

Specifications of functional requirements

Version 2.0

Deliverable 2.2

Kyriaki Antoniadou-Plytaria
Gustavo Pinares

31 January 2018

INTERNAL REFERENCE

- **Deliverable No.:** D2.2
- **Deliverable Name:** Preliminary functional requirements for (multiple) micro-grids integration
- **Lead Partner:** Chalmers
- **Work Package No.:** 2
- **Task No. & Name:** 2.2 Specifications of functional requirements
- **Document (File):** m2M-Grid_Deliverable 2.2_Specification of functional requirements.docx
- **Issue (Save) Date:** 2018-01-31

DOCUMENT SENSITIVITY

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

DOCUMENT STATUS

	Date	Person(s)	Organisation
Author(s)	31-01-2018	Kyriaki Antoniadou-Plytaria Gustavo Pinares	Chalmers Chalmers
Verification by			
Approval by			

CONTENTS

LIST OF ACRONYMS	5
1. INTRODUCTION	6
1.1 Physical micro-grids	7
1.2 Commercial micro-grids.....	7
1.3 Control functions	7
1.4 Objectives.....	7
1.4.1 Micro-grid	8
1.4.2 DSO.....	8
2. PHYSICAL SYSTEM COMPONENTS	8
3. CONTROL SYSTEM COMPONENTS	9
3.1 Connecting components and devices	9
3.2 Advanced metering infrastructure (AMI)	10
3.3 Controllers.....	10
4. CONTROL AND COORDINATION SCHEMES	10
4.1 Hierarchical control of micro-grids	11
4.1.1 Primary control.....	11
4.1.2 Secondary control.....	11
4.1.3 Tertiary control	11
4.2 From operation planning to real-time control	12
5. FUNCTIONAL REQUIREMENTS.....	12
5.1 Interconnection and operation requirements	13
5.1.1 MC requirements	13
5.1.2 DMS requirements for the integration of multiple MCs	13
5.1.3 Islanding and resynchronization	14
5.1.4 IEEE 1547 Standard	14
5.1.5 EU regulations.....	14
5.2 Monitoring and interoperability requirements	15
5.2.1 Smart meters functional requirements	15
5.2.2 IEEE P2030.7 Standard	16
5.2.3 IEC 61850 Standard.....	16
5.2.4 Modbus Protocol	16

5.3 ICT requirements.....	16
5.3.1 Field area network (FAN)	17
5.3.2 Enabling technologies.....	17
5.3.3 Data transmission.....	18
5.4 Requirements for future scenarios of micro-grids	18
6. REQUIREMENTS FOR INDUSTRY APPLICATION	19
7. CONTROL APPLICATIONS AT THE DEMONSTRATION SITES	19
7.1 Chalmers	19
7.1.1 Description of the demonstration site	19
7.1.2 Control application.....	21
7.2 Positive footprint housing	22
7.2.1 Description of the demonstration site	22
7.2.2 Control application.....	22
7.3 SOREA's micro-grids.....	22
7.3.1 Description of the demonstration site	22
7.3.2 Control application.....	22
7.4 Functional requirements for the proposed control applications	27
8. REFERENCES	27

Disclaimer

The content and views expressed in this material are those of the authors and do not necessarily reflect the views or opinion of the ERA-Net SG+ initiative. Any reference given does not necessarily imply the endorsement by ERA-Net SG+.

About ERA-Net Smart Grids Plus

ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

www.eranet-smartgridsplus.eu

List of acronyms

AMI	Advanced Metering Infrastructure
BEMS	Building Energy Management System
BESS	Battery Energy Storage Systems
CHP	Combined Heat and Power
DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distribution Management System
DSO	Distribution System Operator
EMS	Energy Management System
ESS	Energy Storage Systems
FAN	Field Area Network
ICT	Information and Communication Technology
IED	Intelligent Electronic Device
MC	Micro-grid Controller
PCC	Point of Common Coupling
PEC	Power Electronic Converter
PLC	Programmable Logic Controller
PMU	Phasor Measurement Units
PV	Photovoltaic
RES	Renewable Energy Resources
RTU	Remote Terminal Units
SCADA	Supervisory Control and Data Acquisition System
V2G	Vehicle-to-Grid
WLAN	Wireless Local Area Network

1. Introduction

The pursuit for large-scale deployment of environmentally friendly energy resources has put focus on the high integration of renewable energy resources (RES). The Paris climate agreement (in effect from November 2016) has set aspiring targets for reduction of CO₂ emissions, which can be met with increased utilization of distributed RES in the power systems, especially at the distribution level. The intermittent nature of RES motivates the need for special control measures within the network to which they are integrated and, most importantly, the need for coordination among available resources. A promising alternative to the expensive investments on distribution network infrastructure is the micro-grid, which is considered the building block of the smart grid [1]. The micro-grid is a cluster of producing and consuming units (distributed generation, flexible loads, storage). It can operate in connection to the grid (grid-tied or networked micro-grid) and may also have the capability to operate autonomously (islanded or stand-alone micro-grid). The micro-grids can increase the integration of renewable generation as well as provide resiliency to the grid and improved reliability. At the same time, the operation of the main grid can be more efficient with reduced operational and maintenance costs.

The main goals of the m2M-Grid project are:

- To develop an interface between the control system of the distribution network and the individual control system of the micro-grids.
- To develop interface for the interaction of the micro-grids with the market.
- To enhance the network planning process by considering the deployment of multiple micro-grids.
- To identify the functional requirements that are needed for the interoperability of the micro-grids before the physical tests at the demonstration sites.

This report focuses on the specification of functional requirements and defines the functional requirements within the three layers of the micro-grid operation:

- Hardware layer: This is the physical system that includes the micro-grid components and the physical connections of the resources to the electricity network. The hardware layer also includes the components that constitute the hardware prototype of the control architecture.
- Middleware layer: This corresponds to the information and communication technology (ICT) framework, i.e. standards, protocols, and enabling technologies for data exchange, feedback and control signals.
- Service layer: This considers the control and coordination algorithms that will be applied to simulate real-time energy transactions and control of the network. Different time scales apply to the coordination and the interaction of physical and commercial systems. Control decisions start from the day-ahead energy scheduling, they are updated during the day and they are finalized at real-time operation. The modeling of the micro-grid components is also a part of this layer.

The main identified challenge is the coordinated operation of the physical systems (micro-grid, distribution network) and the commercial entities (aggregators). This challenge will be addressed at the service layer with control functions that will take into account conflicting objectives of the stakeholders (e.g., micro-grid operator and market operator). It will also be addressed at the hardware and middleware layer with the design

of hardware prototypes and control architectures that will enable interoperability of different control systems and flow of information between physical and commercial entities.

1.1 Physical micro-grids

The micro-grid can be defined as a cluster of distributed resources (generation, storage) and customers (loads) that are managed by a controller. If the resources and the loads are physically interconnected as part of the same grid (e.g. under the same MV/LV transformer), then this cluster of resources is called physical micro-grid. A physical micro-grid can even be disconnected from the grid and operate in islanded mode if the amount of available generation can supply its loads. The islanding also depends on the micro-grid's or the distribution system operator's (DSO) operation objectives and it can even be unintentional (e.g. after a fault). This project focuses on the operation and control optimization of the distribution network that contains multiple grid-tied micro-grids. In the grid-tied operation mode of the micro-grid, the DSO views the physical micro-grid either as a generation unit or as a load.

1.2 Commercial micro-grids

A commercial micro-grid is a cluster of resources and/or loads that are not necessarily part of a common grid (they might be located on different feeders or under different secondary transformers). The aggregation and management of the resources is driven by a commercial aim: the participation of the commercial micro-grid to energy or ancillary services market. Therefore, the commercial micro-grid is a market actor, i.e. an aggregator of flexible resources.

1.3 Control functions

For the coordination of multiple micro-grids both fast regulating devices (e.g., power electronic converters owned by the micro-grid) and conventional control mechanisms (e.g., remotely controlled switches) will be employed to achieve the global operational objectives of the interconnected system. Four main control functions that are applied for the optimal operation of the distribution network [2]–[6] have been considered in the project:

- Voltage control
- Congestion management
- Phase balancing
- Frequency regulation

These control functions will be applied for both control within the micro-grid and coordination of the system of multiple grid-tied micro-grids.

1.4 Objectives

The operational objectives of an interconnected multi-area power system can vary significantly among the different stakeholders. Micro-grid owners/aggregators and customers can benefit from peer-to-peer energy transactions that avoid buying expensive energy from the utility grid. However, without the proper coordination, this may increase the operational costs for the distribution network or even require upgrade in the grid infrastructure, which the system operator tries to postpone. Moreover, control functionalities that are provided both from the micro-grid operator and the DSO might interfere with each other. In such a case, the micro-grid might even be denied e.g. to freely regulate its voltage. Therefore, the optimal operation of the power system needs to be multi-objective and take into consideration multiple criteria.

