Report on scenarios for micro-grid deployment

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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.

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1 Introduction

Implementation of micro-grids have been considered as a significant step towards the development and adoption of smart grid technologies. The concept of micro-grid was introduced in [1] in order to enhance the reliability of the power distribution networks involving a dominant share of distributed energy resources (DERs) and flexible loads. Although the formal definition has been evolving, a micro-grid conventionally represents a coordinated cluster of loads, distributed generation (DG) units and energy storage systems (ESS). Thus, a micro-grid essentially is an integrated energy system that can operate in parallel with the public network or in an islanded mode. Numerous benefits of micro-grids have been reported in the literature including the improvement of reliability, sustainability, and power quality, reduced costs of supply and transmission and distribution losses. Hence, micro-grids have been fittingly described as fundamental building blocks of future power distribution networks [1]–[7].

Based on operating domains, two main types of micro-grids can be distinguished, namely-physical micro-grids (having physical connections of different components in a common electrical grid) and commercial micro-grids (which are basically clusters of active customers not necessarily connected to a common electrical grid). The objective of this project is to develop suitable interfaces between the main grid and the micro-grids as well as to ensure a seamless interaction between the physical and commercial micro-grids. In order to achieve the overarching goal the project aims to develop: (i) a physical interface, with advanced set of control functionalities, to enable effective communication and coordination among micro-grids and between micro-grids and the distribution grid; and (ii) an interface for commercial micro-grids to enable flexibility and energy transactions for securing local network operation and promote self-power balancing. This project aims also to develop optimal clustering algorithms for such micro-grid solutions in the mega-scale distribution grid which can be integrated into and upgrade the future network planning. Developed solutions from this project will be validated in a whole range of test environments, including software platforms and three dedicated demonstration sites.

In this report, the scenarios for demonstration are defined including the demonstration sites, specifications and projected growth of various emerging technologies. The report is organized as follows. First, the background of the research is briefly summarized in Section 2. Next, Section 3 discusses the demonstration sites along with the specifications of each network. The projected growth of the emerging technologies and research approach are detailed in Section 4 before summarizing with Section 5.

2 Background

The electrical power distribution networks are usually designed with a planning horizon of 40 years [8]. Such a long planning horizon has been feasible owing to a predictable consumption profile with a steady economic growth. Power flow analyses have been used in order to determine required investment decisions considering an estimated peak load and annual load growth. Thus, network assets have been designed to withstand the worst-case loading situations, i.e. the peak loads. Historical load data is used to predict the growth over a certain time window. However, residential peak loads generally do not occur at the same moment and vary in duration considerably. The simultaneity of these demands is included in the planning process in terms of the *coincidence factor*. As shown in eq.(1), the coincidence factor, c expresses the ratio of the peak demand of a group of N consumers to the summation of their individual peak demand.

$$c = \frac{\max \sum_{i=1, i\in N}^{N} P_i}{\sum_{i=1, i\in N}^{N} \max P_i} \tag{1}$$

where, P_i denotes the load profile of the i-th consumer during the time window. The maximum value of c can be 1 and happens if the peak load of all the consumers occurs at the same time. In the conventional LV network planning process, the coincidence factor is assumed to be around 0.2 [9], which shows a high degree of diversity in residential peaks. Since the network is designed to supply the peak demands, a major fraction of the capacity remains unused for most of the times [10].

2.1 Transitions and challenges

The global drive towards a greener climate policy and sustainable economic development has been the motivating factor for changes in the energy system [11]. While an increasing share of renewables is being introduced into the power system, the consumption behaviors have also been influenced by rapid electrification of various energy intensive sectors. Consequently, transitions in both of the generation and demand sides pose implications for the network operators.

Renewable sources are estimated to have a considerable share in the generation mix in the upcoming decades (Figure 2-1). The intermittent nature of these weather-dependent sources introduces additional uncertainties in the network operations. It also necessitates a bidirectional flow in the distribution networks, which have traditionally been designed to host a unidirectional flow. Being weather dependent, the DG units offer inadequate controllability, leading to more complexity in the balancing mechanism of the supply and demand [12], [13]. Moreover, most of these Distributed Generators (DGs) are installed at the distribution networks involving lower voltage levels. This results in frequent operational challenges in terms of voltage control, power quality disturbances and overloading of network components [14]. Next, being the cleanest form of energy, electricity has been growing in popularity in order to match the demanding climate policy. For instance, the heating and transportation sectors are undergoing a massive evolution due to the recent surge in the heat pumps (HPs) and electric vehicles (EVs) respectively [15]. Notable winter peak loads are expected when the PV generation is minimum due to comparatively shorter lengths of the day and considerably higher cloudiness. As a result, the conventional diversity among the end-users is going to be reduced considerably. In other words, a higher simultaneity of the peaks of individual households will result and will subsequently lead to frequent congestions in the network.

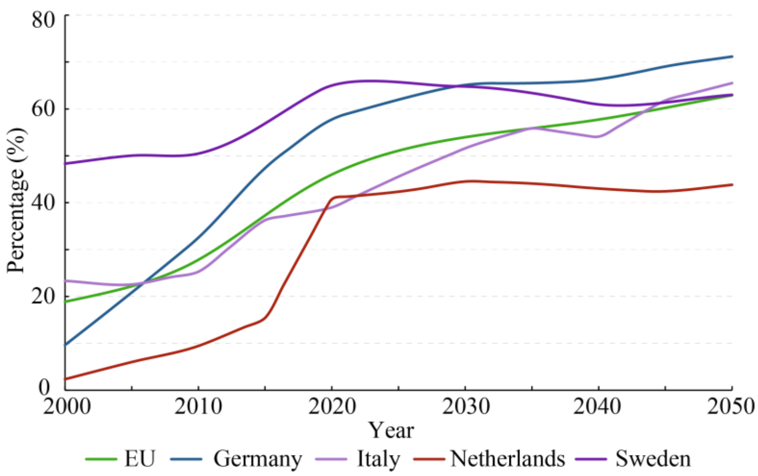

Figure 2-1: Projected share of RES in the overall generation capacity in EU and selected member states [16].

