European Commission | Horizon 2020 European Union funding for Research & Innovation

WP8 Demonstration Specification for Field Testing: Aggregation Approaches for Multi-services Provision from a Portfolio of Distributed Resources

D8.1

EU-SysFlex

© Copyright 2018 The EU-SYSFLEX Consortium

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.

PROGRAMME	H2020 COMPETITIVE LOW CARBON ENERGY 2017-2-SMART-GRIDS
GRANT AGREEMENT NUMBER	773505
PROJECT ACRONYM	EU-SYSFLEX
DOCUMENT	**D8.1**
TYPE (DISTRIBUTION LEVEL)	☒ Public ☐ Confidential ☐ Restricted
DUE DELIVERY DATE	
DATE OF DELIVERY	30/10/2018
STATUS AND VERSION	V0
NUMBER OF PAGES	
Work Package / TASK RELATED	WP8 / Task 8.1
Work Package / TASK RESPONSIBLE	EDF / Ye Wang
AUTHOR (S)	Ye Wang (EDF), Hugo Morais (EDF), Victor Gomes (ENERCON), Bettina Lenz (ENERCON), Thomas Godlewski (EDF), Héloise Baraffe (EDF), Loïc Joseph-Auguste (EDF), Cristian Jécu (EDF), Etienne Deschanvre (EDF), Guillame Lehmann (EDF), Thierry Jouhanique (EDF), Christophe Chaussin (EDF), Ana Kosareva (ENERCON), Konstantin Kunz (ENERCON), Bruno Heili (EDF), Claire Stefanelli (EDF)

DOCUMENT HISTORY

VERS	ISSUE DATE	CONTENT AND CHANGES
1	30/09/2018	First version
2	16/10/2018	Second version
3	30/10/2018	Third version

DOCUMENT APPROVERS

PARTNER	APPROVER
EDF	Marie-Ann Evans (Technical Manager)
EirGrid, EDF, SONI, VITO, Innogy, Elering, EDP, Euractiv, Zabala	Project Management Board
EirGrid	John Lowry (Project Coordinator)

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AB	Advisory Board
AC	Alternative Current
BaU	Business as Usual
BESS	Battery Energy Storage System
CA	Consortium Agreement
CG	Concept Grid
DoA	Description of Action
DB	Demonstration Board
DC	Direct Current
DEIE	Dispositif d'Échange d'Informations d'Exploitation
DER	Distributed Energy Resources
DMS	Device Management System
DSO	Distribution System Operator
EC	European Commission
EC-GA	Grant Agreement
ECMWF	European Centre for Medium-Range Weather Forecasts
EDF	Electricité de France
EU-SYSFLEX	Pan-European System with an efficient coordinated use of flexibilities for the integration of a large share of Renewable Energy Sources (RES)
FACTS	Flexible Alternative Current Transmission System
FCI	Farm Control Interface
FCR	Frequency Containment Reserve
FCU	Farm Control Unit
FOC	Fibre-Optic Cables
FRR	Frequency Restoration Reserve
GA	General Assembly
GED	Grid Edge Device
HIL	Hardware In the Loop
HMI	Human Machine Interface
IT	Information Technology
KPI	Key Performance Indicator
LV	Low Voltage
MAPE	Mean Absolute Percentage Error
MILP	Mixed Integer Linear Programming
MV	Medium Voltage
PC	Project Coordinator
PEMS	Power Energy Management System
PHIL	Power-Hardware-In-the-Loop
PLC	Programmable Logic Controller
PMB	Project Management Board
PV	Photovoltaic
RES	Renewable Energy Sources
REST	REpresentational State Transfer