1.4.1 Micro-grid

The micro-grid operator will seek to optimize the dispatch of its resources in order to maximize its profit. The profit can be maximized either by minimizing the energy cost and the cost of operation or by maximizing the revenue through participation in energy or balancing markets. A micro-grid with physical connections to other grids/micro-grids has more opportunities for energy transactions and therefore it is expected that the grid-tied mode of operation is more advantageous than the islanded mode of operation in terms of operation planning and energy scheduling optimization. Unless there are resiliency purposes, the islanding of micro-grid can be virtual (zero exchange of power with the main grid) and an interconnected micro-grid could sell this flexibility in order to reduce peak demand and solve congestion problems for the utility grid.

1.4.2 DSO

The distribution system operator will seek to minimize the energy and operation cost and, at the same time, optimize the grid operation. The main goal of the optimal operation will be to minimize power losses while keeping within statutory limits (voltage, thermal limits, frequency). Therefore, it is important to investigate the impact of the micro-grid control functions on the power losses of the distribution system in such a way that the system operational objectives can also be defined.

For a robust operation against the intermittency of the RES or abrupt demand changes it is important to minimize the voltage deviations on the buses in such events. However, minimizing voltage deviations does not necessarily minimize power losses. The optimal voltage profile needs to be determined by the goals of the DSO. For example, for energy saving the DSO can opt for a reduced voltage profile along the feeders or impose stricter limits on the permitted voltage deviation on a critical bus.

2. Physical system components

Smart grids take advantage of flexible distributed resources to optimize the operation of the distribution system through advanced control. The flexible resources can be microgenerators, also called distributed generation (DG) units, energy storage systems (ESS), and flexible loads. Aside from their main functions (produce power, store power, consume power), these resources may have in addition regulating capabilities (e.g., reactive power and frequency regulation) that can also be utilized by the smart grid operator (micro-grid, DSO). The interconnection hardware, i.e. the interface between the physical components and the distribution system, is very important for the integration of these resources in the control system. Usually, the distributed resources (for instance, solar cells, battery ESSs) in a micro-grid as well as the points of connection to the main grid or other micro-grids have a power electronic converter (PEC) interface. PECs have advanced control capabilities in terms of speed response and they can control their output in a smooth way. Apart from the flexible resources, there can be remotely controlled switches and devices that can provide reactive compensation to the network, such as capacitor banks (CBs), the static var compensator (SVC) and the static synchronous compensator (STATCOM), respectively.

A micro-grid or even the end-user can combine these flexible resources, enhance its control over generation and/or consumption, become an active prosumer (a market actor that is capable of both generating and consuming), increase its autonomy and reduce the impact of uncertainties in the energy scheduling. The DER can be dispatchable (e.g., diesel generators) or non-dispatchable DG units (e.g. solar panels, wind turbines) as well as ESS. Intermittent or non-dispatchable DG units are usually scheduled to operate at maximum power output unless there are technical limitations. In that case, the alternative is power curtailment, unless there is an ESS. If there is enough storage capacity, then an intermittent DG unit can operate as dispatchable DG unit and its power injection can be fully controlled. ESS technologies include battery energy storage systems (BESS), compressed air energy storage (CAES) systems, pumped hydro, flywheels, power-to-heat, and (vehicle-to-grid) V2G solutions.

The loads or consumers of a micro-grid can also be considered as flexible resources, when demand is directly controlled or responsive to price signals. Flexible loads include thermostatically controlled loads (e.g., heat pumps), where power consumption is dependent on temperature and electric vehicles, where power consumption is dependent on charging rate. Other controllable loads can only control their on/off status and not their power consumption. These can be switched on/off at any time (e.g., ventilation) and others can be switched off only between cycles of operation (e.g., dishwashers, laundry machines).

A micro-grid is usually equipped with a mix of micro-sources that include either storage or dispatchable micro-generators (e.g., small diesel generators) to provide black start capability in case the micro-grid needs to operate in island mode. For autonomous operation, increased reserve capacity must also be considered due to the large share of renewable generation. EES are necessary for the grid-connected mode as well, so that the micro-grid operator can provide an alternative to its customers, when generation from renewable sources is low.

3. Control system components

There are three types of control systems that have to interact in the project for the optimal operation of multiple networked micro-grids: the central control system of the DSO called distribution management system (DMS), the micro-grid controller (MC) and the energy management system (EMS) of the micro-grid. The MC is fully responsible for the operation of the micro-grid, since the DSO does not know all the technical details of the micro-grid operation [7]. In islanded mode, the MC can be seen as a local DMS, whereas in grid-tied mode the MC is part of a hierarchy, which means that its control needs to be coupled with the DMS. If there is no coordination between the MCs and the DMS, then it is possible that the operation of the micro-grid might deteriorate the operation of the interconnected power system.

The DMS has a high-level integrated control system for substation automation called supervisory control and data acquisition (SCADA) system. The SCADA system can be integrated with the MC as well (microSCADA or local SCADA). If the EMS refers to a smart building, then it is called building EMS (BEMS) and multiple BEMS can often be centrally controlled by a building SCADA.

In a commercial micro-grid (see Section 1.2), the corresponding EMS has to be integrated with the control systems of the resources and/or loads, not necessarily physically connected to the same network. In this case, the EMS aggregates and optimizes the dispatch of the resources with the aim to reduce the total cost.

Figure 3-1 shows a diagram of how the different controllers of the physical micro-grids and the commercial micro-grids will interact with each other and with the DSO (DMS and/or market).

The control system components are not always distinguished separately and they could even be integrated in a single device. However, considering their functionalities, they can be classified as follows [8]:

- Connecting components and devices
- Advanced metering infrastructure (AMI)
- Controllers (actuators)

which are described in the following sections.

3.1 Connecting components and devices

This category refers to wires, antennas, I/O devices as well as gateway devices. Gateway devices provide compatibility to heterogeneous devices that are linked to it and may operate under different standards and protocols.

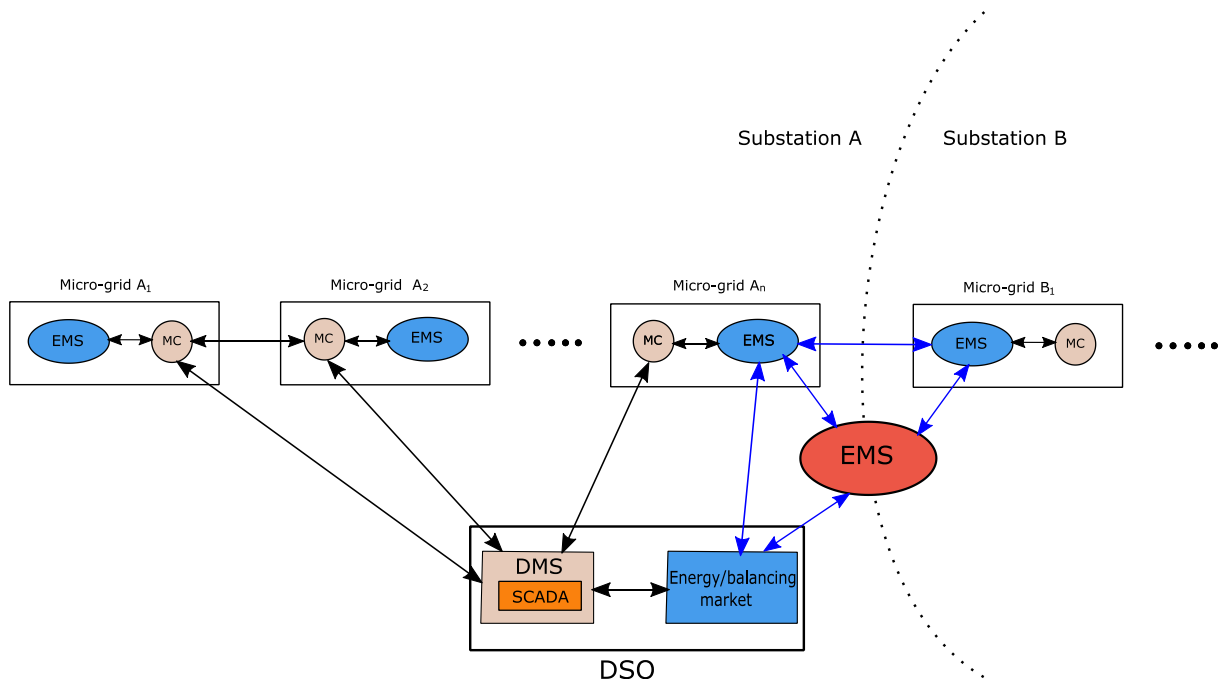


Figure 3-1: Control interface of micro-grids with the DSO. Black arrows show the interaction between controllers, while the blue arrows indicate the energy transactions. The commercial micro-grid (shown in red background) aggregates resources that are located under different substations.