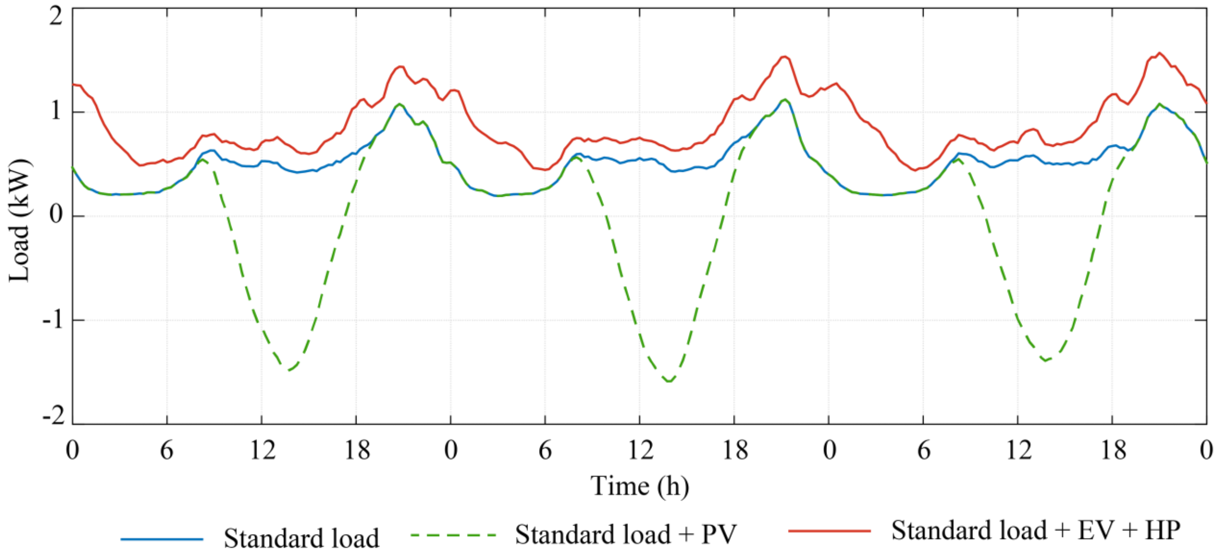

Figure 2-2: Consecutive three-day load profile depicting the effects of PV and EV on residential loading.

Different types of scenario-based analyses have been performed in order assess the adequacy of the network capacities [8], [10], [17], [18]. An extensive penetration of wind energy along with sustained growth in EVs may lead congestions in up to 49% of the Dutch MV/LV transformers [18] in 2040. Due to the proliferation of different DER units, Dutch urban LV feeders have also been reported to have inadequate capacity for loading conditions within the next 15 to 20 years [8].

While DSOs in different EU member states have widely diverse issues concerning DER penetration, many of them face capacity challenges in terms of network congestions and voltage limit violations [19]. Residential LV networks in Grenoble, operated by SOREA, have been shown to be overloaded due to the increased heating loads in winter. At the same time, due to the growth in rooftop PV installations, rural LV networks with long feeders experience overvoltage issues towards the end. Repetitive tripping of the inverters occurs due to the embedded ON-OFF control mechanism to prevent the overvoltage issues. In addition to the overvoltage problem, voltage unbalance has also been a prominent issue due to the single-phase connections of the LV end-users and PV installations.

2.2 Micro-grids for future power systems

The high penetration of RES and flexible loads in the future distribution network requires a more sophisticated energy and information management system than conventional energy management systems (EMS). To this end, micro-grids allow the DSO to coordinate a single entity instead of many DERs and customers. All devices connected inside the physical or commercial (virtual) micro-grid will be managed and operated in a distributed level with a micro-SCADA or decentralized EMS [20]. Since micro-grids can resolve operational issues such as overvoltage and congestion, they are expected to play a crucial role in the future power distribution systems.

The development of micro-grids will continue in the next years in order to increase reliability and interoperability of DERs especially critical loads and intermittent generators, as well as to cluster a significant number of intelligent connected devices in a single connecting point. Thus, a micro-grid is considered among the paradigm of Internet of Energy (IoE) [21].

For financial viability, almost all of the operational micro-grids in the EU have received subsidies from national or EC funding initiatives (e.g. TILOS micro-grid project in Greece).

3 Scenarios and visions

This section discusses the demonstration sites that are being considered for the deployment of micro-grids along with the specifications and future scenarios. The information of the sites and visions for micro-grid deployment were accumulated through workshops following a questionnaire which has been included in the report as Appendix A.

3.1 Demonstration sites

Three demonstration sites have been considered in this project in order to implement and observe the developed control methodologies. The demonstration sites are: Chalmers micro-grid, Göteborg Energi's (GE) positive footprint housing (PFH), and SOREA's micro-grids. Following subsections present the specifications of the demonstration sites more in detail.

3.1.1 Chalmers micro-grid

The campus of the Chalmers University of Technology is supplied by a 12 kV distribution network (Figure 3-1) and hosts electrical loads ranging between 3 and 6 MW. The building automation system has been designed to provide demand response services with curtailable loads of up to 500 kW. The desired services are procured by controlling the ventilation system (down regulation) and other loads in the buildings within the campus.

A 1000 kW combined heat and power (CHP) plant (at bus 07:8.11 of Figure 3-1) supplies the heating demand of the campus. Currently, the campus network hosts 60 kW of photovoltaic (PV) panels. The PV panels that are installed at bus 07:8.11 (15 kW) 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. The PV capacity is expected to grow up to 510 kW by 2019. Battery energy storage systems have also been planned to be implemented with a maximum capacity of 200 kWh.

