprised between sensor nodes or is the last segment after the last sensor node). The sensors are placed in the Public Lighting LV feeder to measure the current and voltage in the LV phase in which they are deployed. The algorithm is based on the measurement of the impedance observed at the location of the sensor within the PL feeder ($Z = V/I$), comparing it with the reference impedance, as well as with how it relates with the next measured impedance (in the last PL feeder sensor node no relation assessment is applicable).

The difference between the reference impedance and its relation between sensor nodes, against cyclically measures values and subsequent calculated impedances, allows the algorithm to detect and locate faulty luminaires in each PL segment, while estimating each specific faulty light bulb number.

Test procedures in the demonstrator

Faults in the PL segment

1. The same procedures as described for UC #22.

Blown up light bulbs detection and location

1. Test if the algorithm is activated only during the scheduled timeframe.
2. During the scheduled timeframe, the algorithm is calibrated based on voltage and current measured in each segment (sensor node), from which the reference impedance and their adjacent relation – when applicable – is calculated. The calibration process is performed with all luminaires on and in steady state operation mode, after luminaires warm up and without any low voltage limit violation detected by the PL sensors.
3. A test is performed, with all the public luminaires on (after the warm up process). Check the result in LV-GMU GUI, which must be ok.
4. Test with one luminary removed. Check the result in LV-GMU GUI, which must highlight an alarm, while detecting the faulty segment and estimating one faulty light bulb.
5. The procedure continues with the removal of the remaining luminaires, one by one, in different PL segments. The result must be highlighted if the form of alarms, while detecting the faulty segment and estimating the number of faulty light bulbs, step by step.

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	System PL feeder topology setup	The configured topology is turned into active mode. It comprises the number and type of light bulbs, comprising their nominal impedance, per observed PL segment.	Internal to the LV-GMU		Topology startup indication (ok, failure) at LVGMU.
2	System calibration by estimating the impedance observed from PL feeder nodes provided with sensors.	Measure the current and voltage through the sensors and calculate the reference impedance at each sensor node location.	LV sensor to LV-GMU, upon polling	Read	LV-GMU displays the received measurements, as well as all estimated node reference impedances.
3	Cyclically, measure the impedance at each PL feeder node provided with sensors.	Measure the current and voltage through the sensors and calculate the observed impedance at each sensor node location.	LV sensor to LV-GMU, upon polling	Read	LV-GMU displays the received measurements, as well as all observed node reference impedances.
4	Regarding each sensor node, compare the measured impedance with the calibrated measurements.	The algorithm will assess if there were any impedance changes, to detect the occurrence of at least one fused light bulb.	Internal to the LV-GMU		If applicable, LVGMU presents an alarm of “occurrence of at least one light bulb fused event”
5	If in step 4 it was detected an alarm event, then relate the impedance measured at each sensor node with the impedance measured at the next sensor node. The last sensor node needs no relation, as the drift is absolute.	The relation of impedances is evaluated at the LV-GMU and compared with the relation based on the calibrated impedances which correspond to the normal state. The PL segments with a non-standard relation will be alarmed.	Internal to the LV-GMU		LV-GMU displays measured and reference impedances of the feeder, as well as the impedance relations between sensor nodes.
6	As a result of the comparison determine the location and number of faulty luminaires.	LV-GMU locates the faulty segments and estimates the expected number of faulty light bulbs.	Internal to the LV-GMU		LV-GMU displays the alarmed PL segments, highlighting them as “predicted segments with faulty light bulbs”. The forecasted number of faulty light bulbs (luminaires) in each faulty segment is presented.

Table 11: Events and Actions for UC #23

5.1.3.10 UC #24: Fault prevention (LV)

Objective: Prevention of voltage limit violations based on voltage measurements of the LV distribution grid and control of the power injection by micro producers, as well as prevention of thermal limit violations on secondary substations' protective fuses and on street distribution cabinets' protective fuses.

Description:
Based on voltage measurements of the LV distribution grid sensors and smart meters, the LV-GMU detects voltage limit violations and sends set-point controls to the micro producers' DERMU, enabling voltage regulation.

The set-point control actions are calculated in the LV-GMU and sent to the smart-meters assigned to PV micro-generation assets. In this scope, the Smart meter acts as a gateway between the LV-GMU and the DERMU associated to the micro-generation asset, participating in a local droop control which also involves the PV inverter.

As final result, the LV-GMU will prevent the voltage limits violation in the LV distribution grid, providing a wider LV feeder perspective and control of PV micro-generation assets, coping with the random nature of demand and of renewable sources.

Concerning the prevention of thermal limit violations on secondary substations' protective fuses and on street distribution cabinets' protective fuses, all for both LV grid segments and public lighting segments, a reverse-time curve – describing each type of fuse behaviour regarding the current – will be used. Each sensor will alarm the LV-GMU upon any occurrence of current limit violations or of current limit warnings, according to each specific reverse curve.

The LV-GMU will highlight locally such occurrences and will be able to report them to other systems within its hierarchy upper levels, namely the MV-GMU. Besides providing useful data for computing the feeder performance KPIs (under another Use Case), the LV-GMU can participate in load curtailment, by responding automatically towards non-priority end users, explicitly curtailing specific consumers via each smart meter, coping with a predefined criteria.

Architecture components involved in the demonstrator

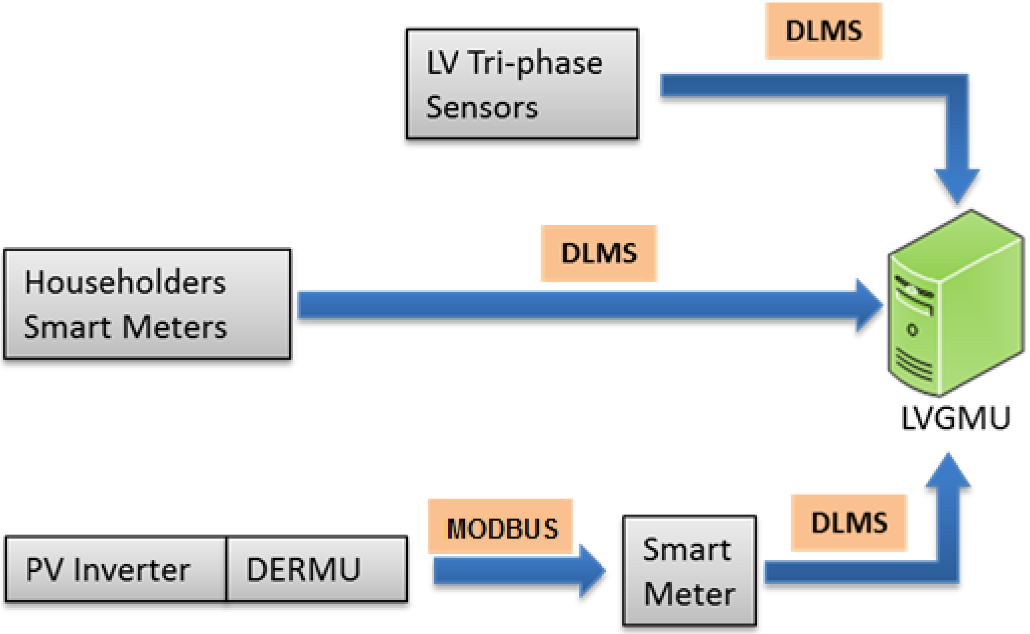

Figure 20: Use Case #24: involved architecture components at Batalha demonstrator

The involved architecture components are: LV-GMU, LV tri-phase sensors and smart meters, PV inverter and DERMU as visualised in Figure 20.

Tri-phase sensors are placed in the LV feeders. They will measure the current and voltage in each phase and will communicate the data to the respective LV-GMU upon reading request, as periodic reports or as alarm notifications (when some event threshold is exceeded). The Smart Meters are located in the customer premises and act as sensor and gateway (for controlling the PV inverters) devices as well. The LV FAN GW is the interface logic between the LV-GMU and the sensors. The LV-GMU runs an algorithm that monitors the voltage for each sensor and smart meter and calculates the set-point values to send to the micro producers in case of voltage limits violation.

The LV-GMU also runs an algorithm that monitors the current at each LV feeder and LV street distribution cabinet, while performing upstream notification in case of alarm. It also performs feeder specific load curtailment, either completely (at secondary substation level) or selectively (at feeder level – less selective – or at each householder – very selective).

The voltage measures and currents from LV sensors and voltages and power consumption from smart meters will be displayed in the LV-GMU.

Voltage limit violation test procedures in the demonstrator (LV)

1. A voltage limit violation is simulated in a certain sensor node. This can be done by changing the threshold alarms values below the normal value so that a customer is not affected.

2. Check the execution of voltage limit violation steps 2, 3, 4, 5, 6 and 7 for this Use Case.

3. Check that all voltage profiles returned to normal

4. Check that voltage values are displayed in the GUI.

Thermal limit violation test procedures in the demonstrator (LV)

1. A thermal/current limit violation is simulated in a certain sensor node. This can be done by changing the time-reverse curve settings at each node, so that a customer is not affected.

2. Check the execution of thermal limit violation steps 2, 3, 4 and 5 for this Use Case.

3. Check that current values are displayed in the GUI.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Normal LV-GMU operation	The LV-GMU reads voltage measurements from LV sensors and smart meters	LV sensor and smart meters to LV-GMU	read	The LV-GMU displays voltage measurements from LV sensors and smart meters in the GUI
2	LV-Sensor Alarm	LV-GMU receives a voltage limit violation alarm from LV Sensor	LV Sensor to LV-GMU	event	
3	Voltage monitoring	LV-GMU reads voltage from LV sensors and smart meters	LV sensor and smart meter to LV-GMU	Read, periodic	
4	Set-point triggering and calculation	Upon voltage violation or in the imminence of voltage violation, the LV-GMU calculates set-points over selected micro-producers aiming at solving locally the voltage violation			Alarm indication Set-points presentation
5	LV-GMU issues a set-point to each DERMU under control	LV-GMU sends a set-point to the DERMU to decrease or increase the injected power	LV-GMU to smart meter	Read	
6	Voltage monitoring	LV-GMU reads voltage from LV sensors and smart meters; The previous step may be repeated	LV sensor and smart meter to LV-GMU	Read, periodic	The LV-GMU displays voltage measurements from LV sensors and smart meters in the GUI
7	Local Voltage monitoring and Set-point calculation at DERMU	DERMU reads voltage from local sensor and calculates provisional set-point to prevent voltage violation; The previous step may be repeated	Local to DERMU	Read	DERMU displays local voltage measurements and set-points in the GUI

Table 12: Events and Actions for UC #24 – prevention of voltage limitations

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	Normal LV-GMU operation	The LV-GMU reads current measurements from LV sensors	LV sensor to LV-GMU	Read, periodic	The LV-GMU displays current measurements from LV sensors in the GUI
2	LV-Sensor Alarm	LV-GMU receives a thermal limit violation alarm from LV Sensor	LV Sensor to LV-GMU	Event	
3	Current / thermal limit monitoring	LV-GMU reads current and thermal limit violation alarms from LV sensors	LV sensor to LV-GMU	Read, periodic	
4	The LV-GMU performs automatic load curtailment, if possible, of non-priority clients	LV-GMU assesses the received alarms and current measures and decides if sends curtailment orders to selected smart meters, coping with the LV grid constraint.	Within LV-GMU LV-GMU to Smart Meters	Write	The list of controls is available at LV-GMU level for browsing. The Automatic function is active and displayed at the LV-GMU GUI.
5	Current / thermal limit monitoring	LV-GMU reads current and thermal limit violation alarms from LV sensors	LV sensor to LV-GMU	Read, periodic	The LV-GMU displays current measurements from LV sensors and the status of each curtailed / non curtailed customers in the GUI

Table 13: Events and Actions for UC #24 –prevention of thermal limits violation on protective fuses

5.1.3.11 UC #29: MV fault detection and location

Objective: The main objective of the MV Fault Detection and Location module is to monitor the MV network and proactively identify and locate MV faults. The module is incorporated at the MV-GMU, monitoring the primary substation MV panels and the respective switching and sensors installed downstream in MV feeders. When a fault occurs, the module is activated in order to locate and identify the faulted equipment.

Description: The e-balance's MV Fault Detection and Location (MVFDL) module is responsible for dealing with MV grid topology status and measurement data, comprising MV substation and feeders overcurrent protections with automatic reclosing strategies, as well as overhead reclosers, switches and sectionalizers deployed along the MV grid.

In the foreseen demonstrator, the MV grid is operated in radial mode, although a meshed topology with open tie-points is current practice.

The MVFDL module is responsible for detecting all kinds of MV grid faults (single or multiple phase faults, earth faults), while detecting the MV grid segment or identifying the faulted equipment where the faults have occurred.

Architecture components involved in the demonstrator

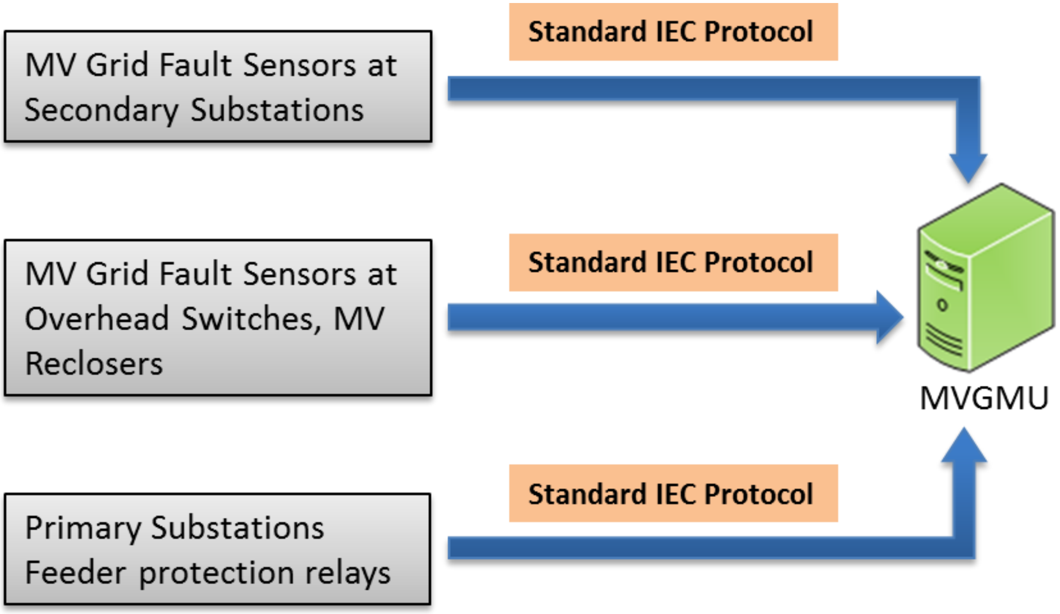

Figure 21: Use Case #29: involved architecture components at Batalha demonstrator

The involved architecture component is: MV-GMU, MV grid fault sensors coupled with *reclosers*, with overhead switches and *sectionalizers*, with the grid MV-side of secondary substations, as well as protection relays coupled to primary substation feeders' circuit breakers as visualised in Figure 21.

Fault sensor devices, e.g. protection relays and fault current sensors, are coupled with MV primary equipment, such as primary substation feeder circuit breakers, MV switches and *sectionalizers*, MV *reclosers* and the secondary substations grid MV-side. These fault sensor devices provide the needed data for the fault detection and location algorithm, which runs centrally in the MV-GMU.

Test procedures in the demonstrator

1. A fault current alarm is simulated in a certain device.
2. Check the detection and location of the fault through visualization of the algorithm steps and visualization of messages in the GUI of the MV-GMU.
3. Simulate more than one fault current alarms simultaneously.
4. Check the detection and location of the faults through visualization of the algorithm steps and visualization of messages in the GUI of the MV-GMU.

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	MV grid / feeders topology setup	The configured topology is turned into active mode.	Internal to the MV-GMU		Topology startup indication (ok, failure) at MV-GMU.
2	Detection of MV faults by fault sensors, *reclosers* placed along the MV grid segments or by primary substation protection relays.	Alarm of fault current is detected by fault sensors or *reclosers* placed along the MV grid segments or by protection relays placed at the primary substation circuit breakers.	Spontaneous fault current alarm events from MV fault sensors, from reclosers or from protection relays to MV-GMU	event	MV-GMU displays the received alarms.
3	Determining the persistence of the fault.	As there is protection coordination between grid equipment sensor/controllers and protection relays, the algorithm waits for a configurable timeout. If protective MV switchgear equipment (e.g. circuit breakers or *reclosers* have locked put), the fault current is stated as permanent.	Event data from MV fault sensors/reclosers to MV-GMU, upon request	Read	MV-GMU reports the occurrence of a transient fault or of a permanent fault, as well as their type
4	Combining topology status and fault data.	Topology assessment combined with the faulty data is performed; the objective is to locate the MV feeder faulty segment and/or the faulted equipment.	Internal to MV-GMU		
5	Fault location algorithm determines the faulty MV feeder segment.	Based on the retrieved data from the MV sensors, *reclosers* and protection relays, the algorithm can determine the exact location of the MV faulty segment.	Internal to MV-GMU		Display location of faults.
6 (optional, yet to be defined)	TL-GMU notification	MV-GMU notifies the TL-GMU about the location of the fault.	MV-GMU to TL-GMU	Event	Display alarm notification and fault location.

Table 14: Events and Actions for UC #29

5.1.3.12 UC #30: Automatic grid service restoration – self-healing (MV)

Objective: The main objective of the MV Fault Restoration – Self-healing (MV) module uses the identification of the MV topological area where a fault occurred (which is provided as a result of the MVFDL module – Use Case # 29) to automatically isolate this area, and then find alternative paths in order to restore service to grid segments not affected by the fault.

Description: The e-balance's MV Fault Restoration – Self-healing (MV) module performs a topological analysis in the faulted feeder in order to determine the minimum area limited by operable switches that fully encloses the faulted area. The MV-GMU runs autonomously in a remote primary substation, which implies that the operable switches to consider are those that are remote controlled and thus can automatically be operated by the system in order to isolate the fault.