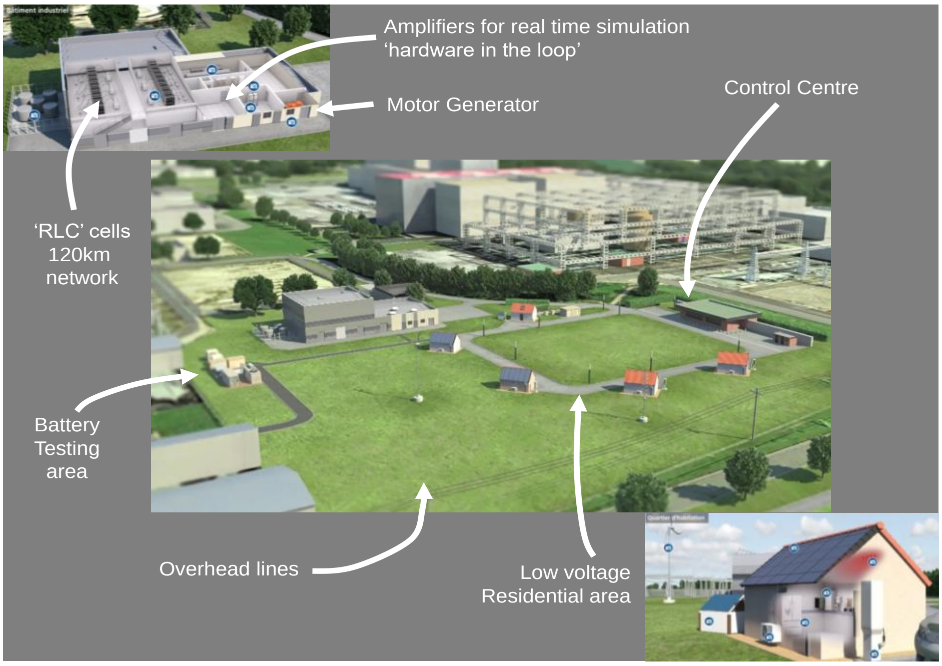
RMSE	Root-Mean-Square Error
RRC	Ramp Rate Control
RT	Real-time
RTU	Remote Terminal Unit
SAI	SCADA Application Interface
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart Grid Architecture Model
SLD	Single Line Diagram
SO	System Operator
SoC	State of Charge
SOSD	System Operation Supervision Device
SUC	System Use Case
TM	Technical Manager
TRL	Technology Readiness Level
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
VPN	Virtual Private Network
VPP	Virtual Power Plant
VRG	Variable renewable generation
WEC	Wind Energy Converters
WP	Work Package
WPP	Wind Power Plant
WT	Wind Turbine
WTG	Wind Turbine Generator

EXECUTIVE SUMMARY

Funded by the European H2020 research program, the EU-SysFlex project is supported by a pan-European consortium including transmission and distribution system operators, utilities, technology providers, as well as research and academic institutes. The overall aim of this 26 M€, 4-year demonstration project is to provide a roadmap for Europe in meeting the challenge of integrating over 50% renewables by 2030. The project includes seven industrial-scale demonstrations to explore the provision of flexibility and services to system operators, using resources from all system levels. This report focuses on the description of technical specifications of the French demonstration (WP8 of the EU-SysFlex project), which aims at coordinating the operation of a portfolio of distributed resources for multi-services provision to the power system.

Modern variable Renewable Energy Sources (RES) and energy storage can provide services and flexibilities to different system stakeholders. However, the services provision may be restricted and intermittent by using single units' abilities only, due notably to unfavourable wind/solar conditions or limited storage capacity. The performance and reliability of the procured services are therefore expected to be highly enhanced, from a local point of view, by aggregating RES and storage abilities. Furthermore, cost-benefit analysis often shows that the revenues of a single service are not sufficient to cover the investment and operating costs. The provision of multiple services can help overcome this barrier thanks to additional revenue streams. In this context, the concept of multi-resources aggregation for multi-services provision is proposed. The practical feasibility of this concept still needs to be proven: this is (one of) the key objective(s) of this field demonstration based in France.

The partners in this demonstration are EDF R&D, with several research teams involved, and ENERCON, with also several branches cooperating for the needs of the demonstration work. The WP8 demonstration is mainly implemented on EDF Concept Grid (CG), which is a private distribution grid dedicated to the test and validation of smart grid equipment, systems and functions as shown in the following figure. It has been developed to study and accompany the integration of renewable energy resources in the electric system, storage and new uses, e.g. electric vehicles or heat pumps. Moreover, Concept Grid is designed to take place half-way between laboratory tests and experiments in the field, where it is possible to conduct, in complete safety, complex testing campaigns that would be impossible to perform on a real system.



The portfolio of resources comprises:

- a 12-MW wind farm of 6 x 2000-KW turbine of type ENERCON E82;
- a full storage system including a 2.3-MW/1h lithium-ion battery as well as an ENERCON E-Storage 2300 power conversion system;
- photovoltaic panels and a variable load test bench installed at EDF Concept Grid, combined with power amplifiers.

Most of the distributed resources are installed on CG with the exception of the wind farm located in the department of "Marne" in France and connected to the public distribution grid. The resources will be controlled remotely through a newly developed full IEC-61850-based and hardware-agnostic communication platform. This platform present several advantages, compared with the traditional ones, such as the flexibility to manage the software, firmware and configurations with an increased level of cybersecurity. It also allows to ensure the interoperability and the evolutivity of the proposed solution, which is essential for replicability and scalability concerns.