3.2 Advanced metering infrastructure (AMI)

An integral part of the implemented controllers is the monitoring of the power system, which is enabled by sensors, smart meters, and remote terminal units (RTU) or phasor measurement units (PMUs). The AMI components transmit data to, for instance, the microprocessors of the inverter-embedded controllers, to the MCs and to the SCADA servers. The deployed AMI components and their interconnection with the controllers define the feedback loop of the control algorithms.

3.3 Controllers

The controllers respond to signals and initiate control actions. They can be autonomous or dependent on external signals. They can also coordinate their actions with other controllers in order to achieve specific goals. The controllers are configured as an integrated system with storage (RAM, ROM), I/O ports and microprocessors, where the control is actually implemented. Their specifications are determined by the amount of data that they will process and the computational requirements of the control algorithm. For additional computational resources, they can be connected to a computer.

Controllers include PI converter-embedded controllers and microprocessor-based controllers (e.g., CRIO, Arduino), which are called intelligent electronic devices (IEDs). Controllers can be characterized as intelligent agents (control agents), when they can sense their environment and operate autonomously or coordinate their actions with other agents to achieve specific goals.

4. Control and coordination schemes

The control schemes can be classified in two categories: a) communication-based and b) autonomous. In autonomous control, the controllers exchange no information and apply control actions based only on local measurements. In communication-based control the

controllers exchange information in order to coordinate their actions. Since the aim of this project is the coordination of multiple micro-grids and the coordination between the main grid and interconnected micro-grids, communication-based control schemes are of interest.

Based on the fashion in which information is exchanged [9], communication-based control can be further divided into: 1) centralized control, 2) distributed control, and 3) decentralized control.

- 1) Centralized control: All data are gathered in a single control point (e.g., SCADA), where the central coordinator determines a solution to the control problem. The central coordinator provides commands to other controllers, which are lower in the hierarchy of the control scheme (e.g. micro-grid central controllers).
- 2) Distributed control: All controllers cooperate to reach a collective decision according to the goal that has been set (e.g., by the DSO). The controllers communicate only with their neighbors, which makes this control scheme highly scalable. In distributed control, there are no command signals, there is only exchange of information.
- 3) Decentralized control: This is a partly centralized and partly distributed control regarding the decisions, command/information signals, and computation. A classic example is the coordination of a multi-area power system, where a central controller is assigned to each area (centralized control within the area) and these controllers are loosely coupled (distributed control) for coordination purposes.

4.1 Hierarchical control of micro-grids

The control of micro-grids follows a hierarchy that defines control actions starting downstream from individual DERs and reaches the highest levels with the main grid and coordination with other micro-grids. At the highest level, the DSO is responsible as the central coordinator.

4.1.1 Primary control

In primary control, voltage and frequency are usually regulated locally. This is a very fast, near-instantaneous response [10] to locally measured signals. PECs usually follow a voltage – reactive power or frequency – active power droop characteristic to drive their outputs. In this case, the amount of reactive or active power a converter injects or absorbs depends on the deviation of voltage or frequency, respectively, from a reference.

4.1.2 Secondary control

The secondary control of micro-grids can be either centralized or distributed. In the first case, a centralized controller (the MC) supervises the operation within the micro-grid and ensures safe and stable operation both in grid-tied as well as in islanded mode. It calculates and transmits the voltage and frequency set-points to all controllers within the micro-grid, so that they can perform corrective actions towards the desired goal during primary control. Secondary control is performed on a slower time scale (few minutes) than primary control aiming at restoring permanent deviations [10]. In a distributed secondary control scheme, the micro-grid components cooperate with each other to reach a final acceptable operating point. Moreover, frequency regulation of the micro-grid for the seamless transition between grid-tied and islanded mode is part of the secondary control.

4.1.3 Tertiary control

This is the interface with the DSO and the micro-grid (and possibly with other micro-grids if more than one micro-grid is connected to the same PCC). Tertiary control responds to

the needs of all systems that are interconnected at the PCC at a time scale of several minutes [10]. The coordination of DSO and multiple microgrids for voltage regulation, congestion management and phase balancing is part of the tertiary control.

4.2 From operation planning to real-time control

The optimal operation of the network involves different stages of control decisions all of them aiming at coordinating the outputs from the available resources in real-time operation. These stages define control layers that are characterised by different time-scales. Moving towards real-time operation, the computational and communication requirements as well as the necessity for robustness increase. Towards real-time there is more automation involved in the control process and the control signals change from power and price signals to voltage and frequency signals.

The day-ahead market schedules the energy resources well in advance before the actual operation (usually 12-36 in advance). The market clearing process determines the dispatch of generation and demand that will lead to energy balance. Intra-day markets take effect during the day and correct the day-ahead scheduling several hours (maximum up to one hour) before the energy delivery. Intra-day markets schedule additional supply or demand to balance outages or forecast errors. Balancing markets decide on last energy scheduling adjustments [11].

The balancing/flexibility markets are very close to real-time operation (maximum up to 30 minutes before real-time) and they are the last chance of the DSO to procure additional services and balance power without resorting to load/generation curtailment. The micro-grid operators or the aggregators sell their demand/generation flexibility to the utility grid and the DSO takes advantage of this flexibility to minimize the energy mismatches. The market actors are unaware of the grid configuration; therefore, the DSO has also to coordinate energy transactions between micro-grids, where capacity constraints can limit the power exchange. Through coordination of the market mechanisms with the system operator, the scheduling decisions at all stages can lead to the optimization of the network operation.

During real-time operation, the DSO and the micro-grid operator attempt to achieve the operational objectives through maintaining the defined power set-points. The market-based procurement of services might not always lead to energy balance, especially with a high integration of renewable energy sources and therefore direct control of the system should be allowed to overrule the market. For this purpose, explicit power signals can be sent during the real-time operation by the DSO to flexible prosumers, who can be compensated for their time of participation in direct power control. A summary of the discussed time scales for each scheduling phase and the different control layers is shown in Table 4-1.

5. Functional requirements

The high integration of DER will have to overcome control challenges, such as bi-directional power flows and the effective coupling of converters with slow regulating devices. Interfacing the DSO's control system with the MCs can increase the controllability of the network and enhance the coordination of multiple DER even if the DSO is not directly controlling them. For the integration of MCs to the DMS certain functional requirements should be followed. These include:

- Interconnection and operation requirements
- Monitoring and interoperability requirements
- ICT requirements
- Requirements for future scenarios of micro-grids

Table 4-1: From operation planning to real-time control

Energy market		
Operation layer	Function	Time scale
Day-ahead scheduling	Energy balance	24 h before real-time
Intra-day markets	Energy balance	Max. 1 h before real-time
Balancing/flexibility market	Energy balance, ancillary services	Max. 30 minutes before real-time
Micro-grid control		
Control layer	Function	Time scale
Tertiary control	Optimal voltage and frequency set-points	Several minutes (or event driven)
Secondary control	Voltage and frequency restoration	sec
Primary control	Active and reactive power sharing	msec

5.1 Interconnection and operation requirements

5.1.1 MC requirements

According to [12]–[13] the main requirements that the MC needs to follow whether in grid-tied or in islanded mode of operation are:

- Maintain voltage within statutory limits
- Maintain grid frequency
- Balance generation and demand either by load-following or by generation following

The grid frequency is determined by the DSO in the grid-tied mode whereas in the islanded operation the MC can choose a different frequency. Additionally, the MC must:

- Support the seamless transition from grid-tied to islanded mode, if the micro-grid has islanding capability.
- Support bi-directional power flows in the grid-tied mode.
- Control active and reactive power both within the micro-grid as well as at the PCC.

5.1.2 DMS requirements for the integration of multiple MCs

The DMS runs the optimal power flow of the distribution network and minimizes power losses by optimal voltage/var control. It is responsible for energy management (generation and load balance), congestion management, voltage regulation and frequency support. Additionally, the DMS should:

- Aggregate the uncertainties due to multiple RES injections.
- Perform frequent state estimation to consider the real-time topology of the network.

In a network of grid-tied micro-grids the DMS has to coordinate and cooperate with the MCs for the optimal control of the distribution network and may even utilize services offered by the micro-grids to solve operational problems.

5.1.3 Islanding and resynchronization

In intentional islanding, if there is a strictly hierarchical architecture where the DSO acts as a central coordinator and can directly control the MCs, the DSO sends a signal to the MC that supports the islanding functionality. Alternatively, the MC may request a permit for intentional islanding from the DSO. In decentralized control, the MCs do not require approval from the DSO; however, they are required to notify them. The DSO may give incentives to the MC to perform an islanding. During an unintentional islanding the MC is requested to inform the DSO, so that the DSO may additionally request islandings from other MCs to ensure stability of the grid.