Open switches also play their role in the process, as they – by their nature – isolate any fault, independently of being remote controlled or not.

Once the grid service restoration assessment – by a duly user – takes place, the module checks that all grid segments upstream the faulty area were properly reenergized, as a result of reclosing of involved primary substation feeder circuit breakers or MV reclosers. If not, the module will provide the new topology proposals for grid reconfiguration.

Downstream restoration consists in reconfiguring the MV grid so that pending segments, located downstream the isolated faulted area and thus not affected by it, could be fed by an alternative power source. Any load transfer to adjacent feeders will bear in mind the existence of thermal limits and other operational constraints such as operational voltage limit levels.

Once computed the isolation and the restoration actions, the module proposes its execution, where the isolation actions are executed first and the reconfiguration ones are executed subsequently. The MV-GMU may execute these actions in two different modes:

Manual – in this case the module generates a switching order that implements the computed reconfiguration sequence. This switching order is then validated and even changed by a duly user. Normally this step would be performed at TL-GMU level. For the purpose of the demonstrator, it will be performed locally at MV-GMU level.

Automatic – in this case the reconfiguration sequence will run automatically at the MV-GMU. This feature will not be demonstrated.

Architecture components involved in the demonstrator

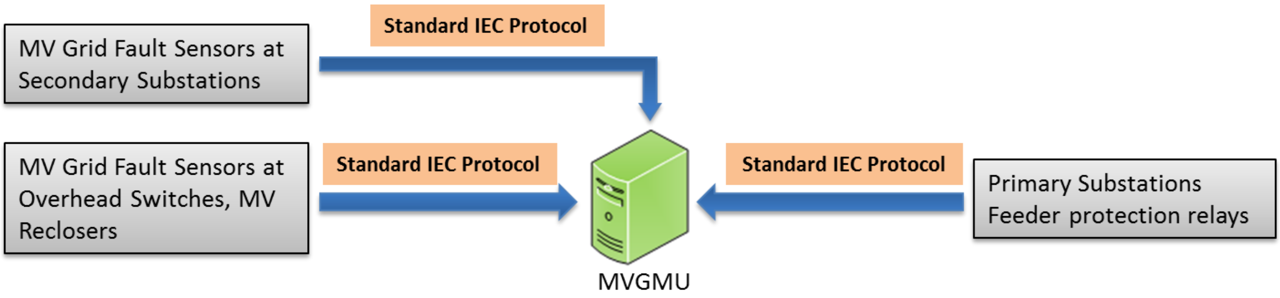

Figure 22 : Use Case #30: involved architecture components at Batalha demonstrator

The involved architecture component is: MV-GMU, MV grid fault sensors coupled with *reclosers*, with overhead switches and *sectionalizers*, with the grid MV-side of secondary substations, as well as protection relays coupled to primary substation feeders' circuit breakers as visualised in Figure 22.

Although the assessment of the isolation and restoration steps being performed internally in study mode at MV-GMU level, the user also runs the OPF over a grid snapshot in order to assess the impact of those steps over the grid, before validating and deploying them.

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Fault location is assumed by the module.	The algorithm performed by the module receives as input the identification of the faulty MV grid area components.	Internal to MV-GMU		MV-GMU displays the faulty area.
2	Definition of the isolation and restoration actions.	The isolation (when applicable) and restoration actions are presented as switching order suggestions to a duly operator at TL-GMU level (in this demonstrator, at MV-GMU level), so that the operator could assess, validate and correct them, prior to executing them.	Internal to MV-GMU		MV-GMU proposes the execution of a set of isolation and restoration actions (switching orders).
3	Assessment (in study mode) of multiple grid service restoration possibilities, based on the previous set of suggestions for service restoration.	When assessed and validated by a duly operator, the isolation and restoration process takes into account operational conditions – tested with the OPF module (Use Case #15) – while assuring that no operational conditions are violated, e.g. as exceeding the thermal limits of grid segments or the voltage limits at grid nodes, when performing load transfer between MV feeders.	Internal to MV-GMU		MV-GMU presents the result of the operator actions when assessing the different possibilities for restoration, all performed in study mode.
4	Self-healing deployment in study mode (optionally in the real grid)	Once validated all possible restoration actions, with no negative impact over the grid, the duly operator performs the set of deemed isolation steps, as well as all restoration steps.	Internal to MV-GMU		MV-GMU presents the result (impact over the MV grid) of the automatic and/or manual isolation steps, as well as the result of the manual restoration steps in study mode (optionally in the real grid).

Table 15: Events and Actions for UC #30

Test procedures in the demonstrator

1. Assess the steps for isolating a faulty grid section, previously detected at MV-GMU.
2. Assess the steps for restoring the grid service to other recoverable grid segments not affected by the fault, yet to be reenergized.
3. Validate the steps in study mode, coping with operational constraints for grid and staff safety.
4. Deploy those steps so that grid service is restored at its upmost extension, in study mode (optionally in the real grid).

5.2 The Netherlands, holiday park Bronsbergen

The main focus of the Bronsbergen demonstrator will be on:

1. Providing bulk power balancing in a planned manner, while respecting customer settings and behaviour,
2. study of grid behaviour as a result of balancing efforts,
3. study of customer behaviour and the effects it has on the balancing system.

The possibility of real-time balancing in an unplanned manner is available via the centralised storage, already present at the demonstrator site. This is not a feature of the e-balance project as such, but will be utilised in the testing of Use Case 11: (virtual) micro-grid energy balancing.

5.2.1 Implementation of e-balance at the Bronsbergen demonstrator

The scope of the e-balance project has been given shape in the form of Use Cases. The Use Cases define the minimum feature set the project will realise. The Use Cases allocated to the Bronsbergen demonstrator are given in Table 16. These are a means to realise and focus a certain functionality of the e-balance framework. Three categories of Use Cases have been defined:

1. Energy balancing: Use Cases directly related to the process of energy balancing
2. Neighbourhood monitoring: Use Cases related to providing insight into grid status
3. Energy prediction and simulation: Use Cases specifically aimed at predicting the powers that need to be balanced

The categories 1 and 2 will together make demand side management possible, via the methods described in Deliverable 5.2. Category 3 will provide the boundary conditions for the balancing methods.

Use case #	Title
	Energy balancing
3	Energy exchange balancing and resilience
9	Intelligent home appliance energy consumption balancing
25	Demand prediction
26	Prediction of renewable energy generation
	Neighbourhood monitoring
13	Neighbourhood power flows
14	DER power flows (restated)
18	Quality of supply measurement
21	Losses calculation
24	Fault prevention (LV)
	Customer data handling and customer interaction
1	Strategy-driven decision on the use of produced energy
2	Energy consumption priorities in case of energy delivery limitations
5	Strategy-driven decision on the usage of grid-connected DER (restated)
7	Customer interfaces for better efficiency and interaction
8	Handling of current and historical customer data for improved safety and privacy
12	Multiuser privacy management in energy grid
	Smart Medium Voltage Grid
11	(Virtual) Microgrid energy balancing

Table 16 : Allocated e-balance Use Cases for the Bronsbergen demonstrator

5.2.2 Technical Site additions by e-balance project

Equipment and software will be added to Alliander’s systems and at the Bronsbergen site at several locations, in order to build up the e-balance system:

1. Secondary Substation Roelofs
    - LV-GMU
        - HomeWaveControl or BeagleBone Black possibly augmented by a G-Smart
    - Communication between measurement equipment and LV-GMU
        - IPoEth RJ-45, used protocol may change during the project to reach best synergy.
    - Communication between CMUs and LV-GMU
        - Communication through the internet using web services (servicestack framework).
    - Communication between LV-GMU and MV-GMU
        - Communication through local network using web services (servicestack framework).
    - Additional sensors/measurements if applicable
2. Secondary Substation Bronsbergenmeer
    - LV-GMU (**Efacec**)

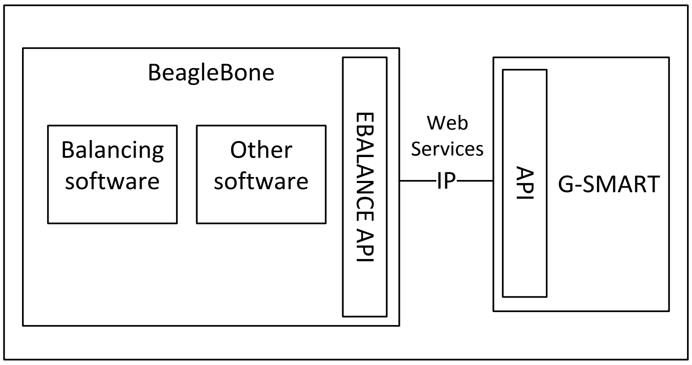

Figure 23: Efacec’s “G-smart” hardware solution to be extended with additional to be developed software on yet to be specified hardware for e-balance functionality.

- Communication between CMUs and LV-GMU
    - Communication through the internet using web services (servicestack framework).
- Communication between LV-GMU and MV-GMU
    - Communication through local network using web services (servicestack framework).
- Multi-phase measurements of V, I, P, Q and optionally power quality parameters on all LV directions and phases, optionally also the medium voltage cable to SS Roelofs (**Alliander & Efacec**)

3. Participant residences
    - In total up to 20 CMUs have been foreseen in the DoW CMU will be implemented on Lesswire’s HomeWaveControl.
    - Communication between CMU and LV-GMU
        - Communication through the internet using web services (servicestack framework).
    - Intelligent Energy Devices (IEDs), total amount depending on amount of participants and available budgets. (Alliander)
    - Communication between IEDs and CMU (**Zigbee 1.2**)

4. Alliander's cottage (number 58)
    - TL-GMU
        - The TL-GMU will not be providing additional functionality on top of the MV-GMU and is considered optional.
        - HomeWaveControl or BeagleBone Black possibly augmented by a G-Smart MV-GMU
    - Communication between MV-GMU and the two LV-GMUs
        - Communication through local network using web services (servicestack framework).
    - CMU **(Lesswire)**
    - Intelligent Energy Devices (IEDs)
    - Communication between IEDs and CMU
    - Communication between CMU and the LV-GMU in Secondary Substation Roelofs

Furthermore:

1. Additions of Smart Meters: exact amount depending on the amount of people willing to participate, for non-participants, the presence of smart meters does not automatically mean access to their data for balancing purposes.
2. Smart Plugs are considered optional and their amount depend on remaining budgets, time and the wishes of participants.

5.2.3 Participants

Up to 20 CMUs have been foreseen by the project, including all research devices. For now, this limits the maximum number of active participating connections of the Bronsbergen grid. Each participant that gets a CMU will also be provided with some means of flexible load. In order to accurately predict the other connections, it can be considered to ask customers permission to use Smart Meter data. Participation in the e-balance project thus goes beyond active participation, as also non-flexible users need to be taken into account for optimal performance. Non-flexible users are users that do not use a CMU. Manual interactions by the user based on recent data from the GUI will not aid the technical balancing system, as the system is not aware of these actions. On the other hand, in hindsight the market mechanisms can reward these manual actions to an extent.

5.2.4 System validation

The e-balance system will need to be tested and monitored on a technical and conceptual level. The technical level involves the correct operation of hardware, software and telecommunication. The conceptual validation concerns the system as a whole. Section 5.2.4.2 describes this validation based on the Use Cases presented in Table 16.

5.2.4.1 Technical validation

The technical details have not been worked out far enough at this stage of the project to be able to provide detailed testing procedures for the e-balance components. In principle, the components will be tested in-lab by their designers.

5.2.4.2 E-balance concept validation

The e-balance system will be validated on a conceptual level by considering the Use Cases. Step wise descriptions explain the different concepts of the e-balance system. Testing them as such, will demonstrate the e-balance system as a whole.

5.2.4.3 UC #3: Energy exchange balancing and resilience

Objective: Automatic controlling and monitoring of the power exchange at the point of connection, allows avoiding failures in the grid and thus, increases the quality of service.

Description: In case a too high amount of energy is exchanged at the point of connection of a grid, grid components can be overloaded. This can be caused by voltages that reach too high values, causing isolation values to be surpassed, causing damage. Another option is that the current through grid components gets too high, causing the temperature to rise to unsafe levels, also causing damage.

The exact method on how to prevent damage to components is subject to debate. The current options are:

1. *A priority signal indicates to the CMUs a different set of criteria should be used to perform balancing.*
2. *A combined balancing and incentive scheme will automatically prevent grid failure conditions*

This Use Case description combines the two options, but is hence subject to change.

By taking the limits of grid components into account during balancing, damage to the grid can be avoided, maintaining a proper energy delivery. In normal operation, peaks in energy exchange are discouraged by providing an incentive coupled to the "flatness"[5] of the daily energy profile.

This Use Case deals with the situation where this incentive is not big enough to avoid grid failure. The LV-GMU sends out a signal, indicating a critical grid status. The CMUs will now also use the settings provided in Use Case #2. An iterative increase of an incentive will attempt to persuade compliance to requested power levels eventually at the cost of comfort. Devices can be turned off, turned on or curtailed by the CMU to comply with the LV-GMU's request, within the boundaries of the user's strategy specification. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 24

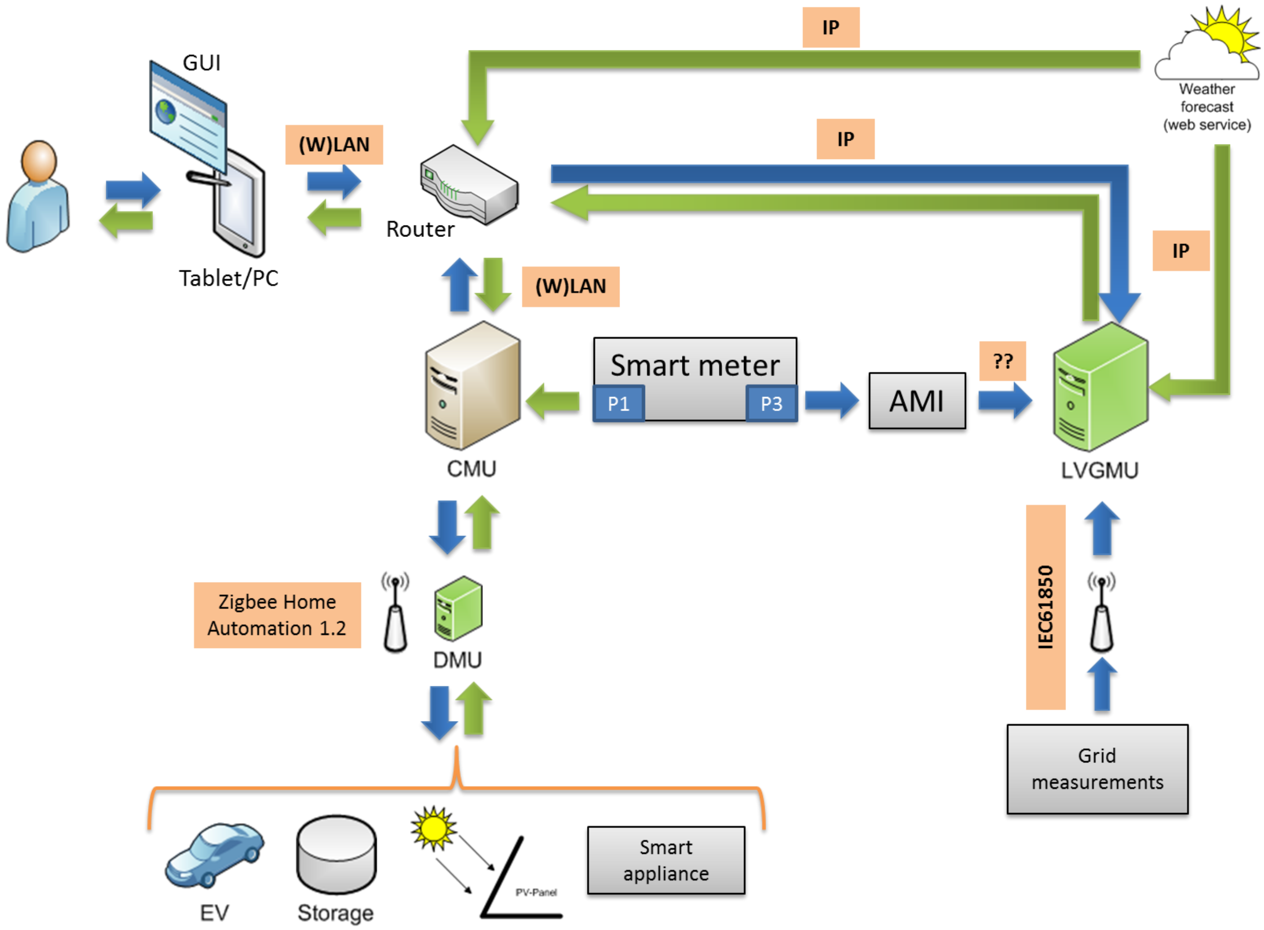

Figure 24: Use Case #3: involved architecture components at Bronsbergen demonstrator

---

[5] The exact reward and pricing mechanism is still under development and will be integrated in deliverable D5.2.

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	Critical grid status detection	The LV-GMU detects a grid critical situation.	Internal LV-GMU		Alarm notification activated
2	Critical grid status notification	The LV-GMU notifies all connected CMUs of a grid critical situation.	LV-GMU to CMUs		Alarm notification activated
3	Priority change	All CMUs switch to a different set of priorities which form the boundary conditions of the balancing algorithms. Thus increasing the available flexibility.	Internal CMU		Alarm notification activated

Table 17: Events and Actions for UC #3

Test procedures in the demonstrator

1. A critical grid status is simulated by altering the internal grid model of the LV-GMU
2. A check is performed whether a critical grid status is detected
3. A check is performed to see whether a notification is sent out to the CMUs
4. A check is performed to see if the CMUs are now able to provide more flexibility. This should become obvious by looking at the balancing iterations. The actual check whether the CMU acts according to UC#2 priorities is performed with the testing of UC#2.