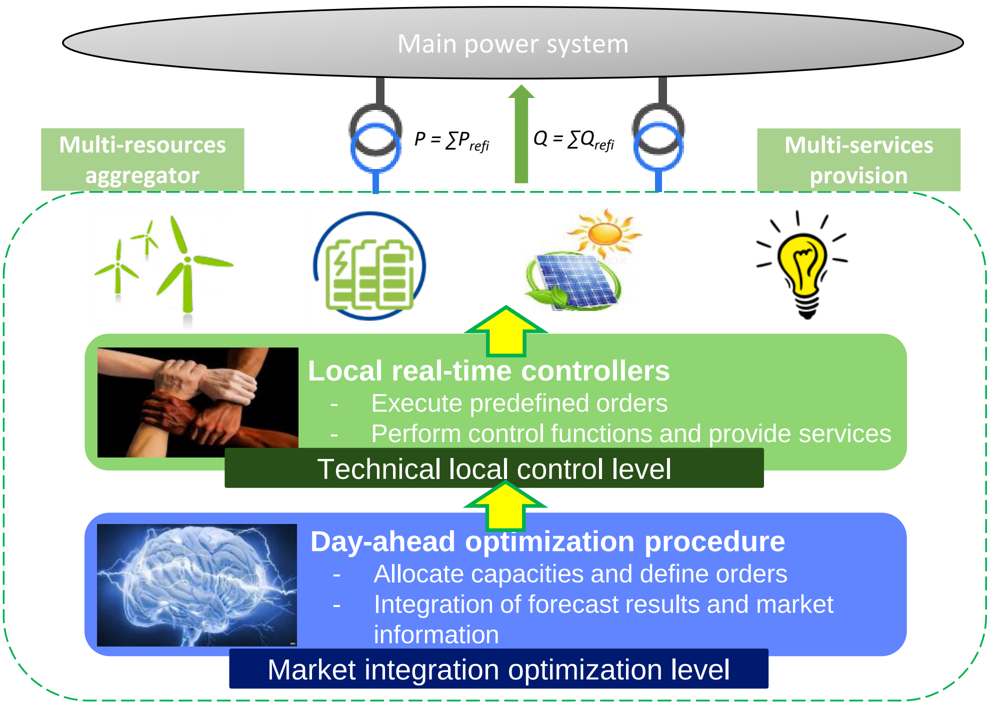
The services that will be tested by the demonstration are well aligned with upcoming power system scarcities identified in WP2 (in terms of ancillary services need such as frequency and voltage controls as well as additional requirement on flexibility solutions provision). They can be classified into 4 categories as summarized in the table below.

Categories	Services
Frequency support services	Fast Frequency Response (FFR)
	Frequency Containment Reserve (FCR)
	Frequency Restoration Reserve (FRR)

Flexibility solutions	Ramp-rate control
	Peak shaving
Reactive power services	Local voltage support
	Dynamic reactive response
+ Energy arbitrage as an aggregator	

Several services will be activated simultaneously in order to maximize the operation potential and the profitability of the aggregated resources. This implies to address several tricky, technical issues such as the compatibility and performance assessment of different services. The coordination of multi-services provision and the allocation of different services on multi-resources are part of the key scientific research topics of the WP8 demonstration. Further in-depth studies will be carried out to investigate this subject through simulation results and according to the experimental tests. It will also be necessary to further discuss with the system operators in order to better understand the performance required of different services as well as the related control methods.

The multi-service operation will be achieved using a dedicated two-level supervisory control as illustrated in a simple manner in the following figure. First, a remote supervision will perform day-ahead scheduling of services allocation to maximize profitability by considering the variable renewable generation forecast results and market information such as energy and services prices, while satisfying different constraints (e.g., battery state of charge) and requests from the system operators. It will also make intraday adjustments of the schedule in order to limit the impact of the deviations due notably to renewable generation forecast errors and take appropriate actions if any contingency occurs.



Secondly, local controllers of each resource will autonomously manage the execution of the optimized schedule in real time and provide allocated services by calculating the active and reactive power references according to local measurement such as frequency and voltage. To achieve a successful operation of the described functions, different software modules and controllers will need to be developed and some existing control functions have to be enhanced to set up this demonstration.

The system use case (SUC) of the WP8 demonstration is defined using the Use Case methodology through key concepts: roles, activities, systems and functions. 6 possible operational scenarios have been identified including the normal operation mode, direct resources control mode, manual operational planning, autonomous operation of local controllers, operation mode under system operators' orders and operation mode under alarms. Detailed step-by-step SUC has been defined for the normal operation mode and first investigations on the operational process of the other scenarios have been carried out.