A respective exchange of permit request and acceptance messages between the MC and the DSO takes place for the resynchronization to the main grid. The synchronization of a micro-grid to another micro-grid (grid-tied or islanded) is a more difficult process as there must be a guarantee that there is adequate inertia and reserve in the system. Moreover, there is the danger that the interconnection of two micro-grids will form a hidden loop in the power system (e.g. if the micro-grids have more than one PCC and they are already connected to the distribution network). Therefore, there must be an approval signal from the DMS, which has a general overview of the topology of the micro-grid and is aware of the status of tie-switches.

5.1.4 IEEE 1547 Standard

This standard defines the requirements for the interconnection of DER to the electric power systems [14]. By extension, the connection interface of multiple micro-grids connected to the main grid can also be defined based on this standard, since a micro-grid can be viewed as a DER from the viewpoint of the DSO. The high integration of DER has called for numerous revisions to enable the DER support of grid functionalities. Although the current operational policies usually restrict reactive power injections from DER there have already been amendments that specify the conditions under which DER can participate in local reactive power support after coordination (offline) with the DSO [15]. There is also an active revision of this standard that heavily promotes the participation of DER in real-time reactive power control.

Therefore, the coordinated voltage control can take into consideration the reactive regulating capabilities of the DER converters. This will also depend upon the needs of the system, since voltage regulation is less coupled with reactive power flow in highly resistive networks. The effect of reactive power control in phase imbalance should also be investigated. The islanding capability and the response of the PECs in contingencies that require islanding is also addressed in this standard. Moreover, recent amendments will allow a wider ride-through tolerance to avoid the trip-off due to higher sensitivity of converter-interfaced micro-grids [13].

5.1.5 EU regulations

Several requirements regarding the interconnection of DGs and by extension the interconnection of micro-grids can be found in [16]. For continental Europe as well as Nordic countries there is a minimum limit of 30 minutes of continuous operation under frequency of 47,5-48,5 Hz or 51-51,5 Hz. The regional TSO can define the minimum limit of continuous operation (not less than 30 minutes) under 48,5-49. This is the limit before a micro-grid operator can choose to disconnect from the network. The micro-grid operator can then decide to take part in islanded operation after coordination with the TSO. The frequency range and minimum limit of operation can be further modified after agreement with the micro-grid operator and the TSO. The deviation of 1 Hz from nominal value is acceptable for unlimited operation.

The voltage limits can also be taken into consideration for islanded operation. For continental Europe they are: minimum 60 minutes between 0.85-0.9 pu, unlimited operation between 0.9-1.118 pu, and 20 to 60 minutes minimum operation between 1.118-1.15. For the Nordic countries they are specified as: unlimited operation between 0.9-1.05 and 60 minutes for 1.05-1.10.

5.2 Monitoring and interoperability requirements

The DMS should have a detailed view of the system starting from the HV/MV transformer all the way down to the secondary transformers. After the secondary transformers the DMS may have some information about the capacity or the operating points of the DER (if they are not part of a micro-grid) or the micro-grids that are connected to them. Not all technical details are shared, however, as the DMS does not require any knowledge/measurements from within the micro-grid. The minimum monitoring requirements for the integration of grid-tied micro-grids with the DMS are:

- The DMS should be able to monitor the PCC.
- The DMS should have a general knowledge of the micro-grid topology.
- The DMS should know at any given time the specific feeder section, where the micro-grid is connected.

It is very important that the DMS is aware of the current network configuration, which may often change for reasons such as congestion management or service restoration. In case the micro-grid has more than one PCC with the main grid or other micro-grids, the DMS must monitor the status of tie-switches to avoid the formation of hidden loops in the power system [7].

For the control interface of MCs to the DMS, it is necessary to extend some of the standards, since they are focused either on the configuration of the controllers inside the micro-grid or on the automations applied at the substation. For example, a basic interoperability functional requirement that has not yet been specified is the response time of the MC to a request from the DMS. One suggestion is that the maximum response time for a local DER (30 sec) could be used, until future regulations address the DMS to MC interface.

5.2.1 Smart meters functional requirements

According to the EU recommendations (March 2012) the deployment of smart meters should comply with some minimum functional requirements [17]. These requirements refer to the customers, the meter operator, the commercial use of the smart meters, the data security, and the distributed generation.

- Customers: The smart meter should provide through a user-friendly interface accurate and timely energy data directly to the customers or a third party as designated by the customers, so that these data can be used for participation in flexibility trade and provide value to active prosumers. A minimum requirement is that the data should be available to the customer every 15 minutes.
- Meter operator: A key functionality is the remote reading of the meters at a frequency that allows the data to be evaluated for future network planning.
- Commercial use: The smart meters must support advanced tariff structures and the remote tariff control. Moreover, they should enable the disconnection of a customer or the limitation of its power consumption.
- Data security: High level security is demanded for all the communications between the smart meter and the meter operator (also metering units) as well as within the consumers' premises in order to ensure the privacy of the data. False data detection and fraud prevention is also of high importance.

- Distributed generation: The active power import/export and reactive power metering is a functionality that should be installed by default and activated/deactivated upon the prosumers' request.

Smart meters have been utilized so far mainly for monitoring and billing of the energy consumption. Depending on the type of smart meter, there is also the possibility to record grid measurements, such as voltage and current, as well as control consumption or even cut-off a customer from the grid. However, there are some limitations in enhancing the role of the smart meter in the control and the operation of the distribution network. These limitations are associated with the link of the smart meters measurements to the DMS and with data storage limitations (in the smart meter or the data center). Typically, the smart meters transmit their data twice a day to the SCADA system, whereas for control applications the data transmission should happen almost real-time. A very frequent transmission could be limited by the structure of the communication network too (see Section 5.3.1).

5.2.2 IEEE P2030.7 Standard

The IEEE Standard P2030.7 is an active project (a draft of the standard has been approved in December 2017) and is expected to be complete by December 2018. This standard examines the operational, control and metering aspects and promotes interoperability and platform-independent operation of micro-grid controllers. The specifications of the controllers and their configuration must comply with certain requirements in order to ensure scalability of the coordination scheme.

5.2.3 IEC 61850 Standard

The IEC 61850 series provides abstract communication service interfaces to improve interoperability among IEDs and support data exchange all over the distribution network and between different voltage levels [18]. This standard can describe the micro-grid automation system as well as the substation automation system and is less strict in its guidelines compared to the IEEE standards. Currently, both IEC 61850 devices as well as devices that operate with proprietary protocols coexist in substation automation systems. It can operate through Ethernet and TCP/IP protocol and is expected to map with web services as well.

5.2.4 Modbus Protocol

The Modbus communication protocol is an open standard that supports the master/slave architecture, where the master (e.g., substation) sends the command to the slave and receives back the response. Modbus RTU is very common in industry applications because it is easy to implement and has very low requirements on memory. There is also Modbus TCP that runs on Ethernet.

5.3 ICT requirements

The ICT middleware layer establishes communication between different control systems after the configuration and the coupling of the controllers is decided. The ICT framework must comply with the specifications set by the control algorithms and satisfy both the requirements of the physical system as well as the requirements of the electricity market. The lower level of ICT includes the data acquired from the sensors that are transmitted to smart meters or entered as input signal to controllers. The higher level of ICT is associated with the information interchanged among neighboring controllers or transmitted from smart meters and gathered at data centers.

A communication platform requires interoperability of the connected devices. The controllers that use an ICT platform must utilize the same protocols or have compatible interfaces even if they are not standardized. Some interfaces might have to be converted with a gateway in order to be linked to the platform. For this purpose, the OLE standard can be used. OLE for Process Control (Object Linking and Embedding for process control) is

often employed for the link of different devices (even if they operate under proprietary or legacy protocols) to the SCADA system.

5.3.1 Field area network (FAN)

The field area network establishes communication between the smart meters or IEDs and the control systems (DMS, MC). The FAN might be owned by the utility or belong to a third party provider (3pp). The FAN structure describes the communication layers that link the data transmission from the smart meters and other measurement devices to the SCADA system and vice versa from the SCADA system to the lower level controllers, e.g. from the DSO SCADA to the MC or from the micro-grid SCADA to converter-embedded converters of the micro-grid.

There are three types of FAN structures: mesh, point to multi-point and peer cloud. The mesh is a low cost structure, where the communication delay scales with the number of communication hubs. In point to multi-point many field devices can report to one collector, which is faster than the meshed network although prone to single point failure. The emerging technology of peer cloud architecture is highly scalable and free of single point failure; however, it is not ripe yet to be employed for critical functions regarding the operation of the power system.

5.3.2 Enabling technologies

A combination of wired and wireless technologies can be used as the connection medium for the communication network. Wired technologies include optical ethernet network, digital subscriber line (DSL), and power line communication. Wireless technologies include Wi-fi, WiMax, ZigBee and mobile network. Some of these technologies use existing infrastructure (e.g., power line communication and mobile networks); in these cases, however, there might be distortion issues.