5.2.4.4 UC #9: Intelligent home appliance energy consumption balancing

Objective: To increase flexibility of the power being exchanged at the connection with the grid.

Description: This Use Case represents the core of the e-balance balancing system. Within the e-balance system, flexibility in power demand or generation from a grid perspective, is rewarded. This flexibility is enabled by Intelligent Energy Devices (IEDs) and controlled by the CMU. Taking into account all the conditions specified by the user's strategy and the capabilities of the IEDs, the CMU will determine the best power distribution in time, which is also referred to as a power profile. This profile will be supplied to the LV-GMU. The LV-GMU can respond with an alternative profile request. Afterwards, the CMU will again determine the best profile, taking also the request of the LV-GMU into account. The eucledic distance between the newly calculated profile and the requested profile is determined and sent back to the LV-GMU. After receiving confirmation, either the original or the revised profile is acknowledge and implemented for a given time-slot. When a CMU profile is acknowledged, the LV-GMU will continue negotiations with the other CMUs to eventually end up with the maximum utilisation of flexibility within the strategies set for each CMU.

At the Bronsbergen demonstrator, the CMU will have a "driver" like interface to make IEDs compatible with the e-balance system, due to lack of standards. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 25.

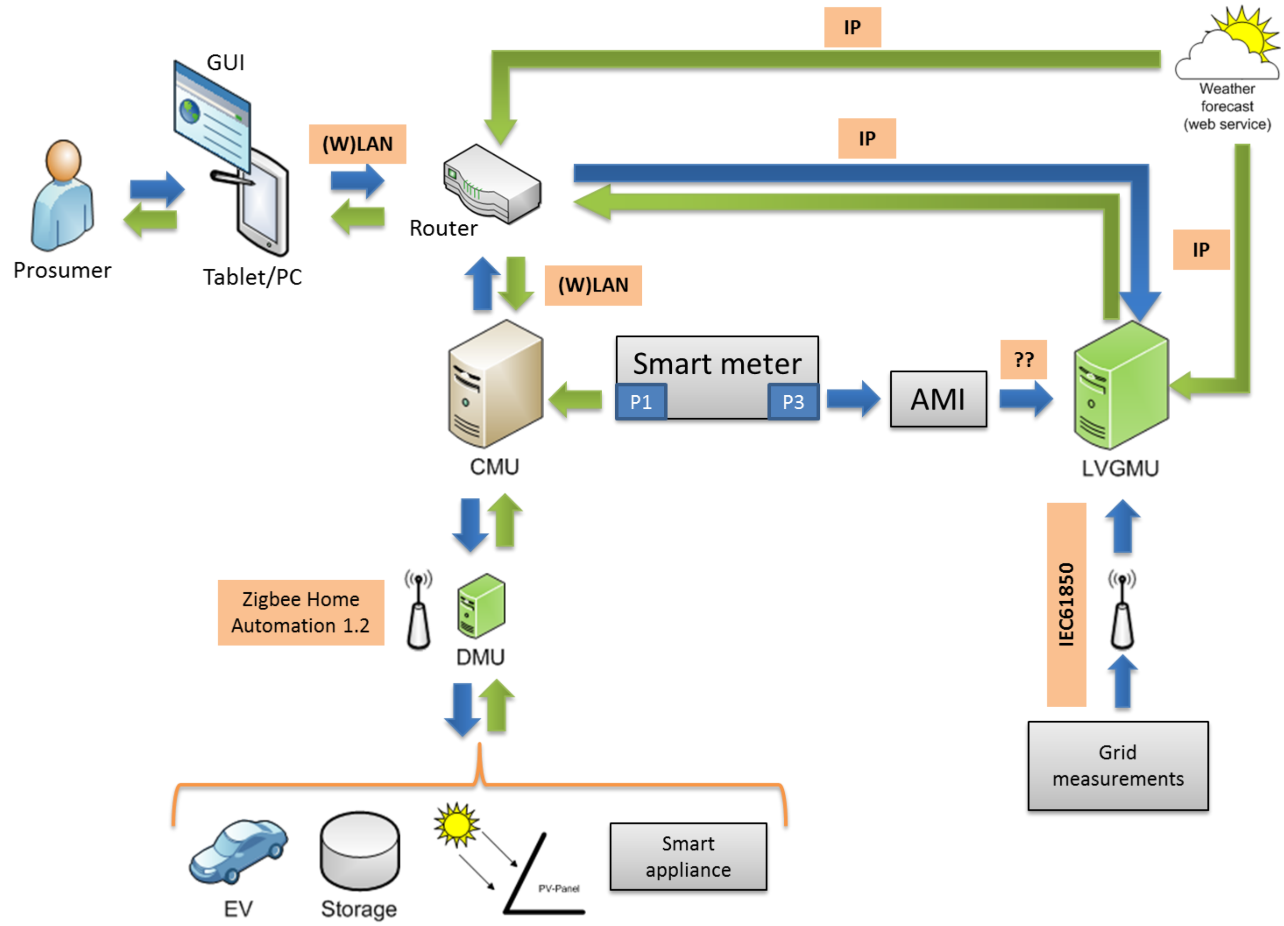

Figure 25: Use Case #9: involved architecture components at Bronsbergen demonstrator

Events and Actions:

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	LV-GMU requests profile	The LV-GMU sends a signal to the CMU requesting its expected power profile	LV-GMU to CMU		
2	UC #25 is executed	A prediction of non-IED energy consumption is made available	Internal CMU: locally stored data is analysed.		If desired, predictions can be visualised to the GUI user.
3	UC #26 is executed	A prediction of DER power, if available, is performed.	Weather information is downloaded to the CMU		If desired, predictions can be visualised to the GUI user.
4	IED power profiles are gathered from IEDs	The CMU requests the expected power usage for the upcoming time periods from IEDs	CMU→IED→CMU		
5	Aggregation of all profiles	Within the boundary conditions set by the strategy of the user (UC#1) and the available information, the profiles are aggregated.	Internal CMU		
6	CMU replies with profile	The CMU responds with the profile of step 4	CMU to LV-GMU		
7	LV-GMU responds with desired (difference) profile	The LV-GMU aggregates the data of all CMUs, MV-GMU, local predictions and measurements. The result is transmitted to the CMUs	LV-GMU to CMU		
8	CMU determines how well the LV-GMU profile can be realised	The CMU determines the amount of power that can be shifted in time, reduced or increased to fulfil the LV-GMU request. The difference between the LV-GMU request and the CMU result is mathematically reduced to a single number.	Internal CMU		
9	CMU transmits single number response	The CMU answers the LV-GMU by responding with a single value, indicating how well the CMU can comply with the LV-GMU's request.	CMU to LV-GMU		
10	The LV-GMU determines the best CMU and requests the accompanying profile from this CMU.	The highest valued CMU response is determined. This CMU is requested its adjusted power profile.	LV-GMU → CMU with highest ranking→LV-GMU		
11	LV-GMU fraud check	The LV-GMU checks whether the CMU profile and single valued reply are consistent	Internal LV-GMU		

12	Best profile retrieval	The LV-GMU sends a confirmation signal to the highest ranking CMU that the supplied profile is approved and requests the profile.	LV-GMU to CMU		
13	Steps 8-12 are repeated iteratively until all CMUs are finalised	EVERY CMU can continue bidding in the iterative process. Only at the end of the iterations, the profiles will be finalised.			
14	LV-GMU finalises profiles	The LV-GMU sends a confirmation to all CMUs the power profiles are now finalised			

Table 18: Events and Actions for UC #9

Test procedures in the demonstrator

1. Determine the specified strategy applicable for a CMU
2. Provide incentives and balancing requests that fall within the strategy limits
3. Check whether the CMU makes flexibility available, as expected
4. Check whether the flexibility is applied, as expected
5. Check whether the LV-GMU provides the correct analysis of the applied balancing
6. Try different variants of incentives and balancing requests

5.2.4.5 UC #25: Demand prediction

Objective: To predict energy demand, which is not covered by information from IEDs (on a household level) or to predict energy demand by non-CMU equipped users (on a low voltage grid level.)

Description: Use case #9 considers demand that is controllable and well known ahead of time. It is the demand caused by devices that communicate their time dependent behaviour to the CMU. On a household level, the amount of devices that can provide this information and control will be limited. This Use Case focusses on the prediction of the remaining energy demand. In order to increase the capabilities of a balancing service it is necessary to also predict the remaining energy demand. Many different approaches can be used to predict energy demand. The methods chosen within the e-balance project are being described in D5.2. Demand predictions of non-CMU equipped users will be carried out by the LV-GMU and the equipped ones will be carried out by the corresponding CMU, which will provide such information to the associated LV-GMU incorporated in the supplied power profile.

Currently, the research is focussing on SARIMAX and simple Neural Networks. Both these models need to be trained by historical data. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 26.

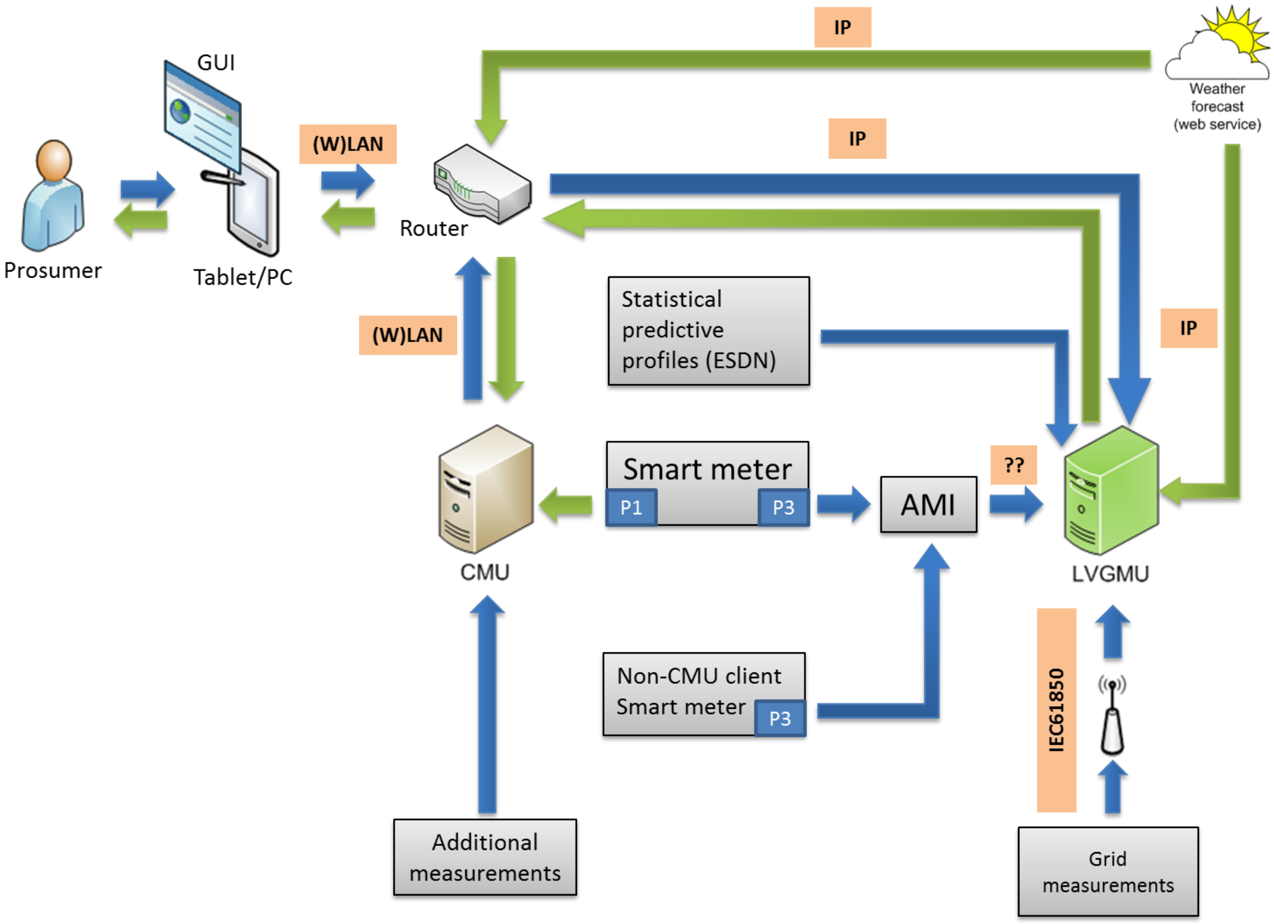

Figure 26: Use Case #25: involved architecture components at Bronsbergen demonstrator

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	Determine non-IED usage data	Based on local Smart Meter read-outs, IED energy data and production data, non-IED energy usage can be deduced.			
2	Categorise non-IED data	Typically, usage pattern differ throughout the week and on holidays. The non-IED data hence needs to be categorised in terms of day of the week, whether it was a holiday or not and possibly the season.			
3	Store non-IED data	Data is stored in a local database in categorised form.			
4	Train prediction module	The locally stored data of the appropriate category is retrieved and sent to the prediction model for model parameter calibration.			
5	Apply prediction module	The prediction module is used to predict the energy usage for the next 24 hour period.			Display predictions upon request.

Table 19: Events and Actions for UC #25

Test procedures in the demonstrator

1. A prediction is made for the next 24 hour period
2. Every 24 hour period is compared with real usage data to determine the quality of the predictions

5.2.4.6 UC #26: Prediction of renewable energy generation

Objective: To predict the production levels of renewable energy resources.

Description: By knowing the expected production values of a DER, it is possible to make a better planning of the household energy exchange with the grid, providing the CMU with better information on which to base the planning. Prediction of DER production numbers is closely related to weather predictions. Within the e-balance project we assume weather information to be readily available from an online resource. Utilisation of locally specified system specifications (for example, PV system set-up numbers like kWp, roof angle, azimuth) combined with weather forecasting allows for production estimation. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 27.

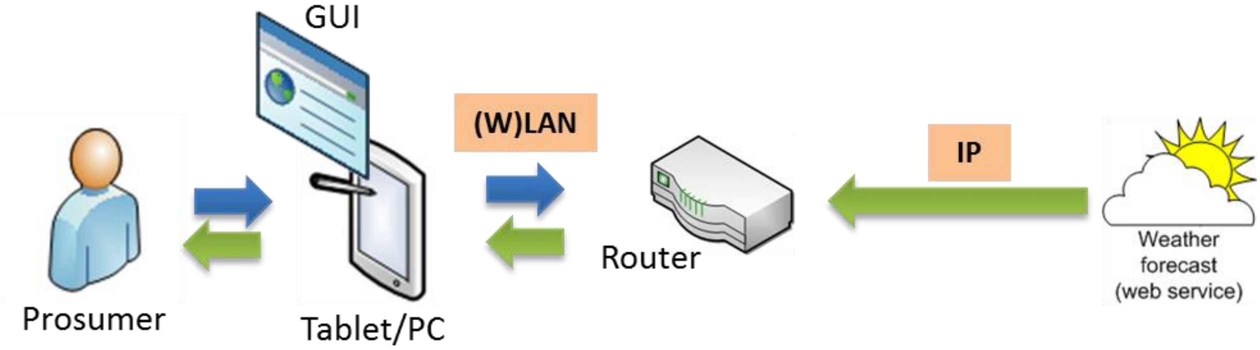

Figure 27: Use Case #26: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Weather prediction data retrieval	Weather prediction data is retrieved from a weather prediction service	Weather prediction data provider →CMU		
2	Conversion of weather information to DER prediction numbers	Based on the knowledge of the local installation(s), the CMU will predict the production of these DER units	Internal CMU		

Table 20: Events and Actions for UC #26 for the CMU

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Weather prediction data retrieval	Weather prediction data is retrieved from a weather prediction service	Weather prediction data provider →GMU		
2	Conversion of weather information to DER prediction numbers	Based on the knowledge of the local installation(s), the GMU will predict the production of these DER units	Internal GMU		
3	Estimation of hidden production				

Table 21: Events and Actions for UC #26 for the GMU

Test procedures in the demonstrator

1. Check whether weather prediction data is being retrieved/received
2. Check whether the algorithms translate this data correctly to production predictions
3. Check how well predictions and productions match
4. Adapt algorithms where possible to improve predictions

5.2.4.7 UC #13: Neighbourhood power flows

Objective: To give detailed insights in Voltage, Current and Power levels in the low voltage (LV) grid and neighbourhood power consumption and production.

Description: This Use Case focusses on measuring and calculating historical grid states. This will provide the DSO with detailed component loading information. As the basis, load information from Smart Meters and grid sensors are used. Also, by using the prognosed loads generated by the CMUs and LV-GMUs, the expected grid state can be verified utilising the same methods. This Use Case will provide the base information for UC 14 (DER power flows) and UC 20 (fraud detection).

This Use Case thus covers both neighbourhood power flow predictions as well as observations in hindsight. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 28.