Next steps within WP8 mainly address the set-up of the hardware components to build the demonstration as well as the development and integration of different tools allowing its operation. In the next months, the WP8 team will:

- Install the storage containers at EDF Concept Grid and perform the commissioning tests;
- Prepare the models of different assets and controllers in order to build the real time simulation platform of the demonstration;
- Develop the algorithms of the energy management system (EMS) of the aggregator and perform first tests.

1. GENERAL DESCRIPTION OF THE WP8 DEMONSTRATION

1.1 CONTEXT AND OBJECTIVES

Variable renewable generation (VRG) such as wind and photovoltaic (PV) are mostly distributed and characterized by their variable nature and by their power electronic interface with the grid. As a consequence, operating the power system with high penetration of renewables will require to overcome significant technical challenges, such as frequency and voltage stability concerns [1]. The fact that VRG displaces conventional synchronous generation reduces both the total system inertia and the number of power plants available to provide ancillary services [2]. In this context, higher reserve and new flexibility requirement would be necessary to ensure power system security and reliability. The provision of ancillary services – so far mainly supplied by conventional synchronous units – would also be required for VRG connection or supplied by storage. It is already the case in several power systems such as the Irish and British networks where the penetration rate of VRG is relatively high [3] [4].

In previous studies and demonstrations worldwide, the ability of VRG as well as of storage systems to provide individually system services has been proven. For example, the frequency reserve and voltage support provided by battery storage have been demonstrated in [5] [6]; the participation of wind farms in frequency controls such as frequency containment reserve (FCR) or frequency restoration reserve (FRR) has been analysed and demonstrated in [7] [8]; the capability of PV panels to provide FCR has also been investigated in [9]. The corresponding technologies and technical solutions have relatively high technology readiness level (TRL) and some of them have already been used in different industrial projects.

However, the provision of the services could be limited and intermittent if using single units' abilities, for example, during unfavourable wind and solar conditions or due to limited sizing and state of charge of storage systems. From a local point of view, the performance and reliability of the procured services could be expected to be enhanced by using an aggregation approach including variable resources as well as storage. Furthermore, cost-benefit analysis often shows that the revenues of a single service are not sufficient to cover the investment and operating costs. The provision of multiple services can help overcome this barrier thanks to additional revenue streams. A coordinated flexibility provision allows to maximize the potential of an aggregator composed of different resources, so as to increase the gain of its operation.

For these purposes, a decentralized multi-resources aggregator[1] containing wind and PV generation, a battery energy storage system (BESS) as well as controllable loads will be built at a reduced scale and operated over a long period in the WP8 of the EU-SysFlex project. The main objectives of this demonstration are:

- To demonstrate the technical feasibility of **performing optimal management** and **coordinated control** of the **multi-resources aggregator** to provide **multi-services** to the power system;
- To **assess the performances** of **different services** and **flexibility solutions** that can be procured from the aggregator by considering the grid codes' requirement.

[1] Also known as a "virtual power plant (VPP)" from a commercial point of view

It is therefore expected to increase the TRL of the concept and the operation of such a "multi-resources multi-services" aggregator through the demonstration works.

1.2 GENERAL APPROACH DESCRIPTION

The demonstration will be built thanks to the collaboration between EDF and ENERCON and will be mainly implemented at EDF Concept Grid (CG) which is a real distribution grid and testing facility dedicated to the test and validation of smart grid equipment, systems and functions. Concept Grid is designed to take place mid-way between laboratory tests and full-scale field experiment, allowing to conduct, in complete safety, complex testing campaigns on a real system afterwards [10]. Severe grid faults or emergencies can be emulated or tested without any consequence on the real power system thanks to the disconnection of CG from the main transmission power system via a fully dedicated transformer. Innovative solutions can therefore be evaluated and challenged in risk-free conditions.

To build the WP8 demonstration, a 2.3-MW full storage system comprising a Li-ion battery will be installed within CG and a 12-MW wind farm connected to the French distribution grid will be controlled remotely through advanced communication means. The generation output of the PV panels as well as of the variable load test bench of kW-size that have been installed at CG will be used to emulate the respective behaviour of a MW-size PV farm and of an industrial-size controllable load through power amplifiers. Detailed descriptions of the hardware components as well as software modules of the studied aggregator can be found in Chapter 2 of the present report.