The network is owned and operated by Akademiska Hus. The operation is supervised by an ABB MicroSCADA at the substation. Smart meters have been installed at multiple locations (building blocks or separate buildings) gathering power and energy measurements. These measurements are mostly used by buildings energy management systems (BEMS) and are not generally monitored by the SCADA except for few critical points in the network. However, the meters are able to collect and transmit the voltage and current measurements to the SCADA with a maximum resolution of one minute.

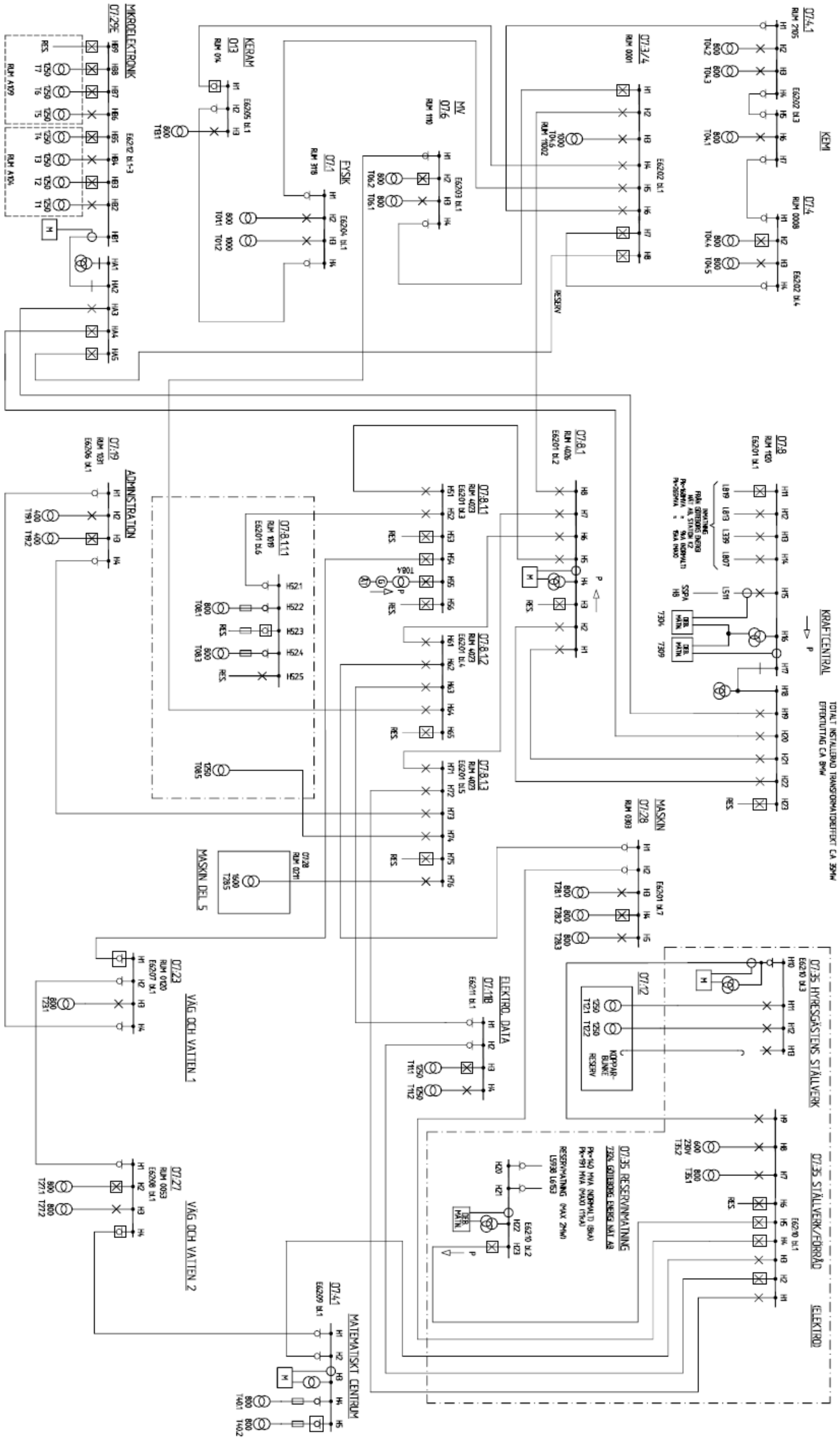

Figure 3-1: The 12 kV distribution network of Chalmers.

3.1.2 SOREA micro-grids

The demonstration sites in France are owned and operated by SOREA. The site is part of a 20kV network at Saint Julien Montdenis (Figure 3-2). 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 SOREA demonstration site will constitute of three physical micro-grids at three LV networks. As highlighted in Figure 3-2, 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 3-3).
- A Lequet: Consists of only rooftop solar PV units randomly distributed in the network. Total installed capacity is 43.36 kWp (Figure 3-4). The PV systems are connected through single-phase inverters.
- Gymanse: Represents a sport complex. The site is equipped with 36 kWh/18 kw lead-acid battery systems and 234 kWp PV installed (Figure 3-4).