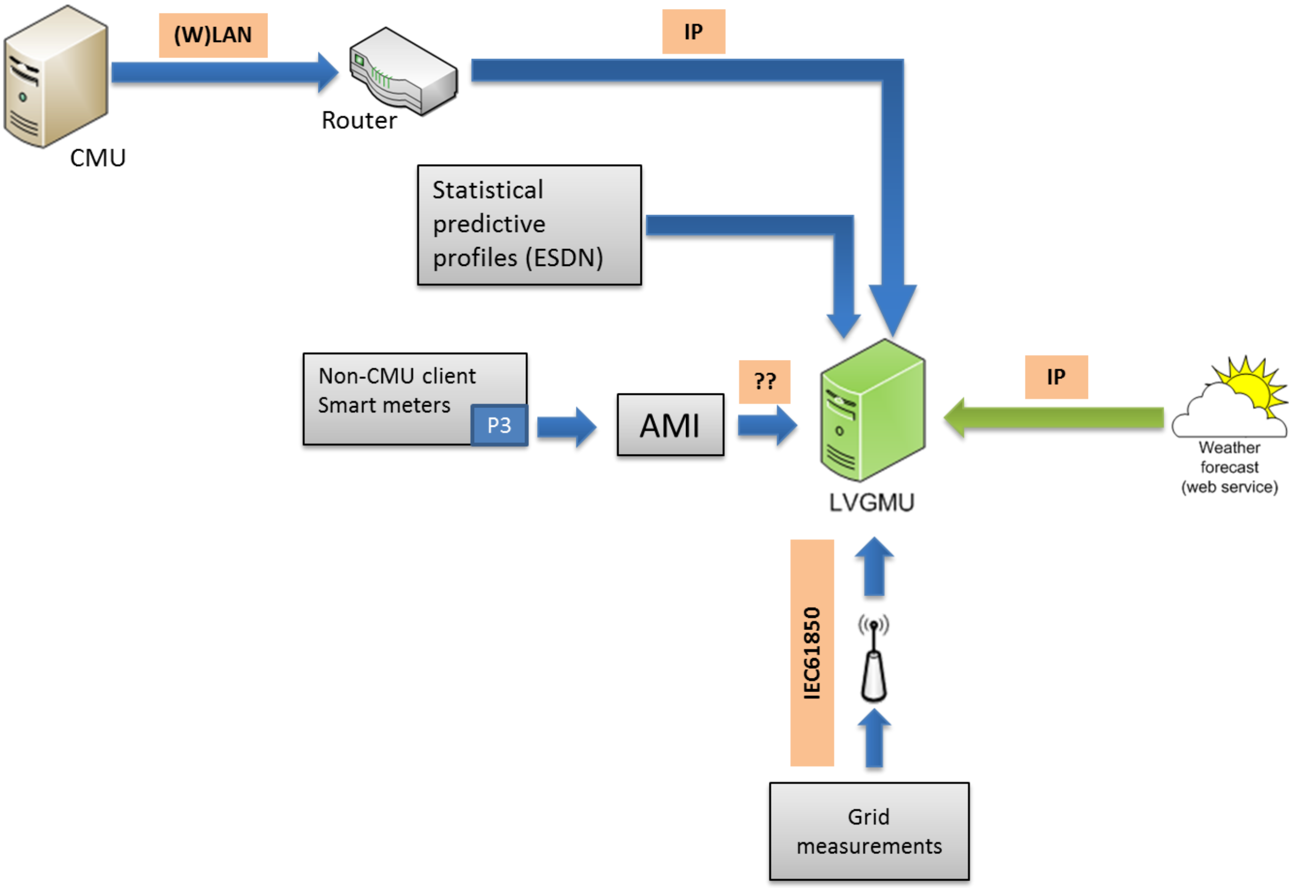

Figure 28: Use Case #13: involved architecture components at Bronsbergen demonstrator

Test procedures in the demonstrator

1. Select a particular feeder.
2. Gather and evaluate all real time measurements from LV grid sensors.
3. Compute and evaluate all forecasted data from smart meters, including from DER assets.
4. The LV-GMU combines all available data, providing NPF outcome.
5. Assessment of the NPF outcome under the real conditions.
6. Assessment of the NPF details related to the DER assets.

Events and Actions

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
0	Neighbourhood LV feeders topology setup.	The DSO updates the local grid topology information when it changes.	MV-GMU→LV-GMU		LV-GMU can provide insight in the current grid topology.
1	Activation of NPF module	In case of an impending grid event (overloading of components) or in case of a validity check by the balancing methods, the NPF calculation is started.	Spontaneous current or voltage alarm events from LV sensor to LV-GMU OR internal GMU balancing validity check request.	event	LV-GMU displays the received event.
3	Periodic report of current or voltage measurements from the sensors placed in the secondary substation	The sensors placed in the secondary substation periodically transmit the current and voltage measurements to the LV-GMU.	Sensor to the LV-GMU, upon request	Periodic read	
4	The algorithm forecasts load demand and generation values at each node, by using historical data, providing pseudo-measurements.	An algorithm running in the LV-GMU, performs load and generation forecasts, by using historical data and data supplied by the CMUs. Pseudo-measurements populate the internal database for NPF use.	Internal to the LV-GMU		
5	The algorithm combines the forecasted pseudo-measurements with the former real time measurements.	The algorithm running in the LV-GMU combines all data, while providing an accurate LV grid segments observability.	Internal to the LV-GMU		LV-GMU displays the grid status.
6	Historical grid state estimation	Once a day, all grid, Smart Meter and weather measurements are used to determine the historical state of the grid for that day. Estimations are used for non-Smart Metered connections. This action will provide refine earlier grid status results.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node.

5.2.4.8 UC #14: DER Power flows (restated)

Objective: To provide insight in DER Power flows in the LV-grid

Description: By knowing the directional power exchange at connection points of the grid, energy that is fed into the LV grid can be traced from source to consumption. This enables direct insight into the actual energy mix at any point of the grid at any given time period. This could for example be communicated to a local municipality or citizen corporation to show how eco-friendly their neighbourhood is. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 29.

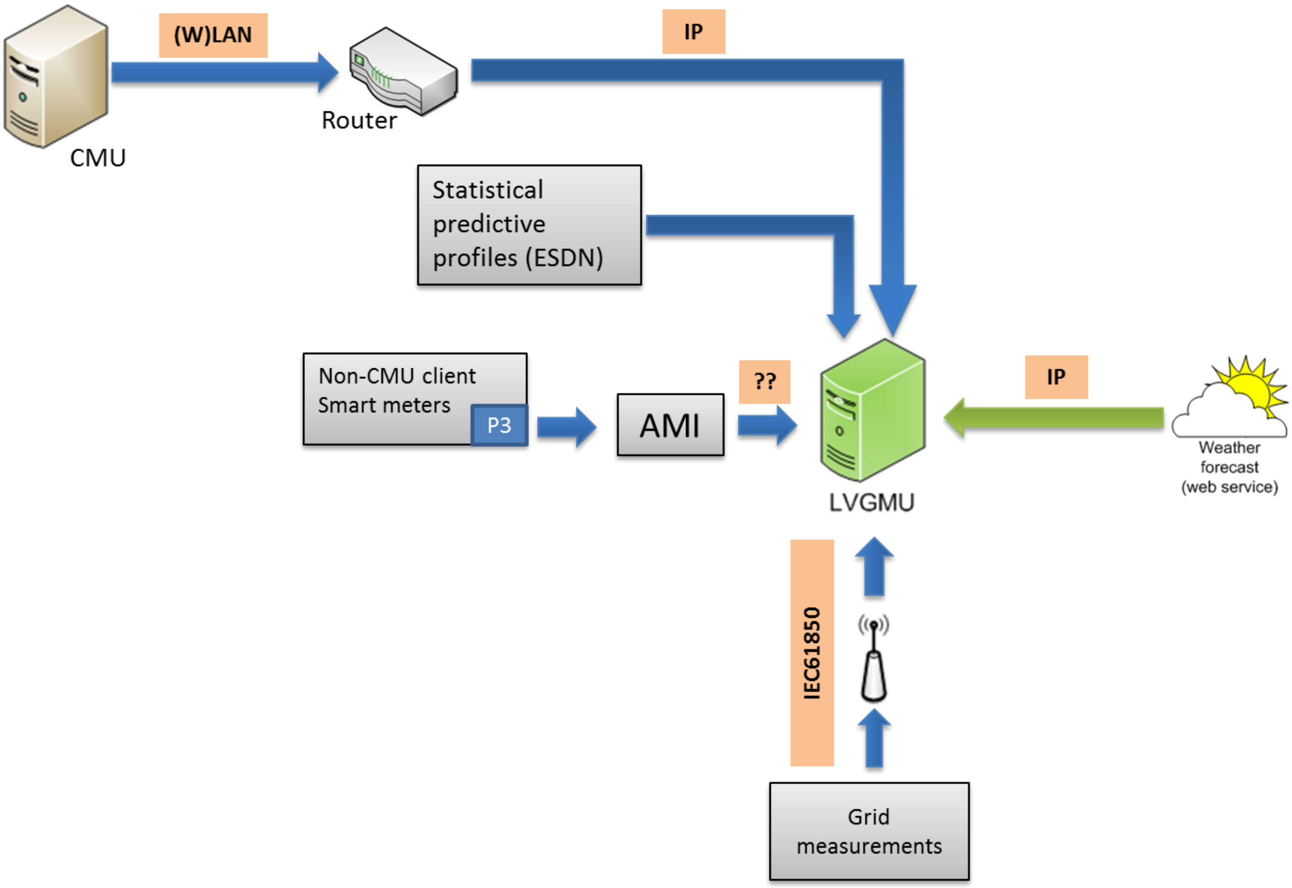

Figure 29: Use Case #14: involved architecture components at Bronsbergen demonstrator

Test procedures in the demonstrator

1. Select a particular feeder.
2. Gather and evaluate all real time measurements from LV grid sensors.
3. Compute and evaluate all forecasted data from smart meters.
4. The LV-GMU combines all available data, providing NPF outcome.
5. Assessment of the NPF outcome under real conditions.

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1 (as in UC # 13)	Neighbourhood LV feeders topology setup	The configured topology is turned into active mode.	Internal to the LV-GMU		Topology startup indication (ok, failure) at LVGMU.
2 (as in UC # 13)	Alarm of current or voltage threshold detected in the sensors placed along the LV grid segments.	When the current is above a threshold (independently of its severity) or the voltage is below or above a threshold (independently of its severity), an alarm message is originated.	Spontaneous current or voltage alarm events from LV sensor to LV-GMU	event	LV-GMU displays the received alarm.
3 (as in UC # 13)	Periodic report of current or voltage measurements from the sensors placed along the LV grid segments.	The sensors placed in the LV feeder periodically transmit the current and voltage measurements to the LV-GMU.	Sensor to the LV-GMU, upon request	Periodic read	LV-GMU displays the received measurements.
4 (as in UC # 13)	The algorithm forecasts load demand and generation values at each node, by using historical data, providing pseudo-measurements.	An algorithm running in the LV-GMU, performs load and generation forecasts, by using historical data. Pseudo-measurements populate the internal database for NPF use.	Internal to the LV-GMU		LV-GMU displays the forecasted values.
5 (as in UC # 13)	The algorithm combines the forecasted pseudo-measurements with the former real time measurements.	The algorithm running in the LV-GMU combines all data, while providing an accurate LV grid segments observability.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node.
6	The algorithm details each of the aggregated power flows, coping with all DER assets within the LV grid segments that comprise the feeders	The algorithm running in the LV-GMU provides an accurate LV grid segments observability, comprising all DER assets.	Internal to the LV-GMU		LV-GMU displays the estimated power flows and other relevant LV grid data, per LV grid segment and grid node, also comprising the details for all DER assets.

Table 22: Events and Actions for UC #14

5.2.4.9 UC #18: Quality of Supply measurement

Objective: The e-balance management system processes information from neighbourhood households and determines the quality of service Key Performance Indicators (KPIs), according to the data retrieved from the smart meters.

Description: This LV-GMU requires periodic data retrieval from smart meters aiming at measuring the technical quality of supply metrics. Based on this information the LV-GMU will analyze and calculate the defined KPI. Namely, the LV-GMU shall receive the information on the number and duration of supply interruptions of each customer and/or each feeder, allowing the calculation of service quality standards and corresponding service level agreements. The LV-GMU shall receive the information on defined service quality events, and perform the processing of this information for the purpose of reporting. The KPI for QoS and for QoE are aligned with regulatory and grid operator parameters. They may comprise: e.g QoS (MAIFI, CAIFI, SAIDI, etc.) and QoE (voltage limits violations). This Use Case will use an implementation of the e-balance architecture as visualised in Figure 30.

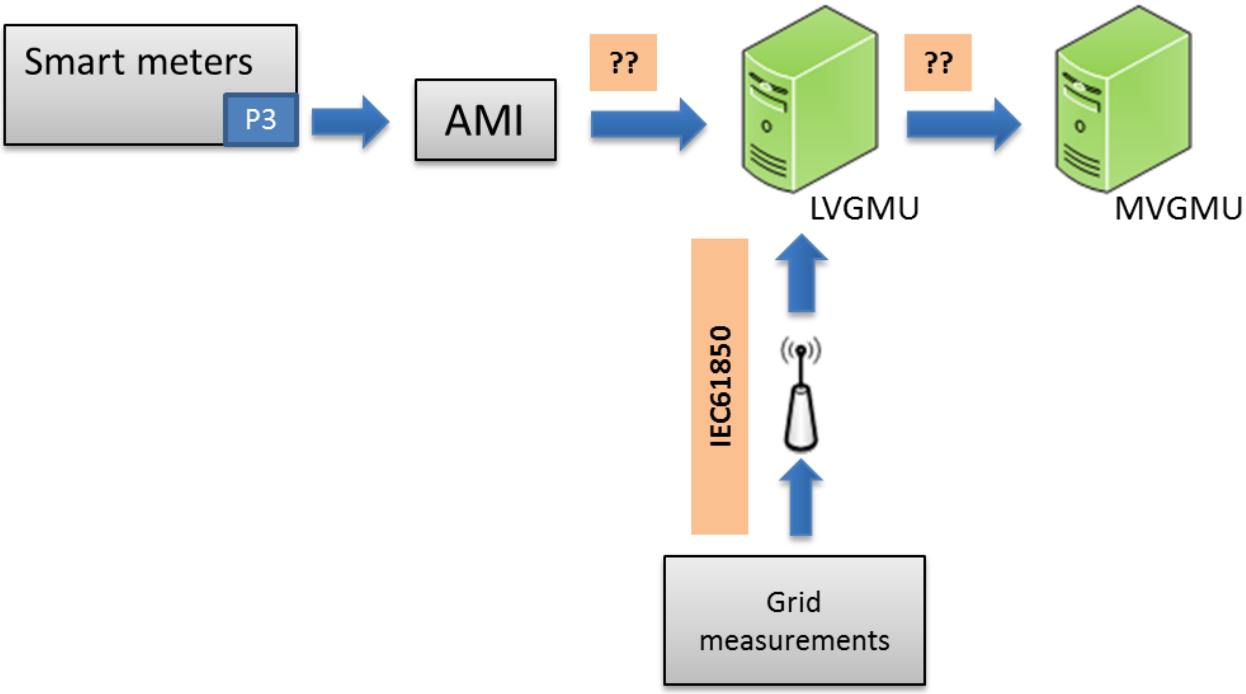

Figure 30: Use Case #18: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Read service quality data and voltage quantities	LV-GMU reads service quality data and voltage quantities from smart meters	Data from smart meters to LV-GMU, by exception or upon request	read, event	
2	Determining KPIs	LV-GMU calculates KPIs based on the retrieved service quality data and voltage quantities.	Internal to LV-GMU		LV-GMU shows KPIs in the GUI
3	MV-GMU notification	LV-GMU sends KPIs to MV-GMU	LV-GMU to MV-GMU	Periodic	MV-GMU shows KPIs in the GUI

Table 23: Events and Actions for UC #18

Test procedures in the demonstrator

1. LV-GMU reads energy quality related information from smart meters.
2. LV-GMU determines KPIs based on the received information from smart meters. Their values can be verified on the GUI.
3. LV-GMU sends KPIs to the MV-GMU. Their values can be verified on the GUI.

5.2.4.10 UC #21: Losses calculation

Objective: To determine grid losses.

Description: Based on the results of UC#13, losses can be determined in the grid. This allows the study of the impact the e-balance system on this particular aspect of energy distribution. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 31

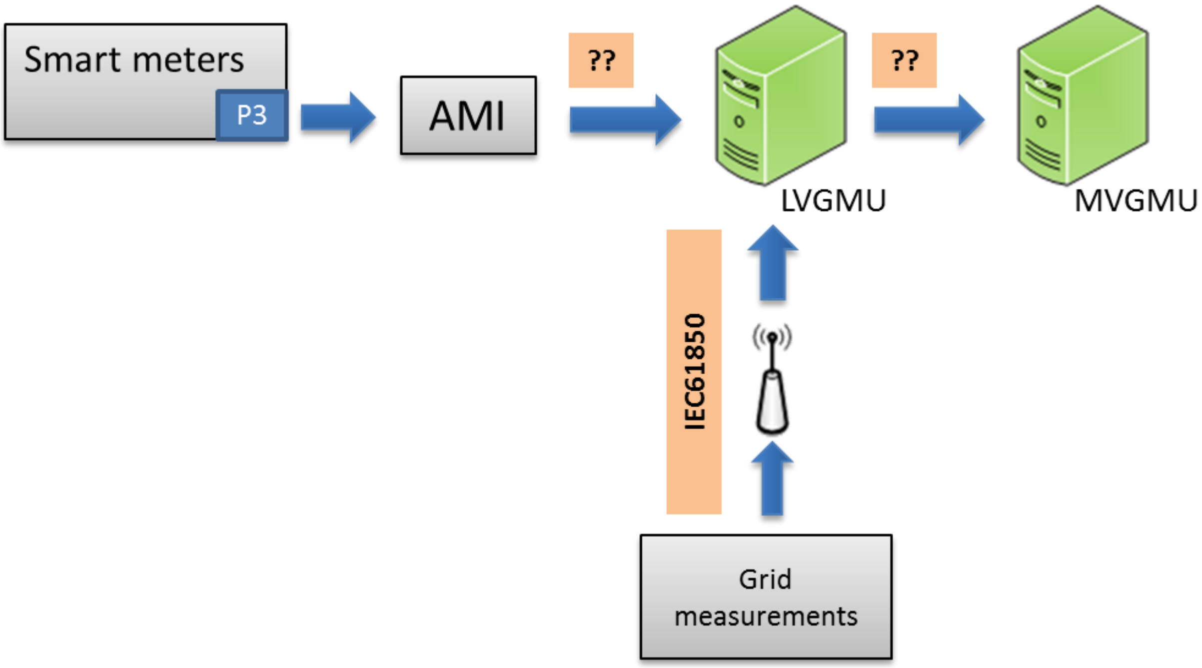

Figure 31: Use Case #21: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	UC#13 is executed	Currents through every grid component is known.	Internal GMU		
2	Losses are calculated based on I^2R	Combining grid data with measured or calculated currents via I^2R, results in known losses	Internal GMU		
3	Losses are aggregated into information for specific stakeholders				
4	Information regarding losses is distributed to stakeholders				

Table 24: Events and Actions for UC #21

Test procedures in the demonstrator

1. Losses cannot be accurately measured at this demonstrator, as such, calculated losses will be judged with common sense.
2. Check whether losses are being output as designed

5.2.4.11 UC #24: Fault prevention (LV)

Objective: To prevent grid (component) failure

Description: By monitoring grid loading based on the measurands “Voltage” and “Current”, grid operators are enabled to take preventive measures to prevent grid failure. In case voltages or currents rise above critical levels, the electrical isolation of components may fail or heating can cause permanent thermal damage.