The approach of "real time simulation – hardware in the loop (HIL) – full-scale experiment" will be applied to perform the demonstration work. Real-time simulation is a complementary tool to conventional offline simulation programs for power system studies [11]. With much more computational power, real-time simulators are able to simulate very complex and large models in real-time or faster [12]. Furthermore, real-time enables power HIL simulation: where part of a model or a system is simulated and connected to real power devices through sensors and amplifiers. This approach will allow to build in a safe manner the demonstration from fully simulated models to the real multi-resources aggregator, as show in Figure 1:

- As a first step, different components and control systems of the aggregator will be modeled and simulated in real-time in order to build an "all-simulation" platform. This simulation platform will allow to verify the functionalities of the developed controllers and to ensure the effective and coordinated operation of the aggregation. The EDF CG's real time simulator will be used for this development.
- In the next step, the real BESS will be introduced and interfaced with the remaining part of the platform that will stay simulated in real-time. First experiments will be performed to validate the storage controllers as well as the satisfactory communication between the storage and the centralized control.
- Likewise, real wind farm, PV panels and variable loads will be integrated one by one into the demonstration and replace the corresponding simulated models. The whole real-scale aggregator will be tested to ensure its well-functioning operation and the effective multi-services provision.

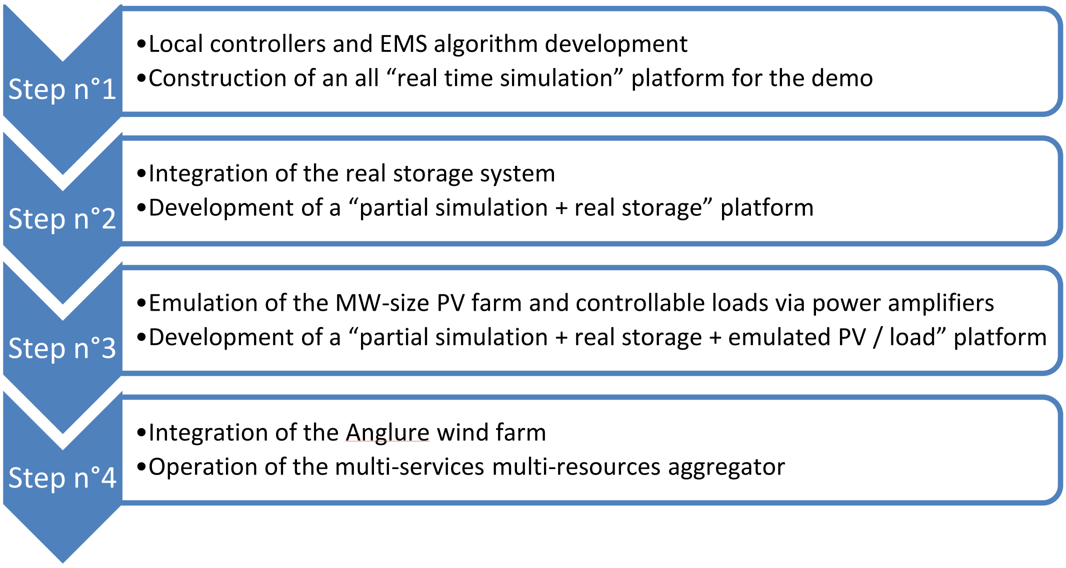


FIGURE 1. PROPOSED APPROACH: "REAL TIME SIMULATION – HARDWARE IN THE LOOP"

By applying this scientifically rigorous approach, all the functions and algorithms developed will be validated step by step before being implemented into real devices, allowing to accelerate the debug and tuning phase for controller settings and to ensure the safety of the demonstration's operation.

1.3 SERVICES PROVIDED BY WP8 DEMONSTRATION

The services that will be tested by the demonstration can be classified into 4 categories as summarized in the table below.

Categories	Services
Frequency support services	Fast Frequency Response (FFR)
	Frequency Containment Reserve (FCR)
	Frequency Restoration Reserve (FRR)
Flexibility solutions	Ramp-rate control
	Peak shaving
Reactive power services	Local voltage support
	Dynamic reactive response
+ Energy arbitrage as an aggregator	

TABLE 1. SERVICES PROVIDED BY THE WP8 MULTI-RESOURCES AGGREGATOR

Each category and related services are described in the following chapters.

1.3.1 FREQUENCY SUPPORT SERVICES

Classical frequency support services are illustrated in Figure 2.