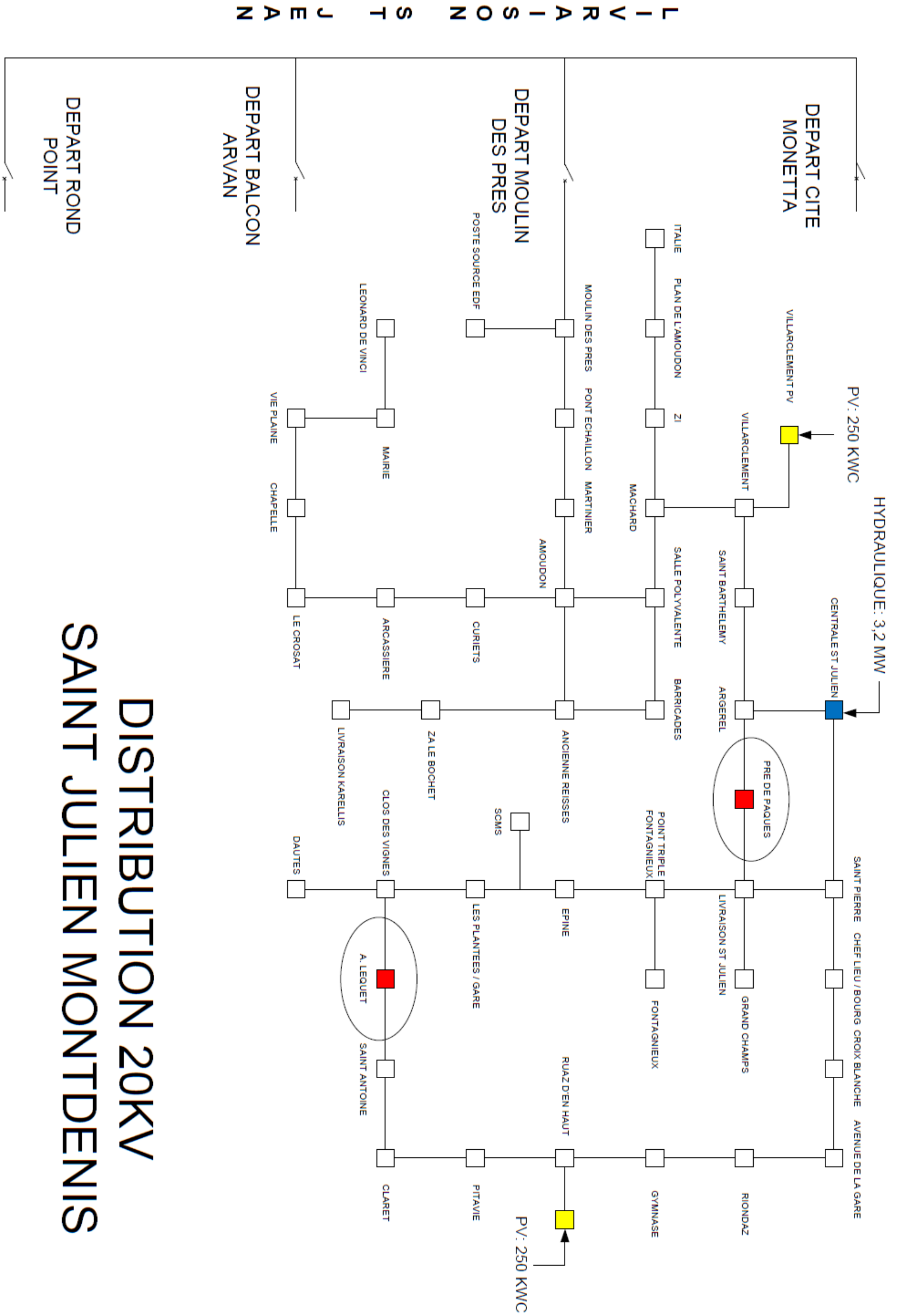

Figure 3-2: 20kV network of SOREA.