The balancing system can reduce grid component loading (thermal and voltage) by :

1. Performing load flow sanity checks during or after balancing negotiations, such that no solution to the iteration process is finished, without checking the effects of the energy exchanges on grid components.
2. Always choosing the desired profile such, that grid loading is minimised at all times, whilst respecting all relevant KPIs.

By incorporating loadflows into the balancing system, peaks can be avoided, reducing wear and tear of components. Also, overvoltages are avoided by adjusting balancing signals to create a robust power supply. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 32.

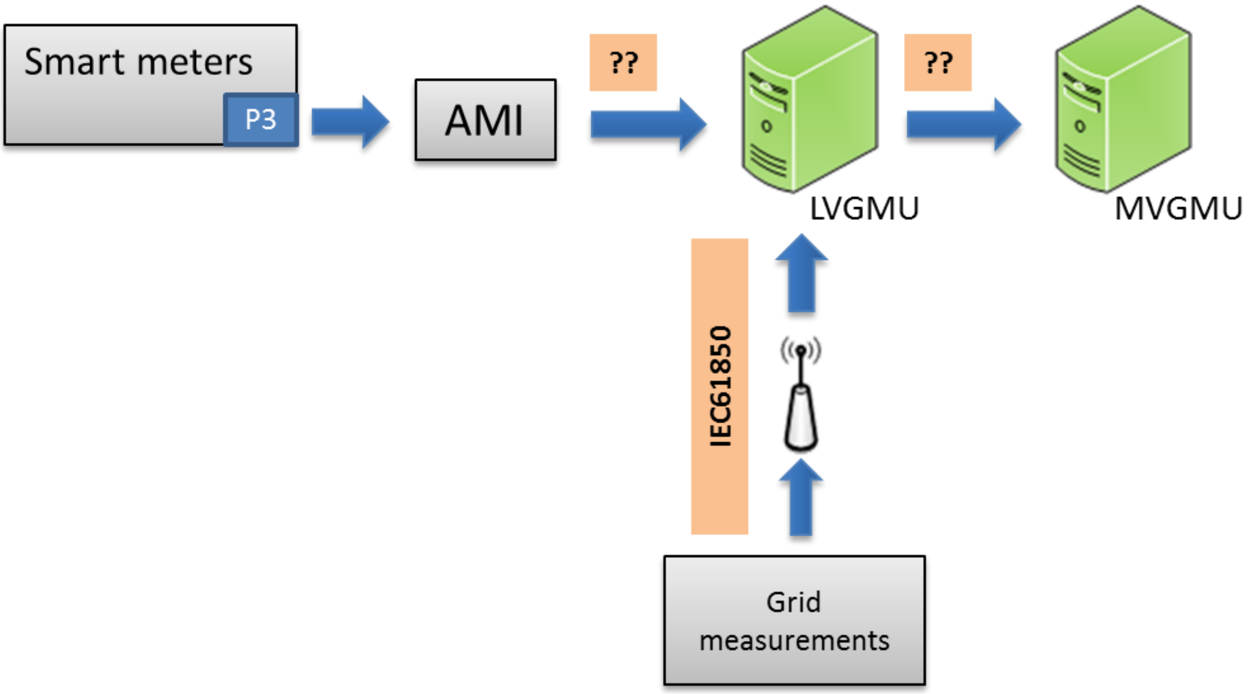

Figure 32: Use Case #24: involved architecture components at Bronsbergen demonstrator

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	UC#9 is performed	Balancing is performed according to the methods described in D5.2 (under development)	GMUs ←→CMUs		
2	Perform loadflow sanity check	At fixed points during the balancing algorithm, the expected contributions and balancing solution will be verified by a loadflow calculation. This will reveal potential grid problems.	Internal GMU		
3	Adjust desired profile	In case potential grid problems are revealed, the desired profile is adjusted to compensate the potential grid problems.	Internal GMU		
4	Flatten desired profiles	By flattening desired profiles as a goal, grid component loading is minimised, prolonging component lifetime and reducing component failure.	Internal GMU		

Table 25: Events and Actions for UC #24

Test procedures in the demonstrator

1. Determine the voltage variations with and without Demand Side Management
2. Compare before and after voltage variations
3. Determine grid component loading and grid losses with and without DSM
4. Compare before and after loading
5. Calculate before and after lifetime expectancies
6. Compare failure statistics before and after

5.2.4.12 UC #1: Strategy-driven decision on the use of energy

Objective: To provide the user the ability to set the control behaviour of the CMU

Description: One of the core features of the e-balance system is the ability by the user to be in control of her energy household if so desired. The implementation of this Use Case defines and provides the means to tell the e-balance system (CMU) how it should respond and handle all relevant information. This Use Case is about the translation between the GUI and the actual balancing methods. The options offered by the GUI will enable both economically driven and ideology driven settings. The GUI can offer for example the following options[6]:

1. “Own energy first!”: maximise local consumption
    - *Description:* The first priority of the CMU is to shift loads such that the prosumer’s energy production is used locally, regardless of the request of the LV-GMU.
    - *Implementation:* The CMU aims for zero energy exchange at times of production and only considers the LV-GMU request in case production is insufficient. In case storage is available, this will be charged or discharged accordingly.
2. “e-balance Mode”: full e-balance participation
    - *Description:* The LV-GMU request is leading in the balancing of appliances, production and storage. The user can still specify energy priorities to make the amount of supplied flexibility dependent on market and grid conditions on the one hand and personal preferences on the other.
    - *Implementation*: The CMU tries to follow the LV-GMU as good as possible, taking personal preferences regarding incentives into account. Initial behaviour will always be based on realising a flat energy exchange profile.
3. “Remote Control Mode”: aggregator in control
    - *Description:* The contract with an aggregator is leading the behaviour of the CMU
    - *Implementation*: The aggregator has its own criteria to come to a certain desired profile that each house should realise. Each CMU contracted by the aggregator receives instructions to realise a certain power profile at the point of energy exchange. This takes precedence over the LV-GMU request.

This Use Case will use an implementation of the e-balance architecture as visualised in Figure 33.

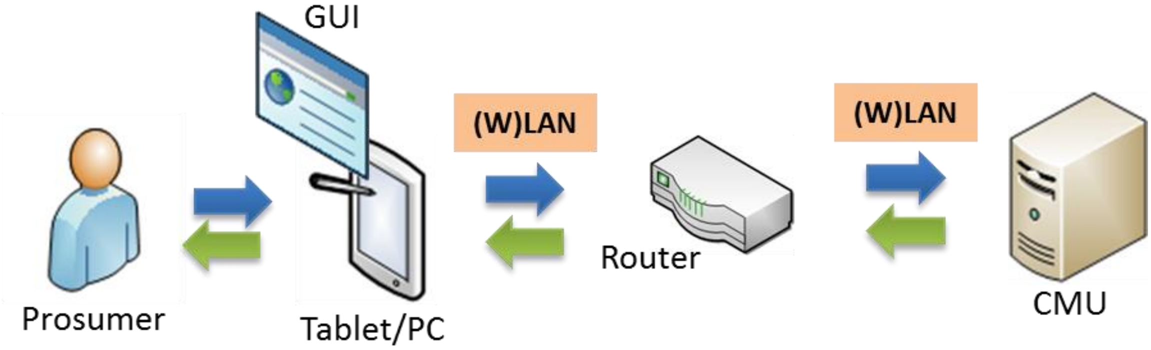

Figure 33: Use Case #1: involved architecture components at Bronsbergen demonstrator

---

[6] Under debate within the consortium

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	Strategy selection	The user selects a strategy in the GUI	Inernal CMU		Options are provided for strategies
2	Strategy execution	The CMU adapts its behaviour to the boundary conditions provided by the selected strategy.	Inernal CMU		

Table 26: Events and Actions for UC #1

Test procedures in the demonstrator

1. Select a strategy
2. Vary input controls of the CMU
3. Determine if the CMU behaves as specified

5.2.4.13 UC #2: Energy consumption priorities in case of energy delivery limitations

Objective: To provide alternative boundary conditions in case of energy delivery limitations

Description: At the moment of writing, the method for energy delivery limitation is not definitive, nor is the exact shape of the GUI. Two variants that are currently being considered:

1. The LV-GMU sends out a signal indication a critical grid limitation. The CMU switches to “critical grid mode” and uses an alternative set of input parameters to increase the amount of available flexibility. The user specifies this by weighing loss of comfort versus very high prices or no energy delivery at all in the most extreme case.
2. The profile based balancing system inherently takes the grid status into account by minimising grid loading. An incentive parallel to the balancing profile negotiations is used to stimulate compliance with the balancing efforts. The user specifies the amount of flexibility he wants to make available, depending on the incentive presented.

Two example cases:

- Grid overloading caused by too much DER power feeding in
    - The LV-GMU will request the CMU to increase the energy exchange with a certain amount in favour of power drawn from the grid.
- Grid overloading caused by too high energy consumption
    - The LV-GMU will request the CMU to increase the energy exchange with a certain amount in favour of power delivered to the grid.

The CMU will determine whether the incentive to comply is high enough to perform the required action. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 34.

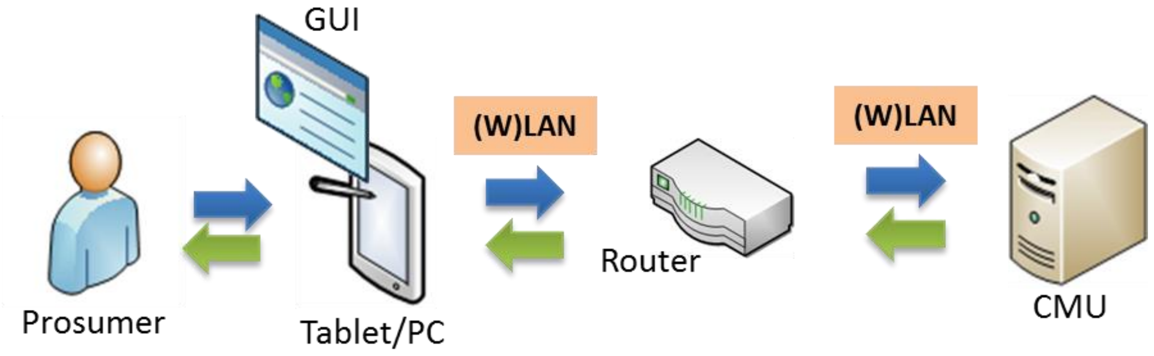

Figure 34: Use Case #2: involved architecture components at Bronsbergen demonstrator

Number	**Event/Action**	**Description**	**Origin and destination of communication**	**Data Interface Primitive Types**	**GUI**
1	Access GUI	The user logs in to the GUI of the CMU	Internal CMU		Log-in screen
2	Menu navigation	The user selects the "Strategy Wizard"	Internal CMU		Strategy Wizard
3	Menu navigation	The user selects "Comfort priorities"	Internal CMU		Comfort Settings
4	Set priorities	The user orders devices registered to the CMU based upon the desired comfort level. If applicable, a (monetary) value is associated with this prioritisation.	Internal CMU		Priority Listing

Table 27: Events and Actions for UC #2

Test procedures in the demonstrator

1. Priorities are set in the GUI
2. The applicable method (grid critical signal or higher incentive) is supplied to the CMU
3. It is verified whether the CMU responds in accordance with the set priorities

5.2.4.14 UC #5: Strategy-driven decision on the usage of grid-connected DER (restated)

Objective: To facilitate grid connected DER

Description: Similar to UC #1, but focussing on a connection that deals purely with DER. The DER unit can be controlled by the DERMU to increase or decrease its power levels, within device limits. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 35.

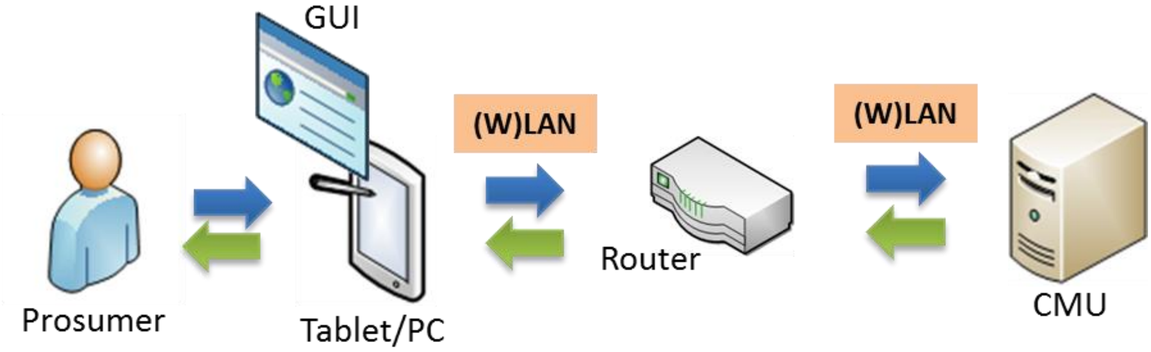

Figure 35: Use Case #5: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Setting strategy	The owner of the DER will set preferences for the control mechanisms of the DER in the GUI of the CMU/DERMU.	Internal CMU/DERMU		A strategy for the usage of the DER-only connection will be specified.
2	Strategy is implemented	The CMU/DERMU behaves according to specified strategy	Internal CMU/DERMU		

Table 28: Events and Actions for UC #5

Test procedures in the demonstrator

1. Check whether the strategy is implemented as it was input in the GUI

5.2.4.15 UC #7: Customer interfaces for better efficiency and interaction

Objective: To provide feedback to customers about their energy household.

Description: The customer is provided with feedback regarding their energy household. The customer can use this information to decide whether or not to invest in more eco-friendly equipment and or change his behaviour. Also, by providing feedback regarding how well the actual energy behaviour corresponded with the profiles provided to the LV-GMU, the user can fine-tune the way the interaction with the e-balance system is performed.

Feedback to be implemented via the GUI:

- Overview of used/produced kWh on a 15 minute or hourly basis for a period of one selected day
- Overview of used/produced kWh on a daily basis for one week or month
- Overview of weekly energy usage/production
- Overview of monthly energy usage/production
- Overview of yearly energy usage/production
- Subdivision of above overviews based on device specific measurements, if available.
- Comparison with externally acquired reference
- Advice on how to gain more benefit by behavioural changes:
    - Economics (€)
    - Environment (CO_2 and kWh)

This Use Case will use an implementation of the e-balance architecture as visualised in Figure 36.

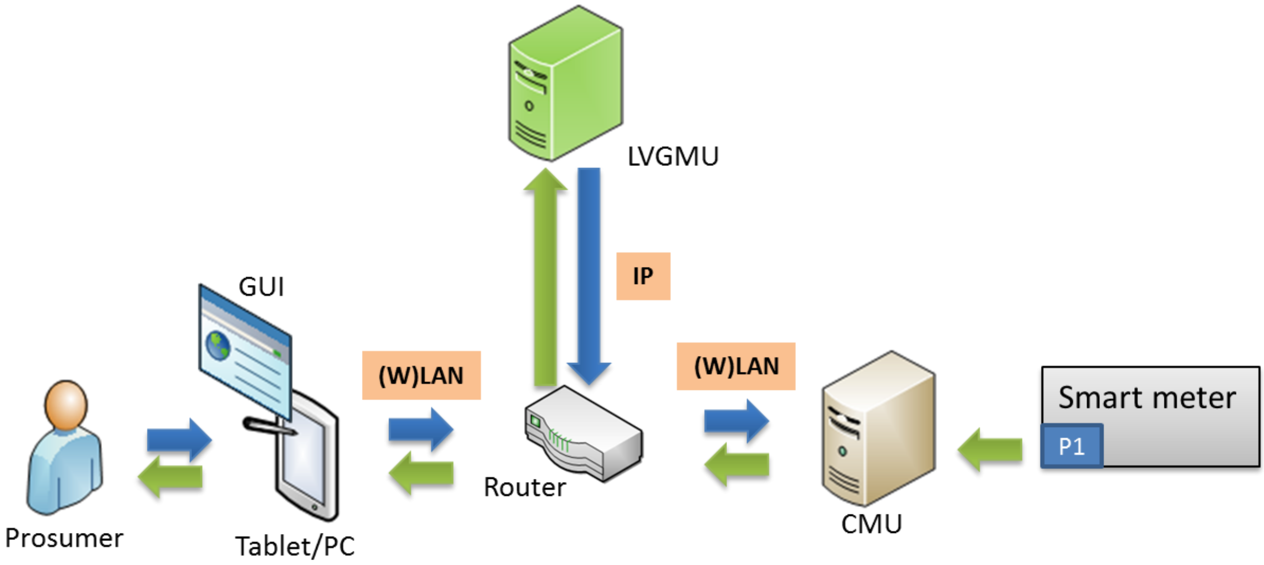

Figure 36: Use Case #7: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	User logs in to the e-balance system	A user of the e-balance system logs on to the system with her credentials.	User → GUI		Log-in screen
2	User selects historical data option	The user selects the GUI option regarding historical data and data analysis based on historical data.	User → GUI		Option selection

Table 29: Events and Actions for UC #7

Test procedures in the demonstrator

1. Check data visualisations by hand by aggregating manually the smallest possible time scale to the longer time scales.
2. Check whether the proper data is shown with each option.