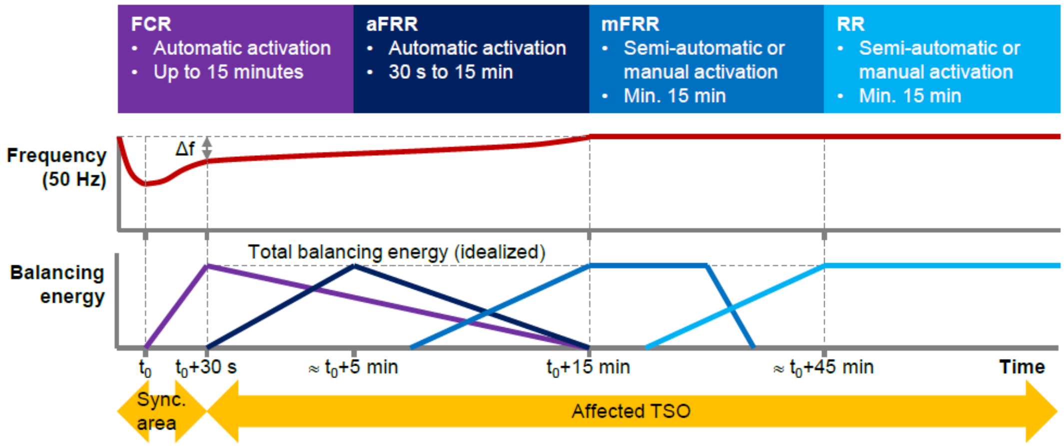


FIGURE 2 : CLASSICAL FREQUENCY SERVICES (ENTSO-E) [13]

Practically, each frequency service is provided by performing an appropriate control of the injected active power, either automatically and based on the local measurement of the grid frequency, or based on an active power setpoint sent by the Transmission System Operator (TSO) request. Moreover, each type of service is characterized mainly by their activation time and duration.

- FCR (Frequency Containment Reserve). This service (known more commonly as Primary Reserve) is activated automatically based on the frequency measurement. It must be fully activated within 30 seconds and the corresponding reserve must be maintained for 15 minutes [13].
- aFRR (automatic Frequency Restoration Reserve)
  This service (known more commonly as Secondary Reserve) is activated automatically based on a signal sent by the TSO. It must be fully activated within 5 minutes and the corresponding reserve must be maintained for 15 minutes.

In addition to the above mentioned classical frequency services, the Fast Frequency Response (FFR) will also be tested. This service will take action before the FCR is activated and is supposed to help the electrical system compensate the decreasing amount of inertia due to the increasing penetration of renewables [2].

- FFR (Fast Frequency Response). This service is activated automatically based on the measurement of a minimum absolute value of the frequency. A unit must be capable of increasing active power output by an agreed amount for the 2 to 10 second period after the frequency dips below a predefined trigger value. Active power output is allowed to “dip” subsequently; however, the extra energy gained during the 2 to 10 second timeframe must be greater than the energy lost during the first 10 seconds of this recovery phase.

Moreover, “service stacking” (also referred to as “service bundling”) refers to a unit ability to provide multiple services consecutively, for example delivering FCR and aFRR. The Irish TSO, EirGrid, have stipulated this as one of their qualification criteria in the DS3 system Services [14], where providing units will be required to provide 5 services consecutively. This will require a response time in 2 second and last up to 20 minutes[2].

1.3.2 FLEXIBILITY SOLUTIONS

As RES (Renewable Energy Sources) inject active power into the grid with relevant short-term variability, the power quality and the grid reliability can be affected. Hence the question of the control and limitation of the active power variation (*dP/dt*) is of importance; the resolution of this issue can be solved to some extent by the mean of a well calibrated storage system coupled to the RES. This has been well demonstrated in [15].

Additionally, and again due to the short-term variability, in some cases local grid congestions occur when a high amount of active power is injected by RES. In such cases, the curtailment of the RES can be a solution but with the adverse consequence of wasting primary energy (wind or solar energy), except if the curtailed energy is stored on a well-designed storage system.

Both solutions, so-called “Ramp-Rate control” and “Peak shaving” will be tested within the WP8.

1.3.3 REACTIVE POWER SERVICES

Reactive power management is a well-known mean to support voltage, and most of the new generation means based on power electronics are well suited for this purpose. Especially, type 4 wind turbines (full-converter technology according to IEEE standards [16]), such as ENERCON technology, are able to provide a wide range of reactive power independently from the wind. Additionally, if storage systems are known mainly to manage the active power (for frequency support for example), they can also be used for the management of reactive power. This capability is not provided by the battery cells but thanks to the power electronics and associated control functions. During the demonstration the impact of the reactive power on the local voltage will be studied.

In addition to this local voltage support, the service of dynamic reactive response will also be tested. As of today, when a voltage fault occurs in the grid, conventional generators based on synchronous machines, react “naturally” by injecting a high level of current into the grid. This inherent capability of synchronous machines results in a natural voltage support for the grid, by limiting the propagation of the voltage dip. For power electronics based generation means, this behaviour is not inherent but can be somehow “emulated” and fast reactive current can be injected as required by System Operators (SOs) as illustrated in the example of EirGrid grid code (Figure 3).