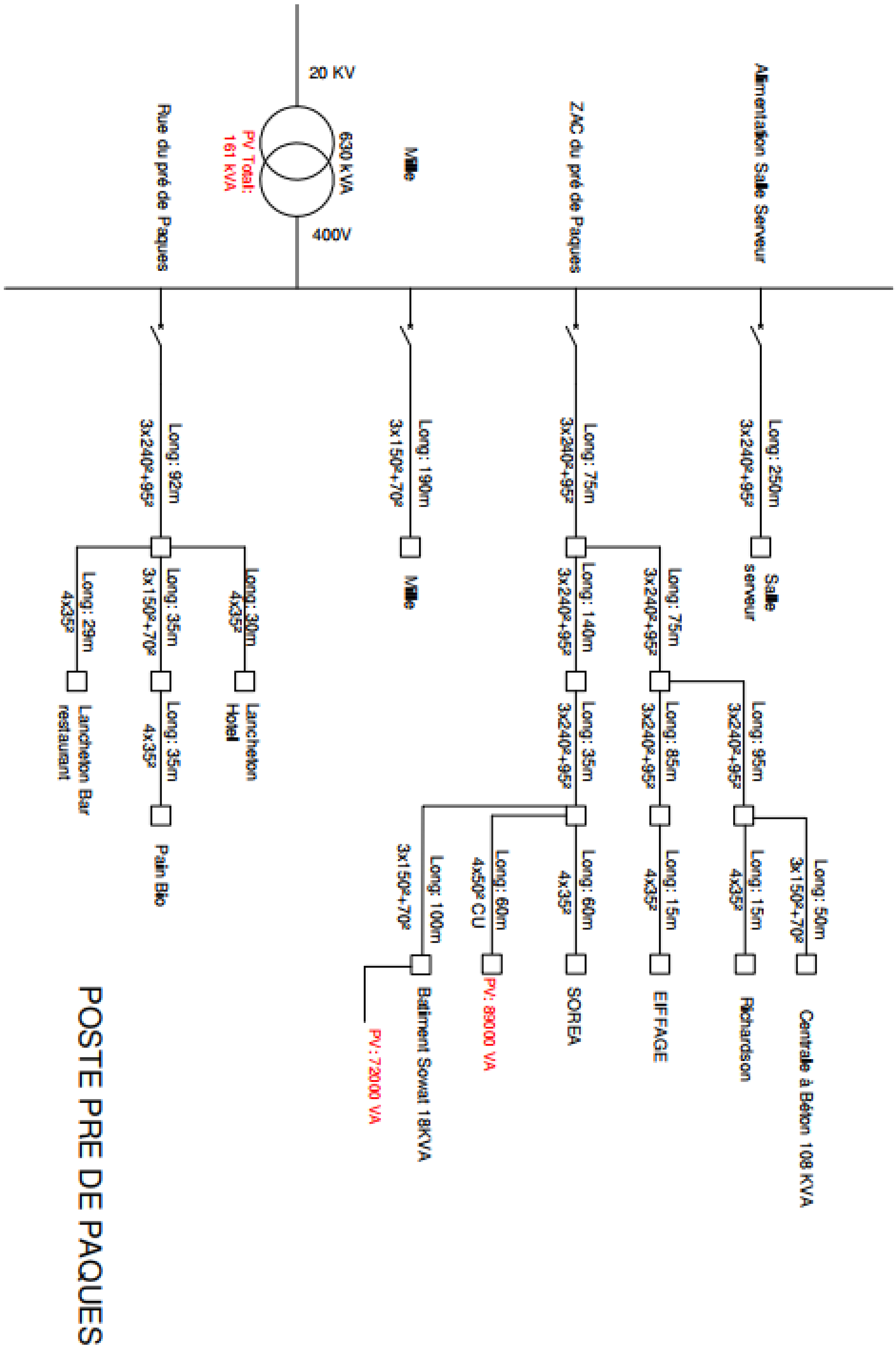

Figure 3-3: SOREA micro-grid at Pre de Paques.

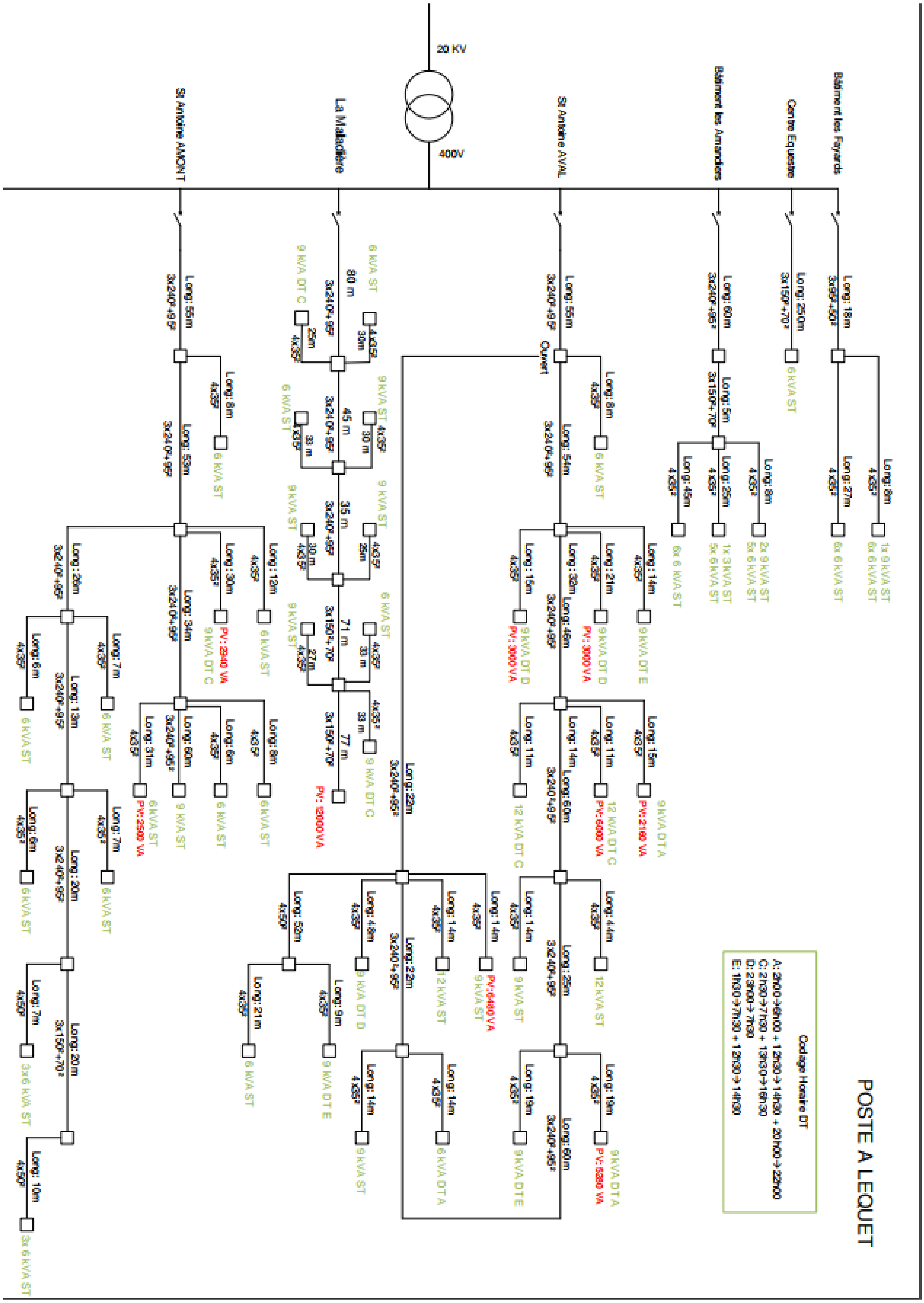

Figure 3-4: SOREA micro-grid at A Lequet.