The most reliable communication network is the fiber optic network; however, its installation is expensive. Wireless communication networks are often preferred for control within a micro-grid because they offer scalability, since they require no physical connections between the components. A significant parameter for wireless communication is the range of the signal, which is defined by the size of the antenna, its type, and its power consumption. Wireless communication technologies that have been used in micro-grids applications along with their technical characteristics are [19]:

- Wireless local area network (WLAN): It connects a device to one or more devices with access to Internet. It is based on IEEE 802.11 Standard, which defines point to point and point to multi-point communications. Wi-fi is a subcategory of WLAN based on IEEE 802.11b protocol providing a data rate of 11 Mbps with a 2,4 GHz bandwidth. The functionality of the control can be affected by signal interference, which will reduce the data rate transmission, therefore some regions might not be proper for WLAN.
- WiMax: Worldwide interoperability for microwave access (WiMax) is a technology based on IEEE 802.16 Standard, radio transmission and microwave reception. It is suitable for long distance coverage and it can operate at higher bandwidth than WLAN (5,8 GHz) with a data rate of 70 Mbps.
- ZigBee: This technology can be used for low-bit rate (up to 250 Kbps) radio transmission and short distance coverages. Its main advantage is the low power consumption. It is most suitable for intermittent transmission or single signal transmission.
- LTE/4G: Long term evolution (LTE) is a private 4G wireless network with high bandwidth and data rate transmission (86,4 Mbps at 20 GHz). It is currently out-dating WiMax in its applications.

For communication between IEDs, such as the case of distributed control, there are low latency requirements due to the short distances. Wireless technologies can be used such as Wi-fi and ZigBee, the latter of which has been very popular for distributed control within a micro-grid, where low-bit rates up to 100 Kbps per IED can be used. For communication between MC and IEDs both wireless and wired technologies can be used. The existing lines are often used to avoid new installation costs. For communication between the DSO-SCADA and the MC high bandwidth is required.

5.3.3 Data transmission

Another important ICT requirement is associated with the data flow and the signals that will be transmitted. There are two types of signals: actuation or command signals and information signals. Their transmission rate dictates the command update rate and the monitoring update rate, respectively. The linking of explicit commands (actuation signals) to multiple controllers (as in centralized control) can be a challenging task. In decentralized control, the actuators only require information signals. Instead of direct control through price signals or optimal power set-points, the DMS sends incentives to induce the desired operation in the power system. This requires the operation of a local energy/ancillary services market, where the DSO can receive feedback from the bids of the micro-grid operators.

In data transmission, there are four requirements that are taken into consideration: bandwidth, latency, security, and reliability. When trying to improve one of these factors, the others get deteriorated so, these requirements need to be determined by the function and the location of the communication network. For example, the data transmission rate (bits/sec) is limited by the bandwidth (Hz) and the signal-to-noise ratio. Therefore, for rapid data update rate in combination with centralized control high bandwidth is a requirement. This, however, may not be suitable in densely populated areas, where there are many obstacles to data transmission. One of the advantages of distributed control is that it can converge using a low-bit rate transmission; therefore, there are many applications of distributed control within a micro-grid, where short distances assist the transmission as well.

The signals that can be sent for control purposes include: voltage (magnitude and phase), current (magnitude and phase), active and reactive power, frequency, relay status (on/off) and price-based signals. A description of the signals that will be used and the data requirements can be seen in Table 5-1.

Table 5-1: ICT data requirements

Description of signals	A/D or D/A conversion	Actuation	Information	Data type
Power	√	√	√	Float
Voltage	√	√	√	Float
Current	√	√	√	Float
Frequency	√	√	√	Float
On/off	—	√	√	Boolean
Price/marginal cost	—	—	√	Integer/float

5.4 Requirements for future scenarios of micro-grids

The universal smart energy framework (USEF) foundation currently tries to develop a common European standard that will act as a unified approach towards the integration of smart energy technologies [20]. This standard proposes a market-based coordination of flexible resources that the DSO can utilize to eliminate energy mismatches during the

daily operation. The focus is put on grid management of radial distribution networks, since this network topology faces the most severe congestion problems.

The procurement of flexibility services will depend on the prediction of voltage deviations and congestions on the feeders. This procurement will either depend on bi-lateral predefined contracts (fixed price) or the flexibility price will be dynamic and will also depend upon the location. The second case, however, increases the risk of failing to provide the flexibility service. In the worst-case scenario, where the flexibility that can be provided cannot cover the needs of the system, then the DSO overrules the flexibility market and initiates precautionary measures (load and active power curtailment) according to the USEF standard.

6. Requirements for industry application

For the deployment and the coordination of multiple grid-tied micro-grids a highly observable network is a prerequisite. Currently, the monitoring at the LV level of the distribution system is inadequate. The DSOs should enhance the data exchange with the customers either by expanding their measurement infrastructure or by empowering the micro-grid operators. In this way, they will be able to estimate the operation state of their network more efficiently and possibly detect problems that are not evident now.

Alongside with the increase in the LV monitoring there will also be a need for big data analysis in the future, since the quality of data and the data synchronization (between customer data and grid measurements) are very important. If the data acquired at the end-user point are to be provided by a third party, the reliability of the service is a critical issue, as the state estimation should be secure. With the exchange of reliable data, advanced control schemes can be applied (e.g., self-healing schemes), and congestion management can be achieved without the need to invest in the upgrade of the grid infrastructure.

7. Control applications at the demonstration sites

This projects includes three demonstration sites: Chalmers micro-grid, the buildings of positive footprint housing (PFH), and SOREA's micro-grid. The hardware prototype and the control architectures at each site will be defined by: the physical network, the configuration of the control system components, and the communication infrastructure that supports the monitoring of the grid (data transmission from measurement units to control systems) and the implementation of control commands (data transmission from high level to lower level controllers).

7.1 Chalmers

7.1.1 Description of the demonstration site

The 12 kV distribution network of Chalmers (Figure 7-1) has a total of electrical load that varies between 3 and 6 MW. The total curtailable load from demand-response applications is up to 100 kW and it can be provided from the building automation systems that control the ventilation (down regulation) in the buildings within the campus area. Other controllable resources include the 1000 kW combined heat and power (CHP) plant (which is at bus 07:8.11 of Figure 7-1) and the installed photovoltaic (PV) panels. The normal operating electric power output of the CHP plant is 600 kW and the control of the electric generator is manual at the moment. The PV installed capacity is 90 kWp and is expected to rise up to 800 kWp by 2019. There is also an investment plan for battery energy storage with a maximum capacity of 200 kWh.

The PV panels that are installed at bus 07:8.11 (15 kWp) operate with a "Sunny Tripower" 15 kVA inverter manufactured by SMA Solar Technology. A computer equipped with Bluetooth wireless technology or Ethernet can interface with the inverter and change its operational parameters.

Akademiska Hus, the owner and operator of Chalmers grid has an ABB MicroSCADA at the substation that supervises the operation of the distribution network. The MicroSCADA monitors the status of switches and also gathers some current and voltage measurements (the monitoring of current and voltage on the distribution network is estimated between 10-20%). There are also smart meters at multiple locations (building blocks or even separate buildings) gathering power and energy measurements. These measurements are mostly used by BEMS and are not generally monitored by the SCADA except for few critical points in the network. The meters have however the capability to collect and transmit to the SCADA system voltage and current measurements with a resolution of one minute. The BEMS are centrally dispatched by a WebFactory building automation SCADA. Optical ethernet is used for the communication between different control levels.

7.1.2 Control application

At the demonstration site at Chalmers (Figure 7-2), optimal control of the network will be applied by utilizing the flexibility provided by the BEMS. The MicroSCADA which is at the highest level of control architecture, will collect voltage and current measurements on the grid as well as switch status information. Additionally, power, voltage and current measurements can be sent from the BEMS (which will represent the EMS of micro-grids).

For the proposed control, the BEMS will bid their flexibility to the DMS, which will interface with the MicroSCADA. The DMS will perform the optimal control and send explicit commands (power set-points or price signals) to controllable resources and mechanisms owned by the utility grid (e.g. PV inverters, switches) as well as to the BEMS SCADA. A gateway will be developed to facilitate the interaction between the DMS and the BEMS SCADA. The BEMS will be responsible for optimally dispatching the resources within the buildings to provide the flexibility by actuating programmable logic controllers (PLCs).

During real-time operation, the flexibility might be inadequate for the network operation (due to forecast errors) or some suppliers may fail to provide the amount of flexibility that was agreed. Therefore, the DMS will perform corrective control by directly sending commands utilizing its own resources and devices and may even overrule the market and request load or generation curtailment by explicit power commands.