5.2.4.16 UC #8: Handling of current and historical customer data for improved safety and privacy

Objective: To provide the option to define who may access a stakeholders data and for how long.

Description: The user can specify in the GUI which data may be accessed by which stakeholder, for what purpose and for how long. The privacy sensitive data gathered within the e-balance system, will only be used for the purpose it is made available for.

For example, power profiles shared during the execution of the iterative balancing system are not stored. Power profiles that are finalised will be maintained in the system for as long as is needed to provide all pre-defined aggregations of information.

The user may define the following strategy aspects for each data item she owns:

- The stakeholders authorised to access that data and for each or for all of them:
  - The allowed use (this may be hard to implement, but is a contract matter?)
  - The access restriction, like access frequency, resolution frequency (for aggregates)
- The lifetime of the data item in the system

The values of these parameters may be influenced by the contract with other stakeholders the data owner has. Users have to acknowledge data agreements explicitly. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 37.

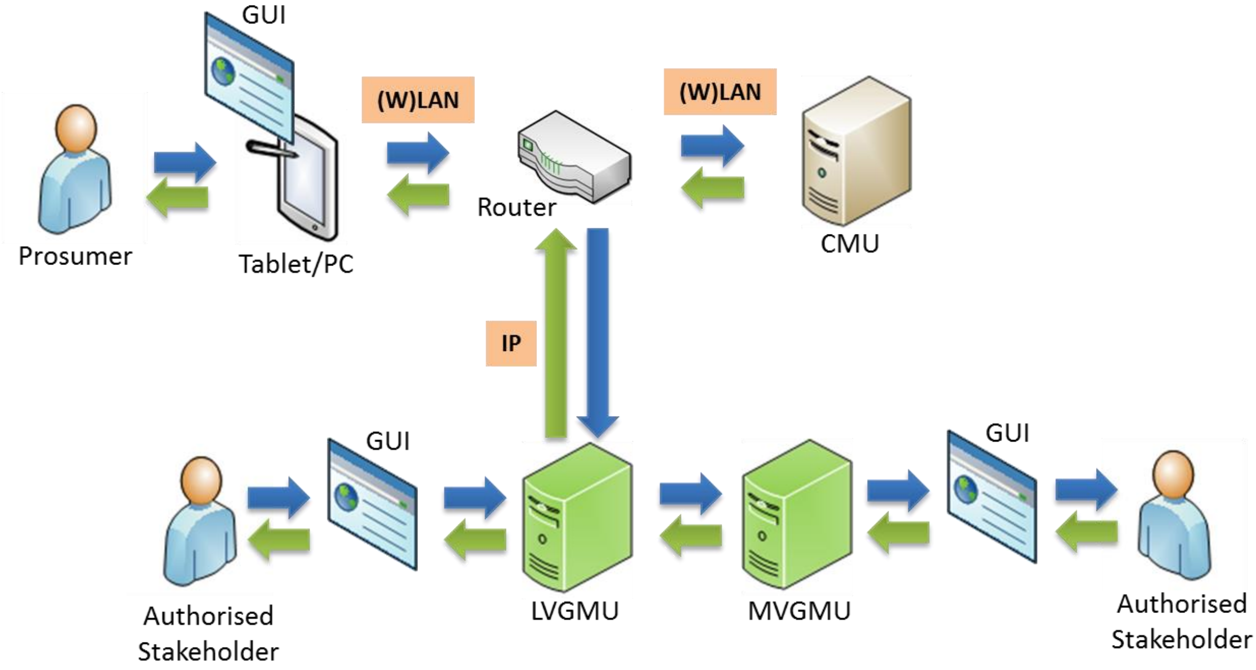

Figure 37: Use Case #08: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	User logs in to the e-balance system	A user of the e-balance system logs on to the system with her credentials.	User → GUI		Log-in screen
2	Users sets preferences	The user selects her data preferences	User → GUI		
3	MU applies data policy	The management unit applies the selected data policy and gives feedback in case new policies restrict functionality.	MU→GUI →User		

Table 30: Events and Actions for UC #8

Test procedures in the demonstrator

1. Attempt to use data during valid timeframe.
2. Attempt to use data with a lower or equal frequency than specified.
3. Attempt to use data with a higher frequency than specified.
4. Attempt to use data for the specified purpose.
5. Attempt to use data for unauthorised purposes.
6. Attempt to use data after expiration date.

5.2.4.17 UC #12: Multiuser privacy management in energy grid

Objective: To prevent data access by non-authorised stakeholders

Description: This Use Case implements the strategy on the handling of the data belonging to different system users. It prevents unauthorised access by means of authorisations. Security meta data is embedded with every data exchange. This meta data will indicate:

1. which stakeholder may have access to the data,
2. for which purpose this data may be used. A more detailed description of these purposes are and will be described in deliverables D3.2 and D5.4.

This Use Case will use an implementation of the e-balance architecture as visualised in Figure 38.

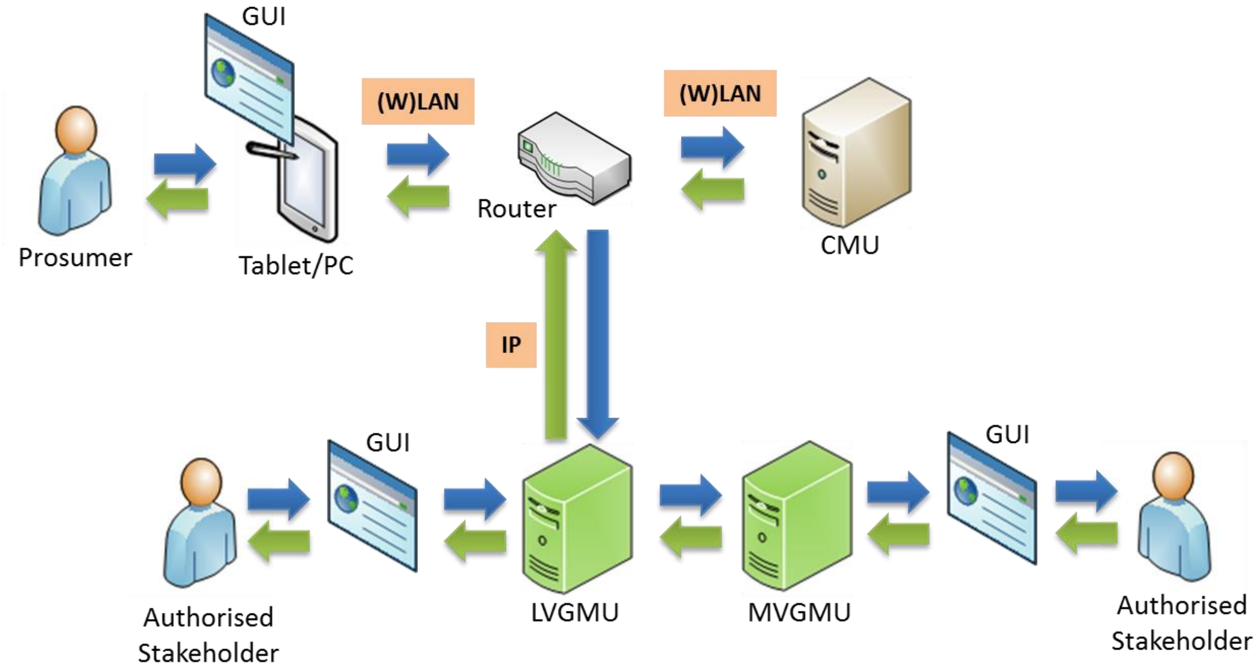

Figure 38: Use Case #12: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	User logs in to the e-balance system	A user of the e-balance system logs on to the system with her credentials.	User → GUI		Log-in screen
2	Data Access request	The user requests data she desires.	User → GUI		Data selection
3	Authorisation check	The system checks whether the user is authorised to get this information.	Internal MU		
4.1	Access granted	In case the user is authorised, access is granted.	MU→GUI →User		Data access feedback
4.2	Access denied	In case the user is not authorised, access is denied.	MU→GUI →User		Data access feedback
5	Data delivery	Data is supplied to the user in case access is granted.	MU→GUI →User		

Table 31: Events and Actions for UC #12

Test procedures in the demonstrator

1. Attempt to acquire data while authorised
2. Attempt to acquire data while not authorised

5.2.4.18 UC #11: (Virtual) Microgrid energy balancing

Objective: To operate a virtual microgrid combined with demand side management facilities

Description: Combining energy storage with frequency control capability and traditional DER, it is possible to operate the demonstrator as a microgrid. This Use Case adds demand side management to the equation. The research focusses on the required control power when demand side management is active. Furthermore, the microgrid will be expanded by an additional secondary substation, allowing to study DSM across a small piece of MV.

The central storage system is not designed to operate for long periods at a time. The research nature of the installation currently requires the installation to be manned during operation.

The focus of the e-balance project at Bronsbergen does not require the Bronsbergen grid to go into a real (disconnected) microgrid situation. Therefore, a *virtual* microgrid will instead be realised, by producing a steering signal aimed at minimising the net energy usage from the MV grid, while allowing energy exchange between the two secondary substations. This Use Case will use an implementation of the e-balance architecture as visualised in Figure 39. The “grid storage” component can be assigned to either LV-GMU or MV-GMU. For visualisation purposes, it is assigned to the MV-GMU.

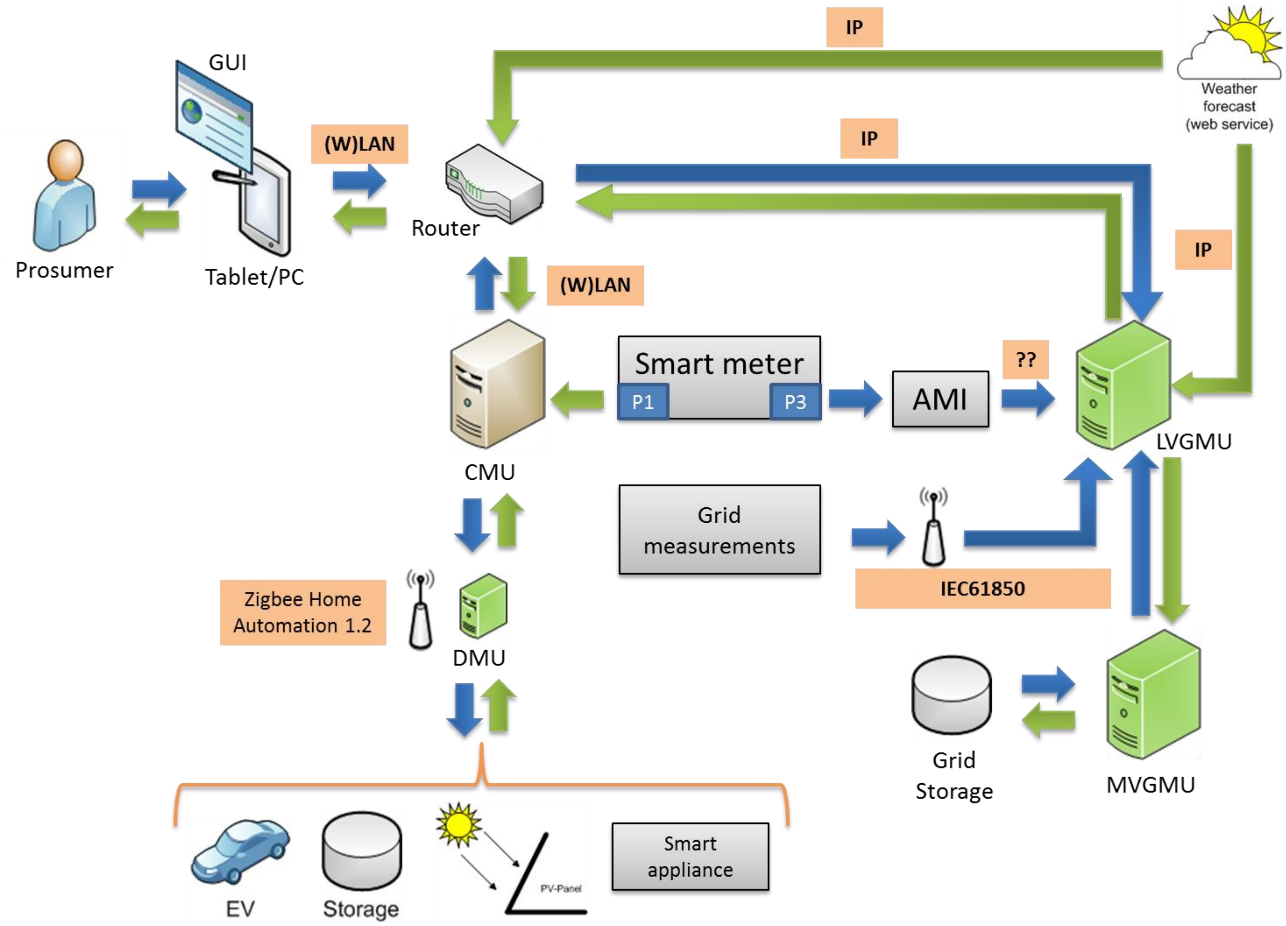

Figure 39: Use Case #11: involved architecture components at Bronsbergen demonstrator

Number	Event/Action	Description	Origin and destination of communication	Data Interface Primitive Types	GUI
1	Initiate e-balance demand side management	e-balance demand side management is activated	GMUs to CMUs		
2	Adjust desired profile	The energy being withdrawn from the grid at SS Bronsbergenmeer should leave SS Roelofs via the MV level, so that the net energy exchange of the two secondary substations combined is zero. This is used as input for the desired profiles of the LV-GMUs.	MV-GMU to LV-GMU		
3	Operate virtual DSM microgrid	By reducing the net energy exchange to zero, a virtual micro grid is approximated based on profile planning.			
4	Stability monitoring	Analysis on stability is performed			
5	Switch to frequency control mode	Frequency control mode is initiated at the central storage at cottage #58			
6	Stability monitoring	Analysis on stability is performed			
7	Control power monitoring	A record is made of the amount of control power that is needed in the DSM + frequency control mode			
8	Disable DSM	DSM is disabled			
9	Control power monitoring	A record is made of the amount of control power that is needed in the frequency control only mode			

Table 32: Events and Actions for UC #11

Test procedures in the demonstrator

1. Check proper operation of balancing system. UC #9 must have been successfully tested and implemented.
2. Check proper operation of the central storage in ‘net zero exchange’ mode.
3. Check proper operation of the central storage and its inverters in frequency control mode.
4. Check the proper operation of the grid in stable virtual islanded mode
5. Check whether the frequency control actions are reduced when the e-balance system is operational

5.3 Germany, in-lab IHP

5.3.1 Implementation of e-balance at the in-lab demonstrator

The in-lab demonstrator allows in some cases a larger flexibility with respect to the allowed test scenarios. As such it has the potential to demonstrate all Use Cases and will act as a test bed for the other two demonstrators. This test bed facilitates testing of the interaction between hardware components and software versions. This enables a quick debugging capability for the complex exchange of information between all the hierarchy components. In the in-lab demonstrator we intend to verify the implemented functionality of the set of e-balance features defined by the Use-Cases as given in Table 33. These Use Cases mainly overlap with those demonstrated in the other two real-life demonstrators.

Use case #	Title
	Energy balancing
3	Distributed generation balancing and resilience
4	Energy consumption and production agreement
9	Intelligent home appliance energy consumption balancing
10	Additional sensors for appliance energy consumption balancing
25	Demand prediction
26	Prediction of renewable energy generation
	Neighbourhood monitoring
13	Neighbourhood power flows
14	DER power flows
15	Optimized power flow
18	Quality of supply measurement
20	Fraud detection
21	Losses calculation
22	LV fault detection and location
24	Fault prevention (LV)
	Customer data handling and customer interaction
1	Strategy-driven decision on the use of produced energy
2	Energy consumption priorities in case of energy delivery limitations
5	Strategy-driven decision on the usage of grid-connected DER (restated)
7	Customer interfaces for better efficiency and interaction
8	Handling of current and historical customer data for improved safety and privacy
12	Multiuser privacy management in energy grid
	Smart Medium Voltage Grid
11	Microgrid energy balancing
29	MV fault detection and location
30	Automatic grid service restoration – self-healing (MV)

Table 33: The e-balance Use Cases allocated to the in-lab demonstrator

5.3.2 The roll-out of the in-lab demonstrator

The in-lab demonstrator does not have a defined part of the grid that it will cover. The grid to be emulated will be created while the in-lab demonstrator will be deployed. The in-lab demonstrator will be consisting of a set of building blocks that can be connected together forming both the grid and the e-balance energy management system running on top of this grid. The topology of the grid will be based on the real world demonstrators with possible modifications due to limiting the number of individual customers (combining several customers in one block) and due to enhancing the given topologies with additional components like switches to show additional system features. The building blocks will be described in the following section.

5.3.3 The grid aspects considered by the in-lab demonstrator building blocks

The in-lab demonstrator provides a playground for the work on the energy management mechanisms as well as on the different aspects of the e-balance system. But, from its basic definition, the in-lab demonstrator is an emulator of the energy grid and as such can only address a subset of all the aspects to be observable in the real grid. The following subsections describe the aspects that are to be addressed by the in-lab demonstrator and how we want to address them. Some of this information was already presented in previous sections, but it is summarized here, consolidated and extended.

In general, the scale of the voltages and currents is as follows. The LV is 24V AC, the MV is 48V AC, the currents are scaled down by the factor of 1000, i.e., 1A is represented by 1mA. The in-lab demonstrator supports only a single phase.

5.3.3.1 Primary Substation (PS)

The primary substation block will be able to emulate voltage drop due to increased load. The block will have a defined maximum power, it can deliver to the grid, and as the current drawn reaches its maximum the voltage level will be controlled accordingly.

The primary substation block will also allow defining/programming the wave to be used by the block as the sine curve for the generated energy signal.

5.3.3.2 Transmission lines

The transmission lines block will allow connecting different elements (capacitors, coils, resistors) to control the parameters of the lines. These elements can be connected in different configurations (parallel or serial).