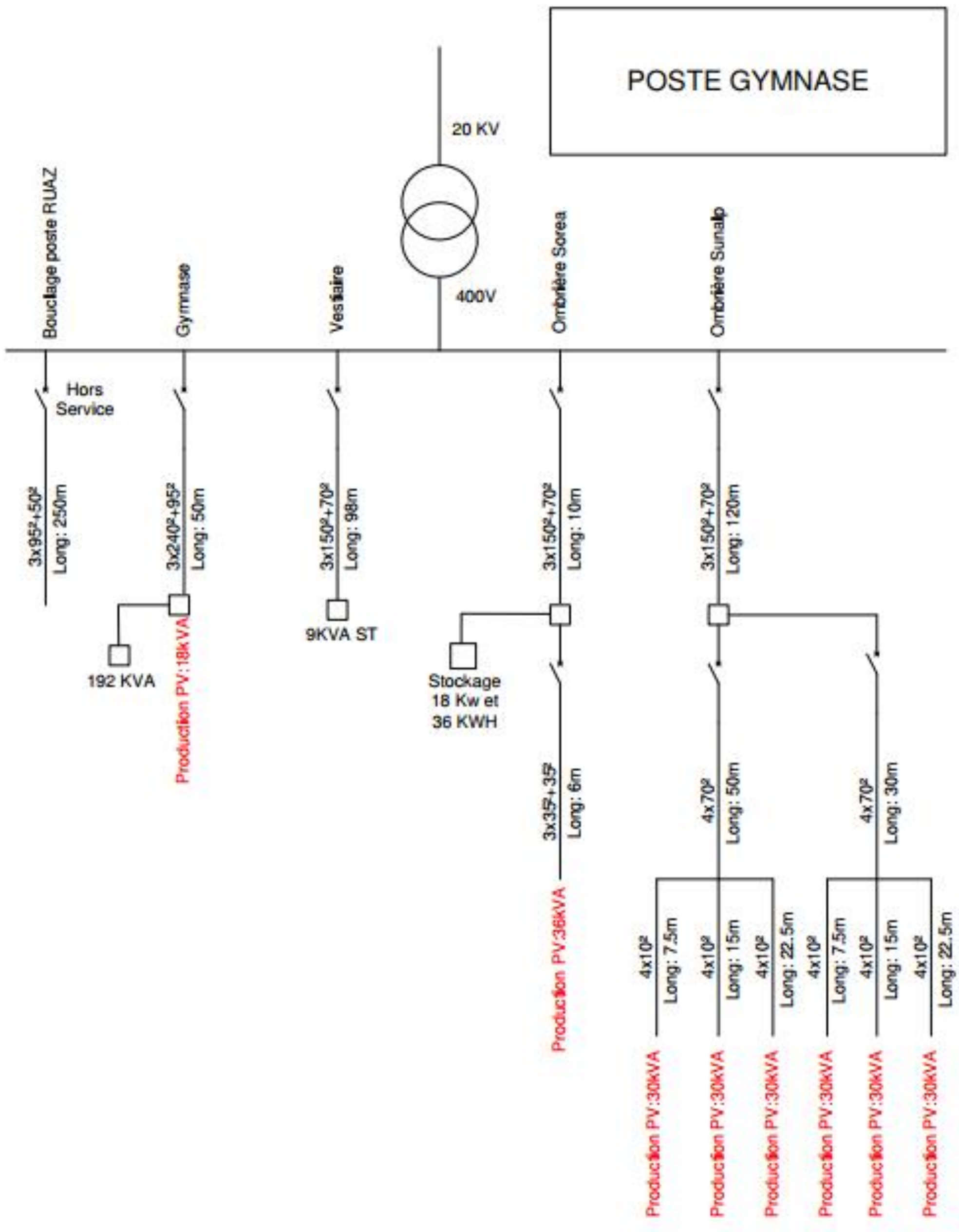

Figure 3-5: SOREA micro-grid at A Lequet.

3.1.3 Positive Footprint House (PFH)

GE's positive footprint housing demonstration project is located in a 2200m^2 area in the center of Gothenburg, Sweden. PV panels with maximum capacity of 140 kWp will be installed in the rooftops of three buildings by 2018. Second life Li-ion batteries with a total capacity of 200 kWh from old electric buses will be used as energy storage.

A BEMS will be responsible for the managing the energy consumption and will be interfaced with the micro-grid controller. Interactions will be realized with the Chalmers micro-grid for the flexibility services.

3.2 Vision

As discussed earlier, micro-grids can be developed for different objectives depending on the requirements and associated constraints. This section discusses the focus, formation and involved actors of the envisioned micro-grids at the demonstration sites.

3.2.1 Focus of the micro-grid

Principal objectives of developing a micro-grid largely varies depending on the type of micro-grids, network topology, geographical locations and involved entities. DSOs have also varying opinions based on their networks and business interests. For instance, rural micro-grids (mostly with the ability of operating in islanded mode) have proven to be of significantly higher interest among prominent European DSOs.

As highlighted in Section 2.1, overvoltage and overloading problems are prominent issues in European distribution networks. In addition, single-phase PV installations have shown to contribute to a higher voltage unbalance in the network. From an operational point of view, coordination among networked micro-grids have also drawn significant research interest of late.

The overarching goal of the project is to investigate the autonomous control and management of micro-grids along with the interaction among the networked micro-grids for flexibility services. The aim of the SOREA micro-grids is to support the DSO with voltage regulation and congestion management involving demand response mechanisms through physical micro-grids. On the other hand, the Chalmers micro-grid and PFH will be developed to study the interaction of micro-grids for flexibility services as well as to lay a foundation for the development of local flexibility markets.

3.2.2 Formation of the microgrid

The SOREA network at Saint-Julien-Montdenis includes PV systems of 500 kWp at the MV network along with the hydroelectric power plant. Three LV micro-grids represent a mix of residential and commercial end-users. The microgrid at A Lequet consists of residential end-users with the static and dynamic tariff systems. Pre de Paques has both residential and commercial consumers along with PV power plants. Finally, the location at Gymnase is considered due to the availability of the battery energy storage system along with canopies and rooftop PV installation.

The characteristics of these sites are summarized in Table 3-1.

Table 3-1: Characteristics of the micro-grids

Micro-grid	Types of DER	Installed capacity	Load types	Remarks
Pre de Paques	PV	161 kWp	Residential and commercial	PV systems represent PV power plants.
A Lequet	PV	43.36 kWp	Residential	Rooftop solar PV systems. Power-based dynamic tariff schemes.
Gymnase	PV	234 kWp	Building loads	Sport complex
	Lead-acid battery	36 kWh		
Chalmers	PV	60 kWp		

	CHP	100 kW	Ventilation and other building loads	BEMS controlling the loads. SCADA available for remote monitoring and measurement.
	Curtailable load	500 kW		
PFH	PV	140 kWp	Building loads	BEMS controlling loads.
	Li-ion battery	200 kWh		

4 Scenarios and approach

This section describes the projected scenarios of different technologies for micro-grid deployment and the multi-disciplinary approach of the project.