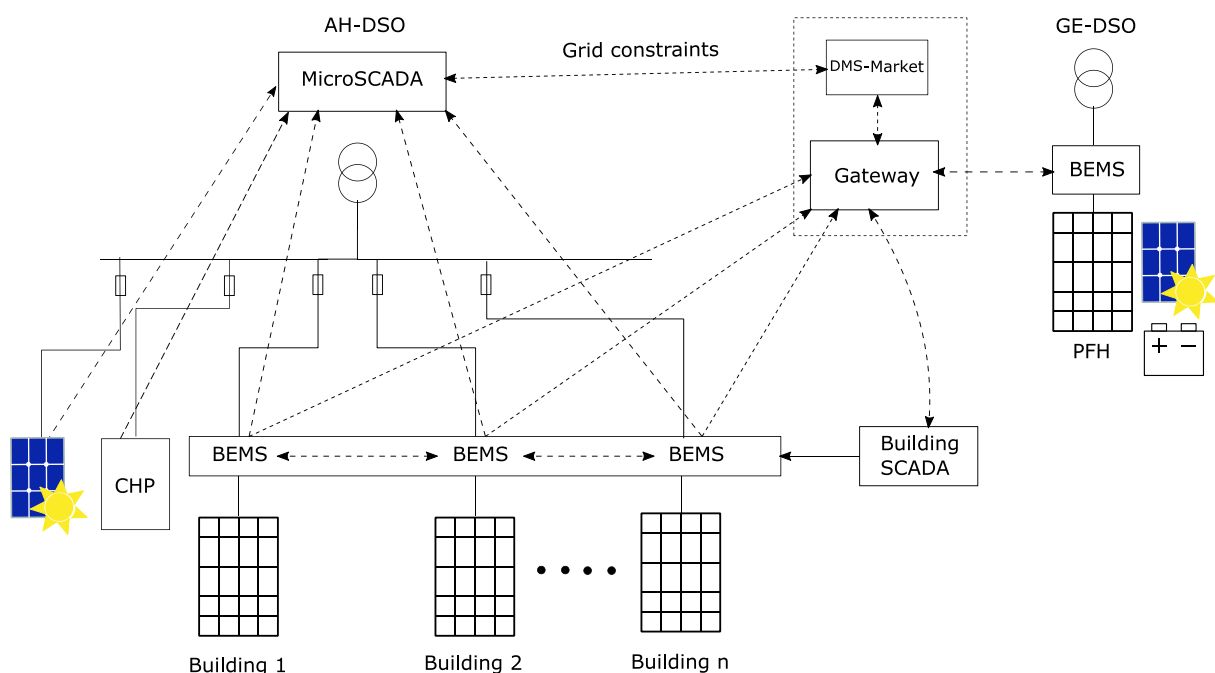


Figure 7-2: Control architecture at Chalmers and interaction with PFH.

7.2 Positive footprint housing

7.2.1 Description of the demonstration site

This demonstration site includes the six buildings of the PFH project, where Gothenburg Energy (GE) is a collaboration partner. The building area is located in the center of Gothenburg. PV panels with a capacity of 140 kWp will be installed in the rooftops of three buildings by 2018. There are also second life Li-ion batteries (200 kWh capacity) from old electric buses.

7.2.2 Control application

The PFH has one central BEMS for all six buildings, which is the EnergyHub system, developed by Ferroamp for energy management of integrated PVs and ESSs. The EnergyHub has a three-phase bi-directional power inverter and can be interfaced externally via the web-portal of Ferroamp or the Modbus TCP protocol. Moreover, the EnergyHub will gather grid measurements (at the main feeder) as well as measurements at its inverter with an update rate of 1sec, while measurements at the PVs and the ESSs will be updated every 5 sec. A separate control system, operated by the property manager Riksbyggen, will control additional resources, such as heat pumps and electric vehicles. The BEMS of the PFH will represent the EMS of a micro-grid and it is proposed that it can interact with the DMS at Chalmers or with the BEMS SCADA at Chalmers' demonstration site as part of the interaction between the micro-grids (see Figure 7-2).

7.3 SOREA's micro-grids

7.3.1 Description of the demonstration site

The demonstration sites in France are owned and operated by SOREA. The site is part of a 20kV network at Saint Julien Montdenis (Figure 7-3). This MV network hosts two solar PV plants (at Villarclement and Ruaz D'en Haut), each with installed capacity of 250 kWp. The network also consists of a 3.2 MW hydroelectric power plant. The SCADA system monitors the MV network with a data update rate of 10 minutes, which can be reduced down to 5 minutes. The Modbus protocol is used for remote control of the switching devices on the MV network.

The SOREA demonstration site will constitute of three physical micro-grids at three LV networks. As highlighted in Figure 7-3, the substations of these networks are located at Pre de Paques, A Lequet and Gymnase. These three sites are part of the 20kV network and are supplied by 20kV/0.4kV transformers. Installed DER capacities for each of them are given below:

- Pre de Paques: Total installed PV capacity is 161 kWp. The total capacity is divided in two plants with capacities of 89kWp PV canopies and 72 kWp in rooftop (Figure 7-4).
- A Lequet: Consists of only rooftop solar PV units randomly distributed in the network. Total installed capacity is 43.36 kWp (Figure 7-5). The PV systems are connected through single-phase inverters.
- Gymnase: Represents a sport complex. The site is equipped with 36 kWh/18 kw lead-acid battery systems and 234 kWp PV installed (Figure 7-6).

7.3.2 Control application

The proposed control application is the optimal dispatch of the micro-grid's resources (PV inverters and ESS). Currently, the dispatch of these resources is local and not optimal, i.e. the batteries are automatically dispatched once they are fully charged until they discharge down to 50% and they are not separately controlled. The aim is the application of intelligent coordinated control for active and reactive power control of the PV inverters to solve voltage deviation issues and reduce active power curtailment associated with a high share of RES. The coordination will be enabled by wireless communication.

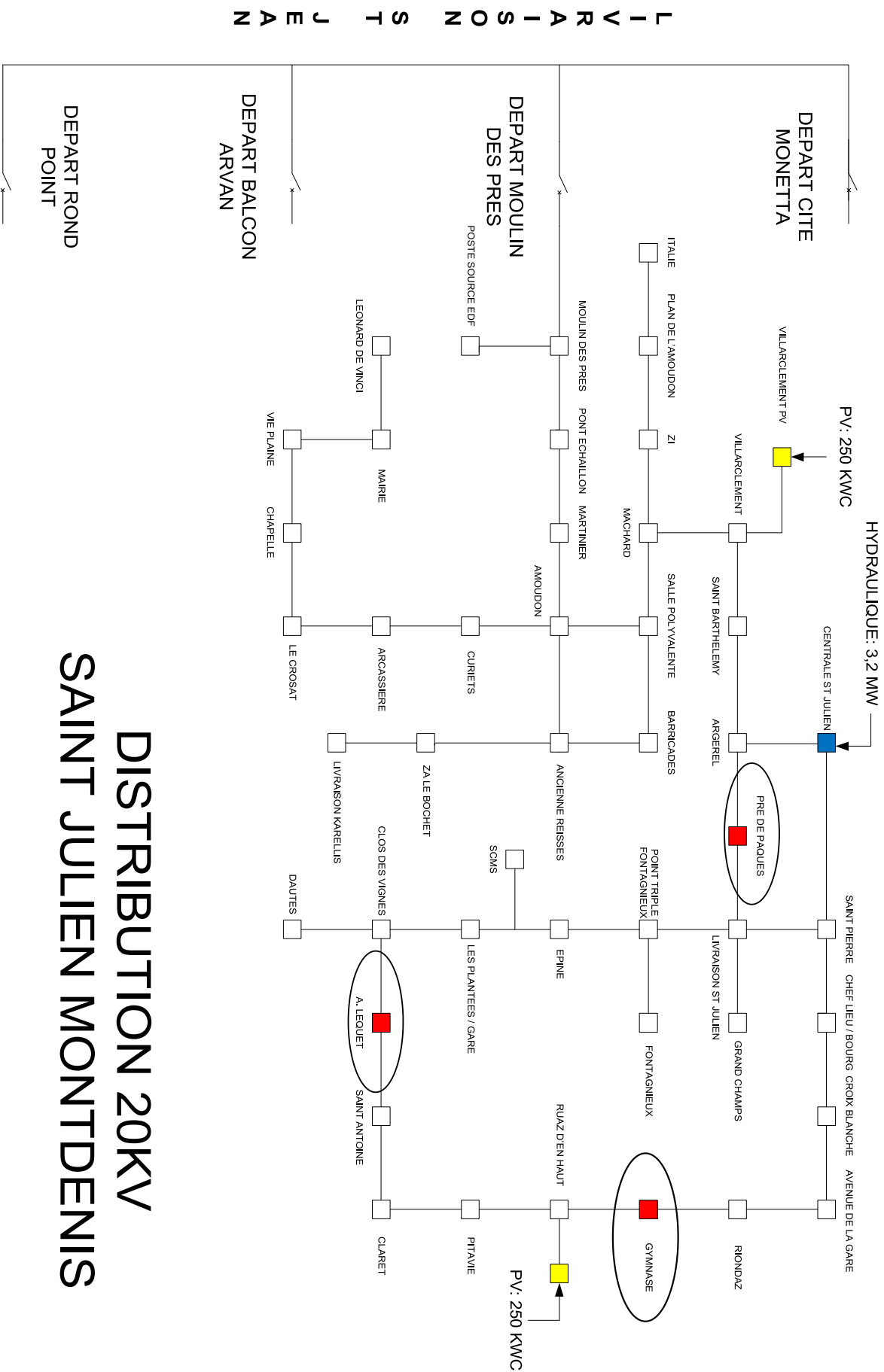


Figure 7-3: The 20 kV network of SOREA.