The transmission lines can also be disconnected or short-cut to emulate extreme cases.

5.3.3.3 Secondary Substation (SS)

The secondary substation block will consist of a transformer, but additional losses can be introduced to the circuit with additional elements, to check their influence.

5.3.3.4 Grid Switch block

The grid switch building block will also provide connectors to extend its basic functionality with emulation of losses and energy signal distortion.

5.3.3.5 Customer (or DER) building block

From the e-balance system perspective the CMU is the core of the customer building block. But from the in-lab demonstrator point of view the block has far more functions than those provided by the CMU. The customer building block will consist of two modules; the energy production and the energy consumption part can be both configured to consume and produce energy according to a schedule. The energy producing part adapts the voltage at its output to assure the current flow in the right direction.

The energy consumption and production can be defined in a way that external drivers, like weather parameters, are influencing them. These parameters will be made available to the respective modules of the block.

Due to the flexibility in describing the energy use and production a diversity of real grid components can be emulated using this kind of block. The block can represent customers only consuming energy, prosumers, but also grid components like energy storage or energy production plants (PV, wind, etc.). The right programming of the module behaviour allows that. Depending on the kind of grid element it represents the block modules will provide the appropriate interface to the management unit (CMU or DERMU) that resides in the building block. Depending on the defined flexibility in controlling the behaviour of the block a diversity of ways to interact with the production and consumption will be provided.

5.3.4 System validation

In order to perform the validation of the system in the in-lab demonstrator a series of means will be defined that allow recording data during the work of the demonstrator and analysing this data on-line as well as afterwards. This includes creating a log file on each system device and the possibility to collect these files in one central tool that allows analysing how the system works and performs at each system device and as a whole.

The recorded data includes all the system variables and their changes for all the management units. These variables store the measured grid parameters as well as the results of their processing. Mainly all the data gathered, processed and generated by the system on the middleware level and exchanged between the devices will be recorded.

5.3.4.1 Technical validation

In order to perform the technical validation of the system components in the in-lab demonstrator the recorded data will be analysed to verify if all the system components work correctly and according to their specification, i.e., the data is gathered and processed correctly and if the data exchange works properly. This procedure has to be executed for all the Use Cases supported by the demonstrator.

Several test scenarios will be defined for a single Use Case (functionality) to determine how the differentiation on the configuration influences the system working. For instance, interfering in the communication between the system devices or configuring the data channels differently can be used to put the system under stress. Further, different grid settings can also expose problems, for instance with scalability. Thus, a proper definition of the test scenarios is a crucial point in the technical validation process.

The technical validation focuses rather on the validation of the system modules on individual devices and on the verification of the correct data exchange, than on the actual evaluation of the energy balancing algorithms.

5.3.4.2 E-balance concept validation

Once the basic technical correctness of the system components is validated, the in-lab demonstrator can be used to execute a series of tests that allow evaluating and tuning the e-balance energy management algorithms. The developed algorithms can be applied under a set of different grid settings and parameterisation to reveal their weaknesses and to allow their further improvement. The diversity in grid settings may include changes to the grid topology by rebuilding the grid model from the building blocks, but it mainly consists of reconfiguring the customer blocks, causing their different behaviour with respect to energy production and consumption.

The e-balance concept validation focuses thus on the testing of the energy control mechanisms under a diversity of conditions, to evaluate how good and efficient they behave, e.g., for changing percentage of actively involved customers.

5.4 Non-demonstrated Use Cases.

The project does not take “Economic dispatching” and “Energy efficiency” definitions into account. The Use Cases #16 and #19 have been marked for deletion in a restatement of D2.1 and will thus not be demonstrated.

Use case #	Non-demonstrated
16	Economic dispatch
19	Energy efficiency measurement

Table 34: Non-demonstrated Use Cases

Annex A Batalha secondary substation circuits

Visualisation of the specific LV circuits of SS PT007 and PT019. Note that green (good voltage level), yellow (near regulatory voltage level limit: +/- 10%) and red balls (low voltage level) reflect the voltage level at deliver points according to an EDP plan tool. Figure 40 to Figure 45 show the individual feeders that together form the coverage area of PT007. The combined picture is given in Figure 3.