---

[2] *Due to the manual dispatch and delivery duration of mFRR and RR (described below), these services will not be demonstrated as part of WP 8.*

- *mFRR (manual Frequency Restoration Reserve)*

This service (known more commonly as “Tertiary Reserve”) is generally activated manually upon receiving a dispatch instruction from the TSO. It must be fully activated within 15 minutes and must be capable to last up to 30 minutes.

- *RR (Replacement Reserve)*

This service is generally activated manually by generator that require a longer start-up time than the generators that would provide the previous services. This service is used to restore the required level of FRR to be prepared for additional system imbalances or frequency disturbances. It must be fully activated within 45 minutes and must be capable of lasting for a number of hours.

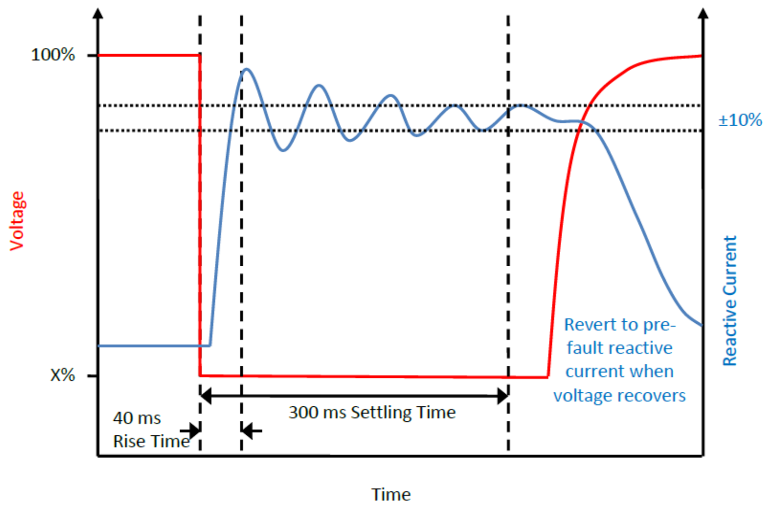


FIGURE 3 : DYNAMIC REACTIVE RESPONSE REQUIRED BY EIRGRID

1.4 MULTI-SERVICES MULTI-RESOURCES APPROACH

As discussed before, distributed resources can generally provide various services such as local voltage support and frequency services provision. However, if these services are considered individually, they often mobilize only a part of the whole power/energy capacities of the resource and do not generate enough revenue to reach profitability. Besides, as resources have their own operational limits (e.g., wind/PV generation depends on the local weather conditions, and maximum charge/discharge of a battery on its current state of charge), they are generally not available at the same time to provide a given service.

That is why the present demonstration proposes to develop and experiment an innovative multi-services, multi-resources control approach, the main objective of which is to maximize the operation and the profitability of any set of aggregated resources. This implies to address several tricky, technical issues, for instance:

- to define how compatible a service is with another, and in particular to what extent two services may be successfully provided over the same period (see the illustrative example below);
- to dispatch the services between different resources efficiently, so as to maximize profitability while ensuring very high service performance;
- to assess the performance of a service when it is delivered by a set of aggregated resources;
- to maximize profitability under services prices and wind/PV generation variability.

Illustrative example of services compatibility:

Let us consider a single resource (e.g., a battery) that can deliver three service products:

- *Service A, which is a high-capacity energy service (e.g., "Energy arbitrage");*
- *Services B and C, which are small-capacity power services with similar temporal patterns but different objectives (e.g., "Frequency containment reserve" and "Ramp rate control").*

When a resource provides only one service, its performance can be assessed hypothetically using the response measured at the resource connection point (Figure 4).