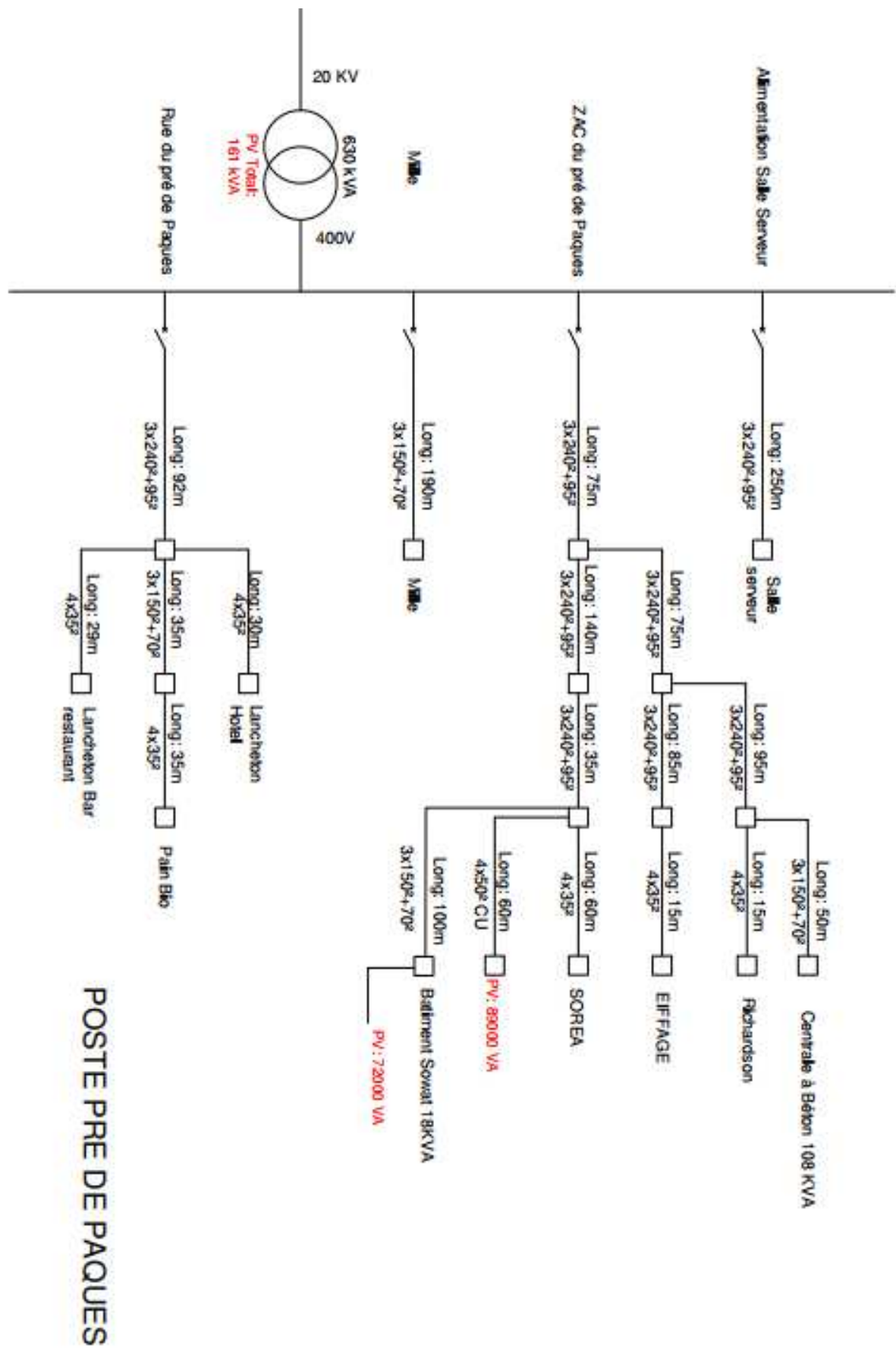


Figure 7-4: SOREA micro-grid at Pre de Paques.

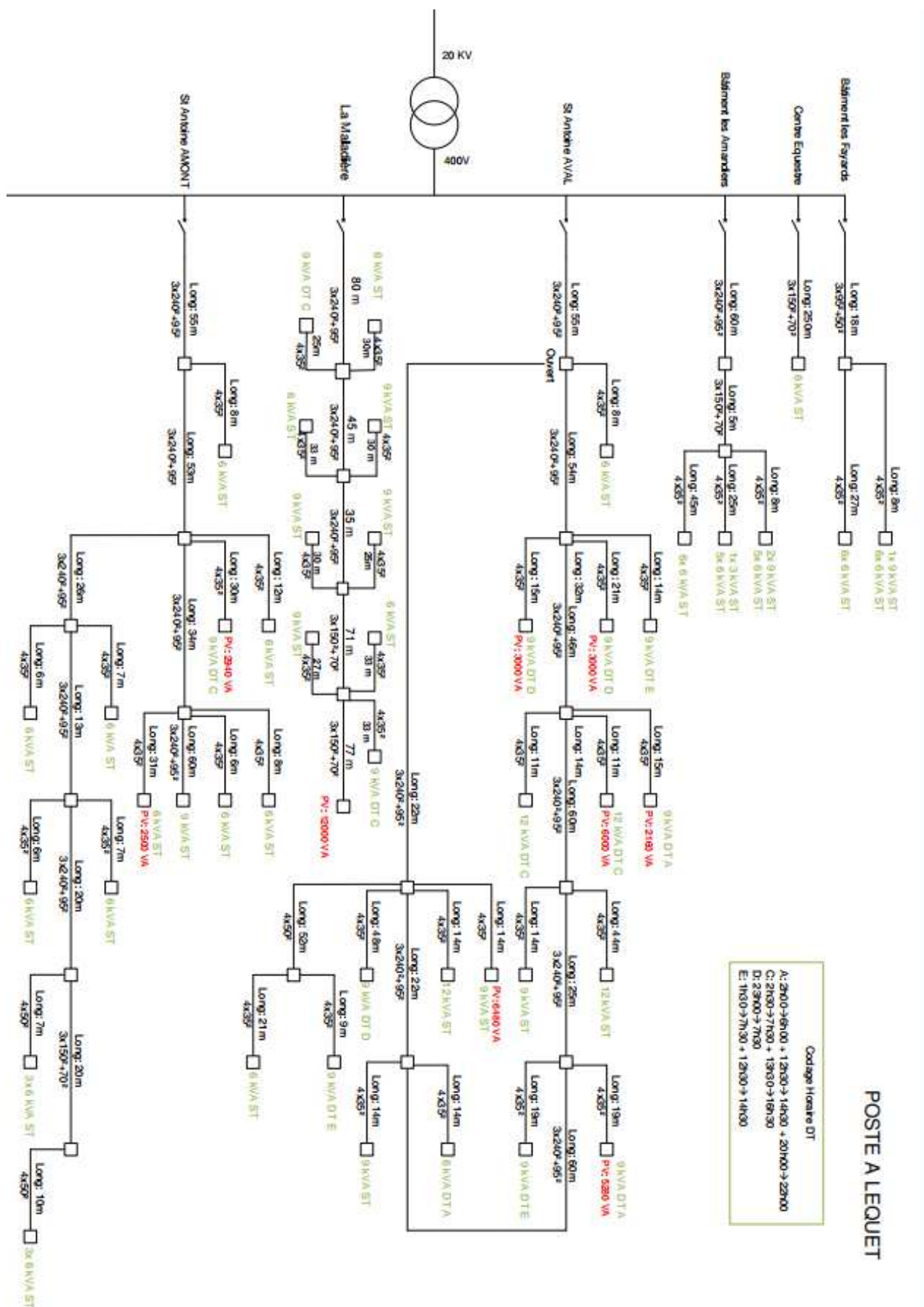


Figure 7-5: SOREA micro-grid at A Lequet.