4.1 Projected scenarios

As discussed in Section 2, the transition towards a sustainable energy solution poses challenges for the network operators. In order to facilitate the transition, the DSOs need to ensure sufficient capacity and maintain power quality requirements. To this end, several technologies have been widely identified to have the most profound impact on the networks. These are PV, EV, µCHP and heat pump [22], [23].

In order to assess the influence of these technologies in the upcoming decades, their adoption rate needs to be taken into the consideration. For the planning purpose of the micro-grids, the adoption scenarios of these technologies are modelled through S-curves [23]. As depicted by eq. S-curves denote how certain technologies will be adopted within the planning horizon given the adoption rates:

$$y = \frac{y_{\max}}{1 + e^{-a(t-t_0)}} \qquad (2)$$

where y_{max} is the maximum penetration level, a denotes the rate of adoption of a technology and t_0 is the year in which half of the maximum penetration is reached. These values are obtained from national and international reports focusing on forecasts of different scenario elements [23]. The associated values of these parameters for different technologies are tabulated in Table 4-1.

Table 4-1: Implementation of the scenarios for different technologies

	High			**Medium**			**Low**		
	y_{max}	a	t_0	y_{max}	a	t_0	y_{max}	a	t_0
PV	63	0.25	2029	29	0.23	2028	4.6	0.15	2027
EV	84	0.25	2031	33	0.23	2031	7.2	0.18	2028
Heat pump	46	0.31	2034	5.2	0.31	2034	0.1	0.29	2033

µCHP	9.7	0.24	2031	2.7	0.24	2030	0.2	0.023	2031

Based on the values, scenarios have been derived for PV, EV, heat pumps and µCHP for 40 years from 2015 to 2055. Three probable scenarios have been envisioned for each technology considering high, medium and low adoption rates. The developed scenarios are illustrated in Figure 4-1.

As shown in Figure 4-1, a high adoption rate will lead to considerably larger penetration of solar PV systems and EVs, while almost 50% of the end-users are expected to meet their heating demands through heat pumps in 2055.

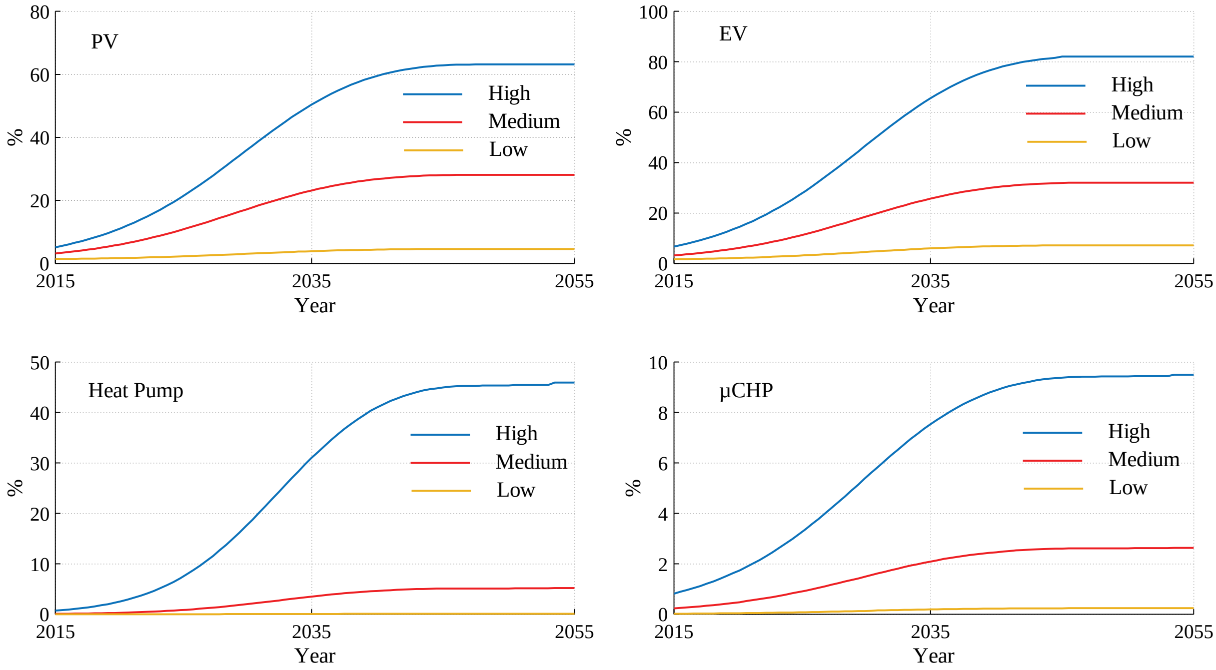

Figure 4-1: Projected penetration scenario of PV, EV, heat pump and micro-CHP over the years.

4.2 Approach

Micro-grids will be a cornerstone for the development of smart grids by enabling decentralized control and active participation of end-users. In this project, a multi-disciplinary research approach will be adopted encompassing hardware power electronics, ICT and advanced control and flexibility market services.

Thanks to the development in flexible embedded controllers and communication capabilities, power electronics interfaces, i.e. inverters are becoming popular for micro-grids connection to the distribution network. These interfaces play a crucial role by routing power flows within micro-grids in islanded operation mode and by coordinating multiple micro-grids in grid connected operation mode. From a DSO’s point of view they can be interpreted as smart actuators ensuring reliable and secure operation of an active distribution network. These power electronic interfaces will be investigated in detail for their roles in the management of physical micro-grids.

Next to power electronic interfaces, advanced algorithms will be developed in order to ensure an effective coordination and to enable loads sharing capability among micro-grids. Once implemented, this coordination could ease the power flow managements from distribution networks upstream by actively dispatching the distributed resources, hence achieving higher utilization of downstream facilities and infrastructure. On one hand this will reduce the complexities in the network operations; on the other hand, it will engage the end-users more actively in the energy value chain.