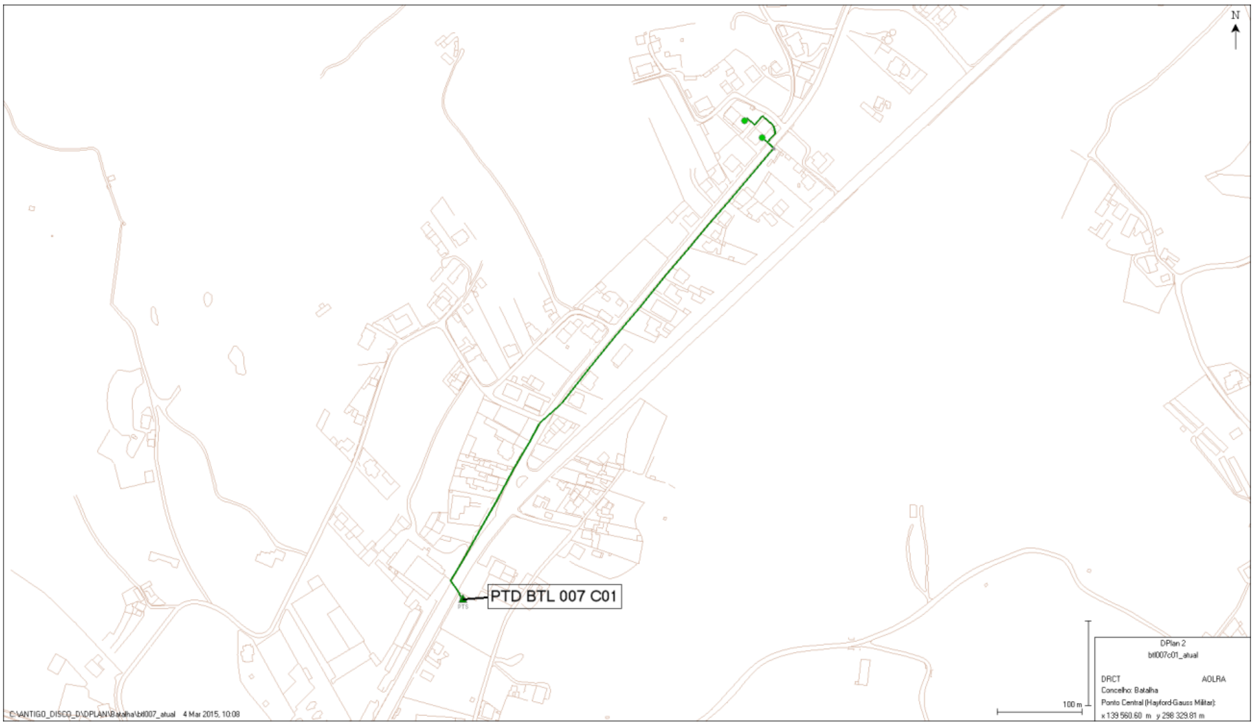

Figure 40: PT007 circuit 1

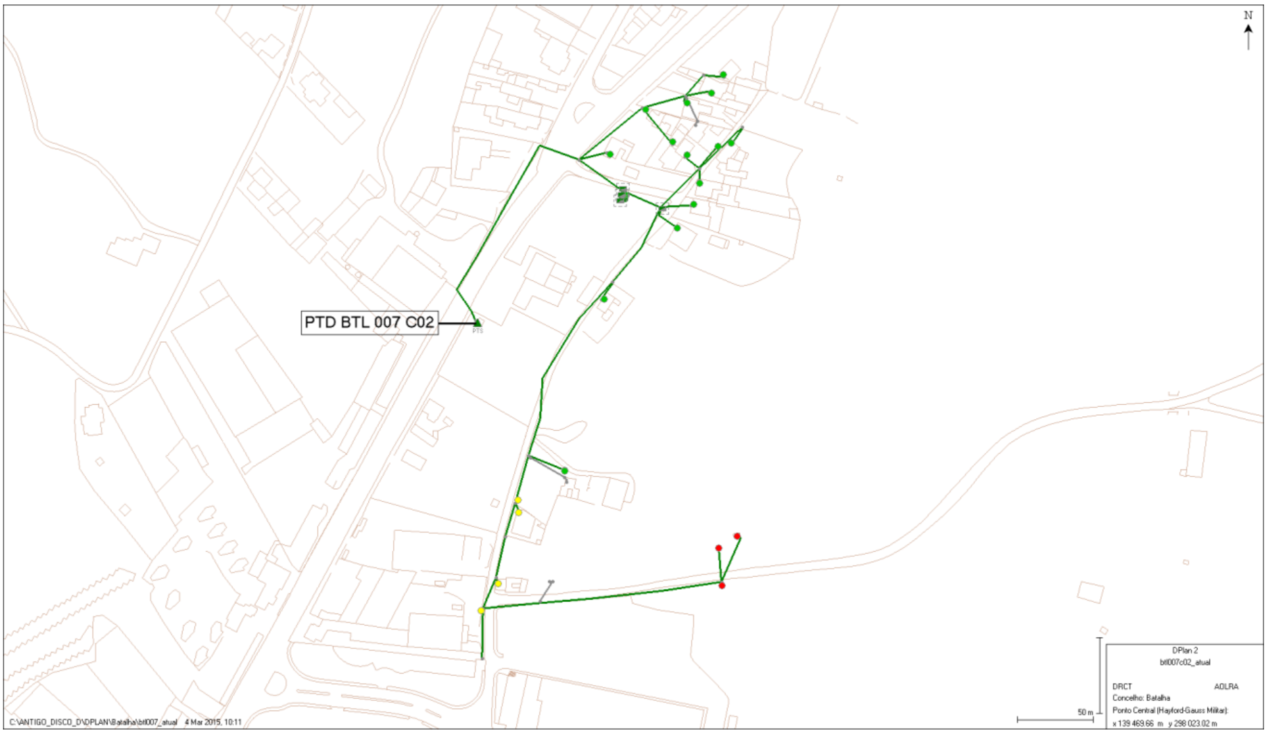

Figure 41: PT007 circuit 2

Figure 42: PT007 circuit 3

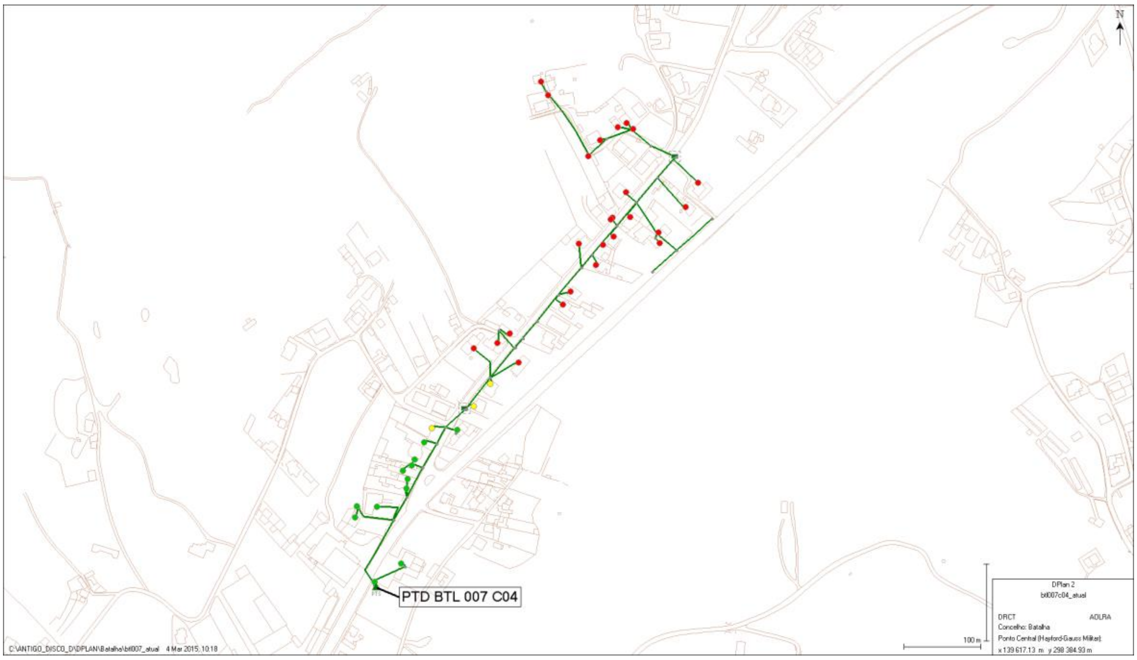

Figure 43: PT007 circuit 4

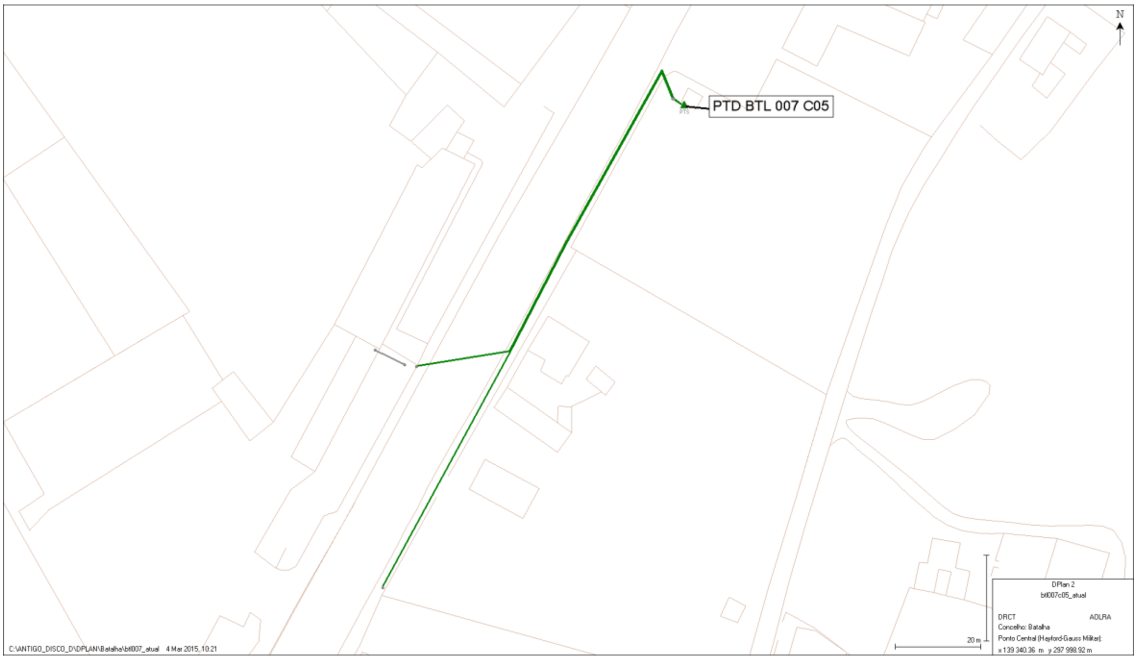

Figure 44: PT007 circuit 5

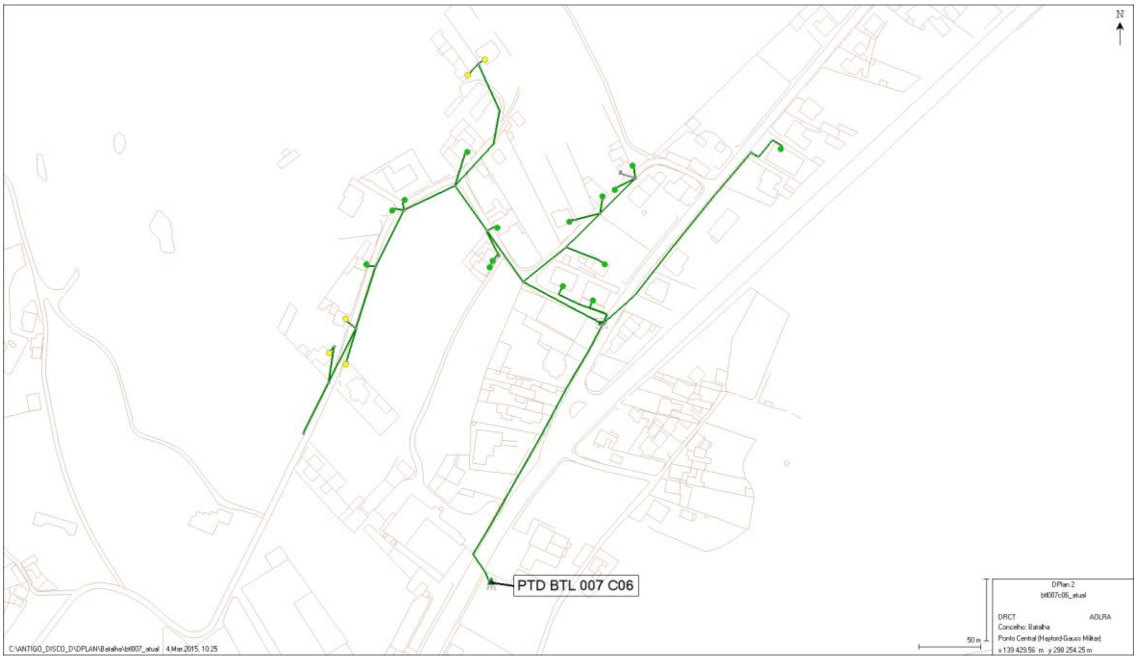

Figure 45: PT007 circuit 6

Annex B Bronsbergen grid data

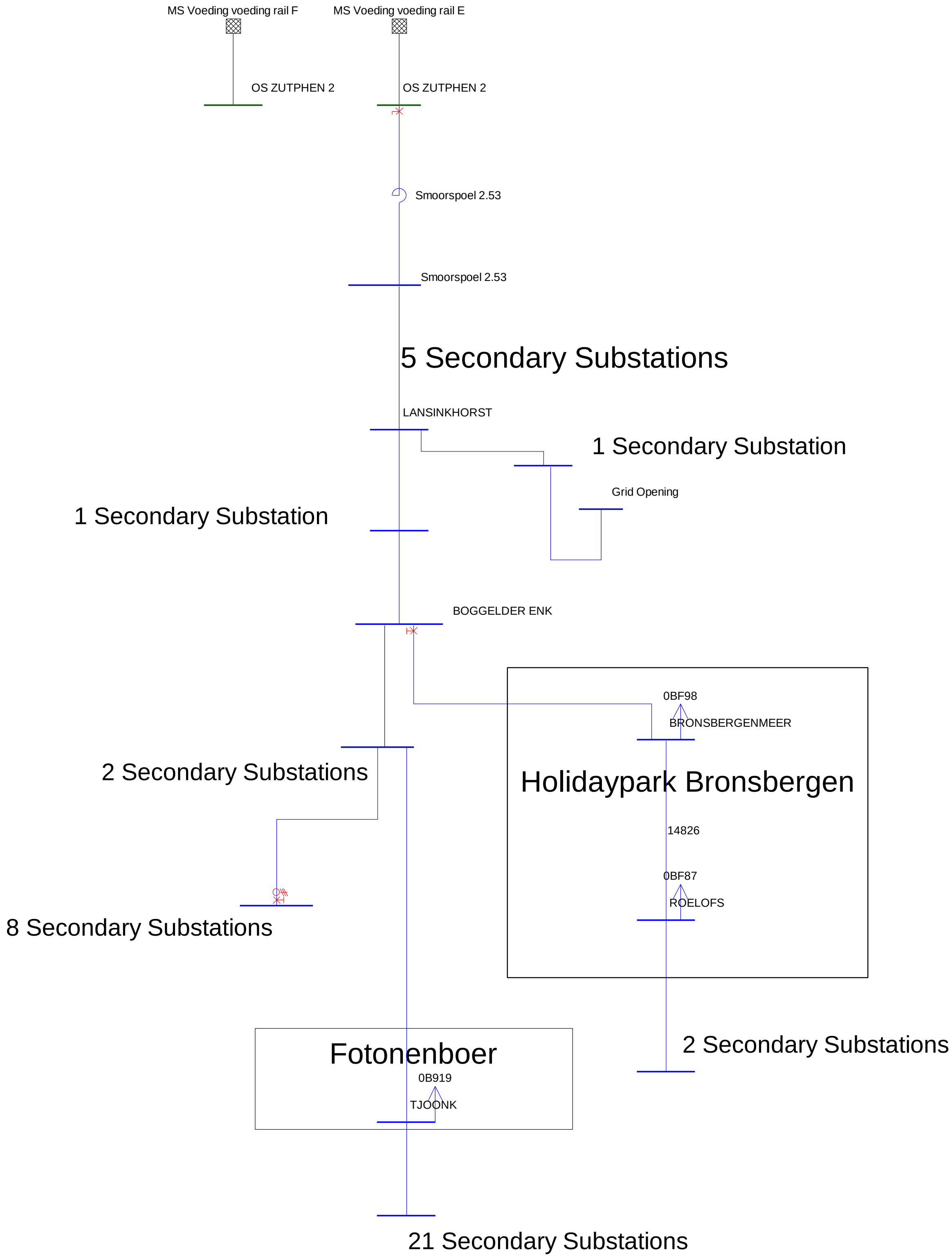

Figure 46: Schematic overview of the MV feeder at which Bronsbergen is connected

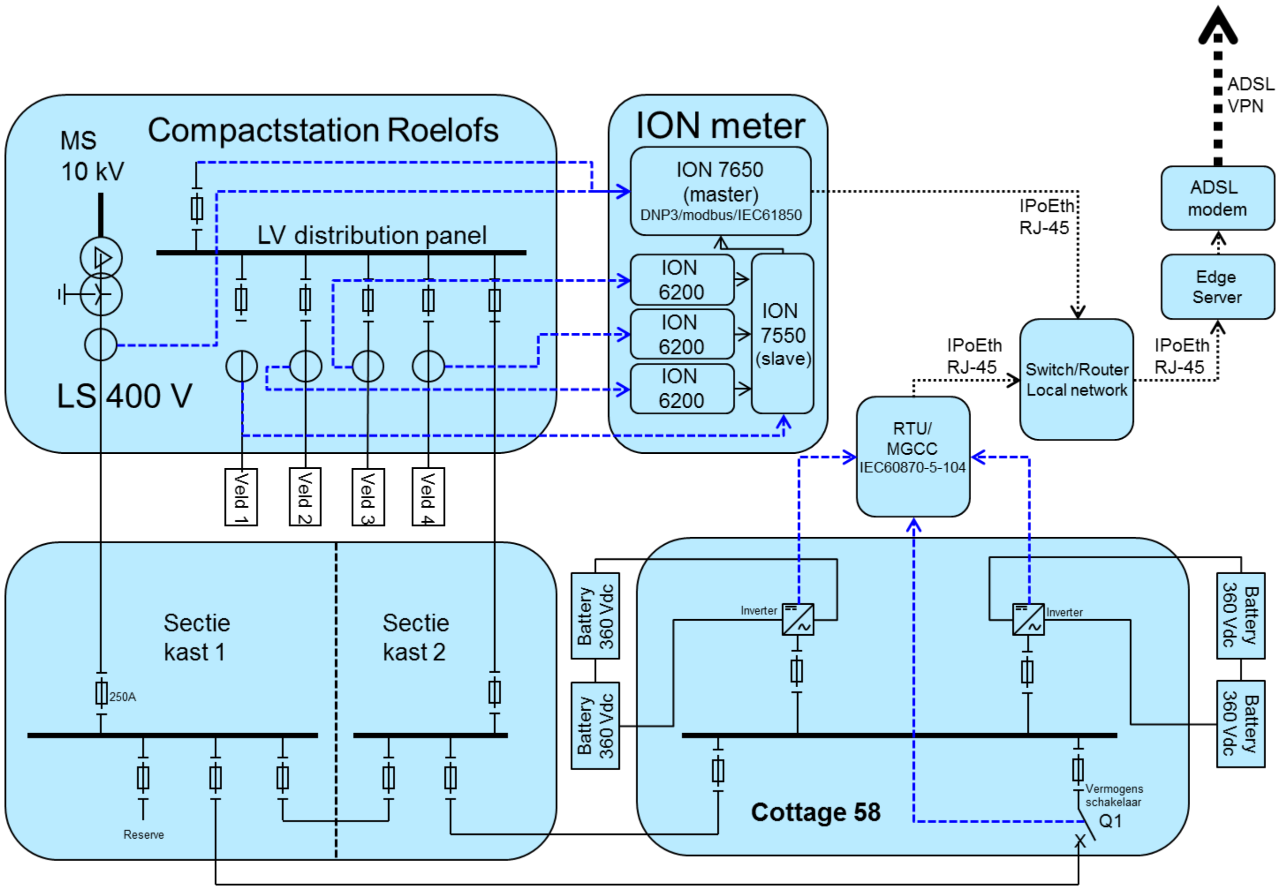

Figure 47: Schematic overview of Secondary Substation Roelofs and Cottage 58

Annex C In-lab demonstrator building blocks

The building blocks of the in-lab demonstrator

The electricity grid defines the connections between producers and consumers of energy. Transmission lines have parasitic properties like inductance and resistance, so these aspects should be properly emulated as well. The use of proper transformers is necessary to introduce realistic losses while transforming the electricity between voltage levels. Representing customers that actually consume and produce energy is crucial for proper emulation of the real energy grid allowing for instance operating in islanding mode. For a meaningful application of the tool it is crucial to properly define the required and the neglected features of the real grid components to be represented by the in-lab demonstrator building blocks.

In the in-lab demonstrator we decided to scale down the voltage levels to make it a safe model of the grid. The LV grid will operate at 24V AC and MV grid at 48V AC to meet safety reasons. The HV grid will be the 230V from the wall socket, but it will not be accessible and transparent to the user. The real world currents are scaled down by a factor of 1000. Thus, if a household has a grid connection of 50A it will be represented by 50mA in the in-lab demonstrator.

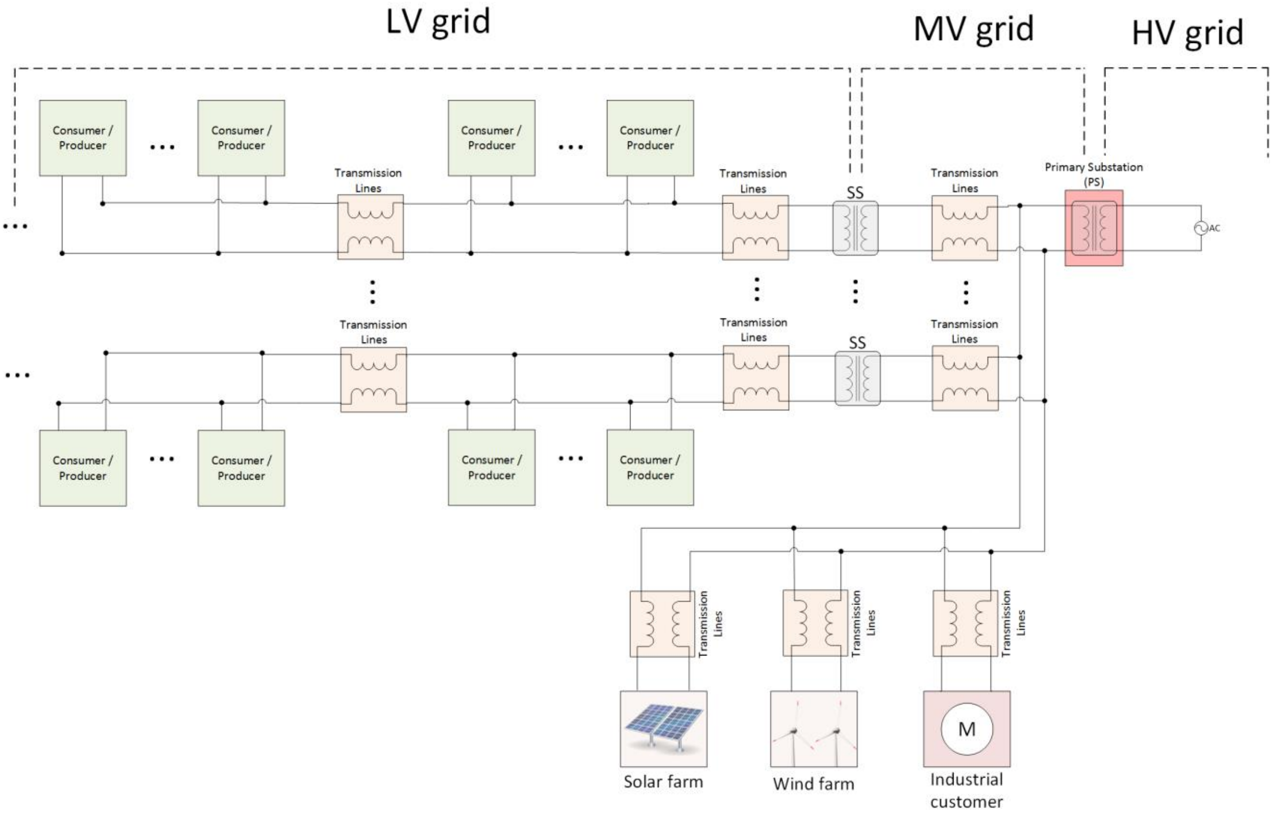

Figure 48: An example of the grid topology

Figure 48 shows an example of (a part of) a grid topology. In this grid there is only one primary substation with bulk generation and the HV part of the grid behind it, but there are numerous consumers and producers in the LV part as well as numerous conversions between MV and LV (secondary substations). Additionally, there are producers with a solar farm, a wind farm and an industrial customer (consumer) in the MV part. This exemplary grid could represent a town with one power plant, numerous settlements in different locations in the town, additional solar/wind farms near bigger settlements and industrial customers on the outskirts of the city.

The purpose of the emulator is to represent grid blocks physically with electronic circuits that would be able to form different configurations of the grid. Each block is an abstract representation of the part of grid that emulates this real grid accordingly. In the following sections each kind of in-lab demonstrator building block will be explained separately.

Primary Substation (PS)

Figure 49 shows the primary substation block. This block represents a MV power source in the grid with high current output capabilities. As the HV grid is transparent, this block physically outputs the generated power. Therefore it may be thought to be like a power plant, its distribution lines and the PS transformer.

This block electrical circuitry is similar to Producer in MV, however considering much higher output power it is designed to deliver large amounts of current. Therefore this block is unique in the emulator.

Output voltage of the PS is scaled down to 48V AC (the MV level). The maximum output current should be at least as large as the sum of a large amount of energy users. On the other side, too much power should not be dissipated in the emulator as it would introduce thermal and high current paths problems.

The primary substation block will be able to emulate voltage drop due to overload. The block will also incorporate the MVGMU that will collect the measurements on both sides of the primary substation transformer (HV and MV part of the grid) as well as all that data from the sensors in the MV-FAN and all the LVGMU in the MV part.

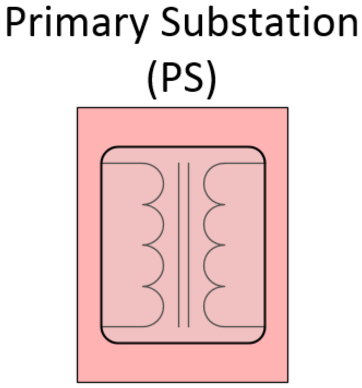

Figure 49: The Primary Substation block

Transmission lines

Transmission lines, a block representation is shown in Figure 50, emulate long connections between parts of the grid in LV and MV. Effects that come from long distance connections, such as reactive power, are mostly seen and present in MV. In contrast, a LV grid is as local as possible, so the distances are much smaller and these effects are less dominant.

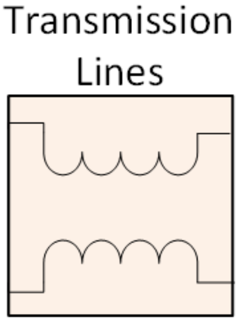

Figure 50: Transmission lines block

What matters in reality the most for transmission lines is its series inductance and resistance, as well as capacitance to ground, so those parameters will be considered in the building block. A single transmission line block includes connectors for the two wires it consists of. These connectors are visible and easily available, so that different components (resistors/inductors/capacitors) can be put to emulate different types of lines and different distances of the transmission line.

The block will be generic to be applicable for both the MV and the LV part of the grid. It will include sensors that measure current and voltage at both ends of the transmission line. These sensors will become part of MV-FAN or LV-FAN, depending on the part of the grid the block will be applied within.

Secondary Substation (SS)

Secondary substation block, as shown in Figure 51, consists of a transformer that exchanges energy between the MV and LV parts of the grid. In most common type of operation this block will lower the voltage by changing MV to LV. That happens when there is more consumption than production in LV side. However, raising the voltage from LV to MV is also possible, which would happen when more energy is produced than consumed in the LV part of the grid.

In reality secondary substation transformer introduces conversion losses that affect efficiency. Those losses are present because of transformer's internal resistances, but besides that the transformer will have parasitic inductances and capacitances.

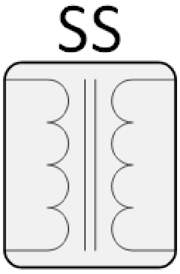

Figure 51: Secondary substation block

The secondary substation block will be realized as a 48V AC to 24V AC transformer with its losses matching conditions in reality. Voltage and current measurements will be made on both sides of the transformer to provide the necessary data. This task will be realized by the LVGMU that will also be included in the secondary substation building block. The LVGMU will also communicate with all the sensors and actuators in the LV-FAN and with all the CMUs (or DER-MUs) in the customer blocks in the respective part of the LV grid.

Grid Switch block

The grid Switch building block (see Figure 52) represents a controllable switch, i.e., an actuator that is part of the LV-FAN or part of the MV-FAN and is thus controlled either by the LVGMU or the MVGMU, respectively.

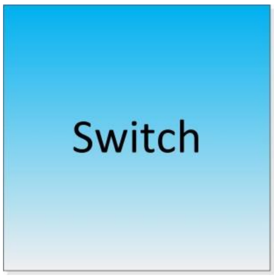

Figure 52: The Switch building block

The general switch block is realised as a single-pole double-throw (SPDT) switch with a common (COM) connector that may be either output or input and two connectors; one normally open (NO) and one normally closed (NC). This allows either closing or opening a single connection, but it may also be used to connect the COM either to NO or to NC. As already mentioned, the corresponding management unit controls the state of the switch.

The switch block is not only an actuator; it also incorporates sensors to measure voltage and current in order to provide feedback on the correct switch function.

Customer (or DER) building block

The in-lab demonstrator building block used to emulate the customers in general is presented in Figure 53 This general block can represent a variety of grid elements that consume and produce energy. It may represent a single household or a DER, but it may also represent a complex neighbourhood.

This block consists of the energy consuming part and the energy producing part. This allows emulating the energy consumption and the energy production in the time domain in parallel. This enables emulating real life energy generation and consumption dependent on time and weather conditions.

Figure 53: The Customer (or DER) building block

In the block, the consuming part is separated from the producing part. Those two meet at the junction between the block and LV grid.

The consuming part consists of the resistive load (main type of load) and the capacitive or inductive load that can introduce phase shift in the grid. This way not only active power consumed can be emulated, but also the distortion coming from inductive or capacitive loads introduced by the customer devices.

The part of the block that generates the energy can represent any kind of energy production that forces the energy into the grid. The sinus wave for the generated power can be influenced to emulate a diversity of energy quality scenarios.

Both consumption and production are measured with sensors (voltage and current). These measurements are collected by the CMU (or DERMU), present in the block. The SM will also be present in the block. It will be realized as a part of the CMU (or DERMU).

Additionally, a SM controlled switch will be applied to allow the energy supplier or DSO to disconnect the given customer from the grid.

The Customer or DER block will be realized as a generic module that can be applied to represent the above mentioned functionality for both the LV and the MV part of the grid.