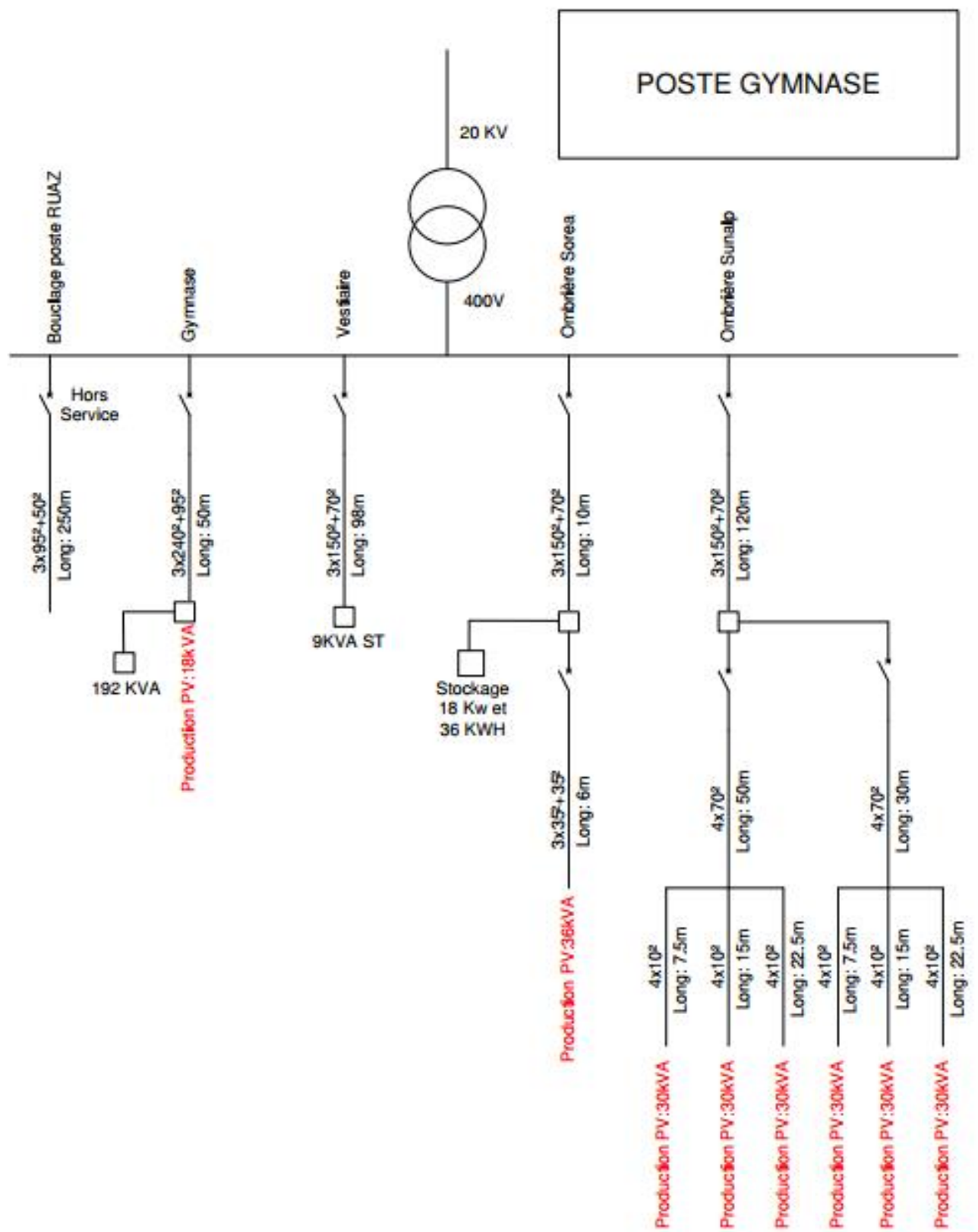


Figure 7-6: SOREA micro-grid at Gymnase.

7.4 Functional requirements for the proposed control applications

The preliminary work of the project has shown that for the field validation of the control algorithms it is necessary to increase the current observability and controllability of the demonstration sites. This will be achieved by installing smart meters (SOREA's LV micro-grid) or by utilizing a greater extent of the monitoring capabilities of the existing smart meters (Chalmers distribution network). Chalmers will also seek to take advantage of the the regulating capabilities of the existing distributed resources (e.g. PV inverters).

The MicroSCADA at Chalmers might have potential limitations in collecting many grid measurements at high update rate. However, that limitation can be overcome by choosing properly the date of demonstrations so that there will be minimal effect on the SCADA monitoring. The FAN is also of high importance as it will determine the data transmission rate. A meshed communication network is of lower cost and will be easier to implement in case there is absence of previous communication infrastructure. However, compared to a point to multi-point FAN the data transmission might face delays (up to several minutes) that can affect the time frame of the control application.

Before the control applications at the demonstration sites there will be tests with simulation models and validations in a lab environment. The simulation models that will be developed must be verified by the grid measurements acquired from on-site monitoring. The work for Task 2.3 will prepare the demonstration sites according to the functional requirements that have been described in this report.

8. References

- [1] N. Hatziaargyriou, "The microgrids concept," in *Microgrids: architectures and control*, Wiley-IEEE press, ch. 1, pp. 1–24, 2014.
- [2] K. Christakou, D. Tomozei, J. Le Boudec, and M. Paolone, "GECN: Primary Voltage Control for Active Distribution Networks via real-time demand-response," *IEEE Trans. Smart Grids*, vol. 5, no. 2, pp. 1–10, Sep. 2013.
- [3] P. Balram, O. Carlson, and L. A. Tuan, "Demonstration of voltage control in a real distribution system using model predictive control," *IET Gener. Transm. Distrib.*, vol. 11, no. 16, Nov. 2017.
- [4] S. Huang, S. Member, Q. Wu, and S. Member, "Dynamic Subsidy Method for Congestion Management in Distribution Networks," to appear.
- [5] R. Yang and Y. Zhang, "Three-Phase AC Optimal Power Flow Based Distribution Locational Marginal Price," in *Proc. IEEE PES Innovative Smart Grid Technologies Conf. (ISGT)*, Washington, DC, USA, Apr. 2017.
- [6] R. Zamora and A. K. Srivastava, "Multi-Layer Architecture for Voltage and Frequency Control in Networked Microgrids," *IEEE Trans. Smart Grid*, to appear.
- [7] J. Wang, X. Lu, and C. Chen, "Requirements for DMS integration with DERMS and microgrids," in "Guidelines for implementing advanced distribution management systems," Argonne National Laboratory, U.S. DOE, Argonne, IL, Aug. 2015.
- [8] M. Al Faruque and K. Vatanparvar, "Energy management-as-a-service over fog computing platform," *Internet of Things Journal*, vol. 3, no. 2, pp. 161–169, Aug. 2015.
- [9] K. E. Antoniadou-Plytaria, I. N. Kouveliotis-Lysikatos, P. S. Georgilakis, and N. D. Hatziaargyriou, "Distributed and decentralized voltage control of smart distribution networks: models, methods, and future research," *IEEE Trans. Smart Grid*, vol. 8, no. 6, pp. 2999–3008, Nov. 2017.
- [10] D. E. Olivares et al., "Trends in microgrid control," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1905–1919, July 2014.
- [11] Morales, Juan M., et al., "Balancing markets" in *Integrating renewables in electricity markets: operational problems*, vol. 205, Springer Science & Business Media, 2013.
- [12] A. Maitra et al., "Grid interactive microgrid controllers and the management of aggregated distributed resources (DER)," EPRI, Palo Alto, CA, 2015.
- [13] G. Liu et al., "Networked micro-grids scoping study," Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, 2016.
- [14] *IEEE Standard for interconnecting distributed resources with electric power systems*, IEEE Standard 1547, 2003.

- [15] *IEEE Standard for interconnecting distributed resources with electric power systems- Amendment 1*, IEEE Standard 1547a, 2014.
- [16] The European Commission Regulation (EU) on establishing a network code on requirements for grid connection of generators (2016/631), Official Journal of the European Union, Apr. 2016.
- [17] The European Commission Recommendation on preparation for the roll-out of smart metering systems (2012/148/EU), Official Journal of the European Union, Mar. 2012.
- [18] Q. Yang, J. A. Barria, and T. C. Green, "Communication infrastructures for distributed control of power distribution networks," *IEEE Trans. Ind. Informatics*, vol. 7, no. 2, pp. 316–327, May 2011.
- [19] S. Safdar, B. Hamdaoui, E. Cotilla-Sanchez, and M. Guizani, "A survey on communication infrastructure for micro-grids," in *Proc. Wireless Communications and Mobile Computing Conference (IWCMC)*, pp. 545–550, July 2013.
- [20] Smart Energy Collective (2013). *An introduction to the Universal Smart Energy Framework* [Online]. Available: <http://www.smartenergycollective.com>