The project will also focus on commercial micro-grids to exploit flexibility potential by clustering end-users with proper incentives and price signals. To this end, suitable demand response programs will be developed incorporating distributed and computational intelligence. While it will help the DSO by ensuring a higher utilization of the assets, the end-users will also be benefited through financial incentives.

5 Summary

Micro-grids present an important challenge for all stakeholders in the electricity value chain, starting from producers and TSO/DSO going through aggregators and retailers, and ending by customers and DGs. Micro-grids can be implemented on the existing infrastructure in the majority of the use cases without surplus investment, even commercial implementation without new physical connections (Virtual model). However, it gives to the network operator more flexibility and reduces exchanged data outside of the micro-grid. Hence, micro-grid decreases network traffic congestion, resulting in a more resilient global network. On the one hand, micro-grids support the utilities as an ancillary service as well as dispatchable resources. On the other hand, it can be operated in the connected mode but also in the islanded mode if necessary with keeping the exchange of information with the DSOs.

In this report, the scenarios for demonstration and prospective simulation analyses have been discussed. Three micro-grid sites have been proposed in Sweden and France. The envisioned micro-grids represent a mix of residential and commercial end-users with varying levels of distributed energy resources. Battery storage systems are also available providing a notable source of flexibility.

First, a series of simulation analyses will be performed in order to assess the effects of the DERs considering different levels of their penetration throughout the years. This will essentially pave the way for analyzing prospective issues before the demonstration. Finally, the developed methodologies of the project will be tested and evaluated through real-life demonstrations at the sites.

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Appendix A

Task 2.1 Scenarios for demonstration

Questionnaire

Part A. Current situation

1. For GE and SOREA, please specify the Distributed Energy Resources existing in the utility grid?

Distributed energy resources	**Available**	**Installed capacity (kW)**	**Types**
Solar PV	☐		
Wind turbine	☐		
Fuel cell	☐		
Battery storage	☐		
Thermal storage	☐		
Small rotating generators	☐		
Others	☐		

2. For GE and SOREA, is there an existing microgrid developed in the utility grid?

Yes ☐ No ☐ If Yes, please specify:

	(1)	(2)
Microgrid name/location:		
Often operation mode (Grid-connected / Islanded):		
Operational voltage level (kV):		
Installed capacity in total (kW):		
Peak power demand (kW):		
Solar PV installed capacity (kW):		
Wind turbine installed capacity (kW):		
Fuel cell installed capacity (kW):		
Energy storage installed capacity (kW):		

Rotating generator installed capacity (kW):		
Control and management solutions being applied		

3. For GE and SOREA, were any existing European or national scenarios considered during the development of the microgrid?

   Yes ☐ No ☐ If Yes, please specify:

Scenarios	**Quality**	**Reference name**	**Main features**
European scenarios			
National scenarios			
Other scenarios			

4. For other stakeholders, please indicate the other scenarios on European and national levels that you think suitable.

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5. Please briefly indicate if there has something already been done in order to implement the scenarios.

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6. Did you encounter any problem in the past related to the penetration of DER in your grid, such as congestion problems or voltage issues?

   ____

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7. What kind of network tariff is implemented in your grid? Is it allowed from the regulation to offer dynamic network tariff?

Type of tariff		Share of the component (%)	Comment
Power-based (€/kW)	☐		
Energy-based (€/kWh)	☐		
Time-Dependent tariff	☐		

8. Do you have any experience with Demand Response programs implemented in your grid? (Results, problems, etc.)

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9. Is there any aggregator or utility company managing the aggregation of DER within your grid?

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Part B. Vision of scenarios

10. With your vision, what would the use cases that future microgrid scenarios would focus on be?

Use cases	**Sugges-tion**	**Priority level (High/Medium /Low)**	**Target applica-tion**
Business (e.g. trading energy on market, ancillary services, etc.)	☐		
Control and management (e.g. balancing supply&demand, demand side management, etc.)	☐		
Others	☐		

11. Regarding the microgrid structure, what would the future scenarios cover?

Distributed Energy Resources	**Sugges-tion**	**Expected share/capacity**
- Solar PV	☐	
- Wind Turbine	☐	
- Fuel cell	☐	
- Small rotating generators	☐	
- Others	☐	
Energy storage system	**Sugges-tion**	**Expected share/capacity**
- Battery	☐	
- Flywheel	☐	
- Thermal storage	☐	
- Others	☐	
Controllable loads	**Sugges-tion**	**Expected reduction/shifting**
- Household	☐	
- Commercial buildings	☐	

- Industry	☐	
- Others	☐	

12. Who are the actors involved in the development and implementation of the proposed microgrid scenarios? (The actors could include people, organization, system, and devices)

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13. What would the additional related work be to develop and implement the proposed microgrid scenarios you think as necessary?

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14. Within the Winter Package, the European Parliament proposes a directive on common rules for the internal market in electricity.

The Article 32 says that "Member States shall provide the necessary regulatory framework to allow and incentivize **distribution system operators** to **procure services** in order to improve efficiencies in the operation and development of the distribution system, including **local congestion management**. In particular, regulatory frameworks shall enable distribution system operators to **procure services from resources such as distributed generation, demand response or storage** and consider energy efficiency measures, which may supplant the need to upgrade or replace electricity capacity and which support the efficient and secure operation of the distribution system. Distribution system operators shall procure these services according to transparent, non- discriminatory and **market based procedures**".

In the future, is the company willing to use market-based procedure for procuring flexible energy from DER and controllable loads?

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15. What do you think is the possible aim of a local flexibility market operated by the DSO? What will be more useful in your case considering your future scenarios?

Main aim		**Comment**
Solve congestion or voltage problems procuring flexible energy from DER	☐	
Trade energy with the utility grid or neighbor microgrids	☐	
Use flexible energy in the medium-term planning for avoiding or defer grid investment	☐	
Promoting DER by creating value for flexible energy	☐	
Others	☐	