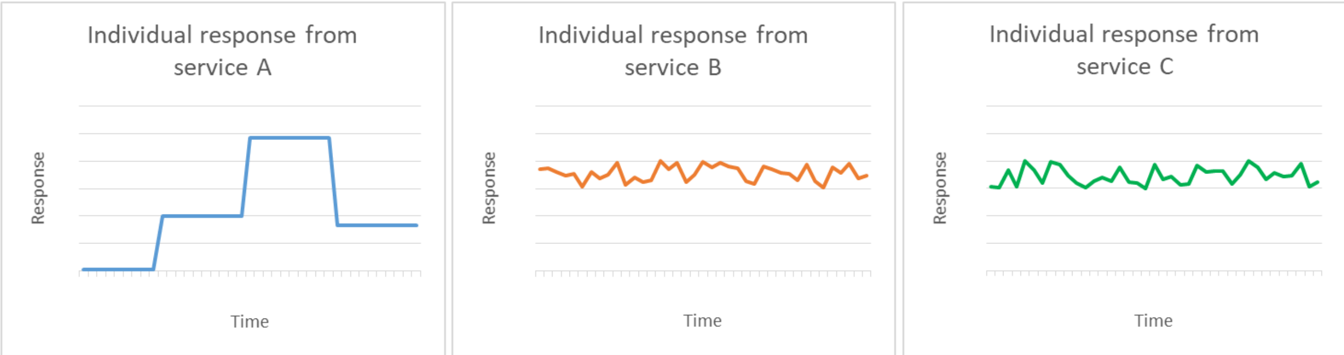


FIGURE 4. RESOURCE RESPONSE WHEN ONLY ONE SERVICE IS DELIVERED: A (LEFT), B (MIDDLE), OR C (RIGHT).

However when a resource provides several services at the same time, only the aggregated response of these services can be measured at the connexion point of the resource. If the delivered services have similar temporal patterns, it is difficult to identify which part of the aggregated response corresponds with each service, and thus to assess the individual performance of each service. Therefore, in this case it will be difficult for the SOs to consider this combination of services as effective contribution for the power system.

In this example, the responses from services A and B can be theoretically deduced from the aggregated response (Figure 5), whereas those from services B and C cannot (Figure 6). The individual performance of services B and C cannot be assessed when they are delivered jointly. ***Service B is therefore not compatible with service C.***

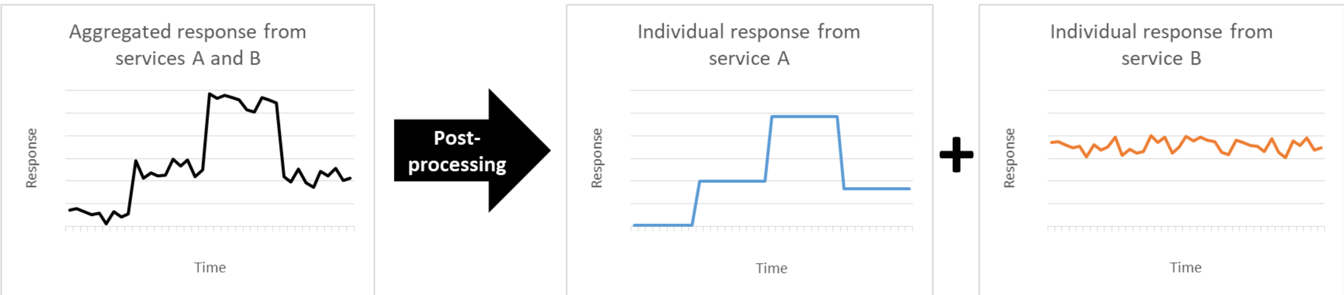


FIGURE 5. AGGREGATED AND POST-PROCESSED INDIVIDUAL RESPONSES WHEN THE RESOURCE PROVIDES SERVICES A AND B.

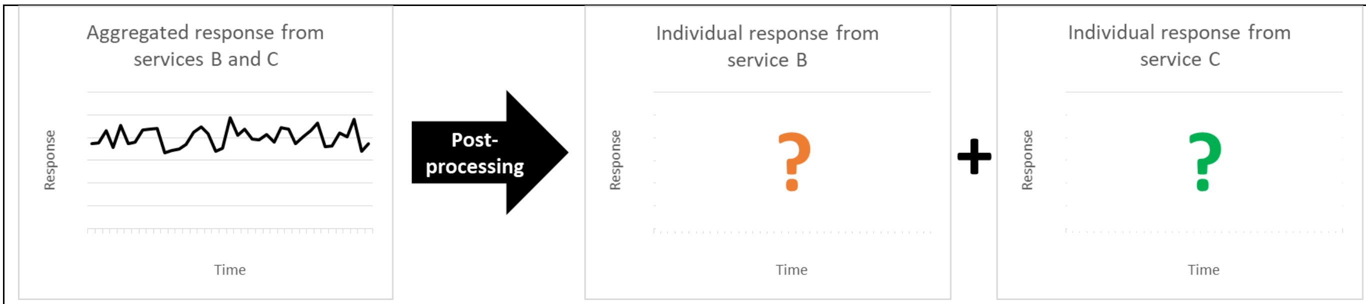


FIGURE 6. AGGREGATED RESPONSE WHEN THE RESOURCE PROVIDES SERVICES B AND C.

The coordination of multi-services provision through an aggregation of multi-resources as well as the compatibility of different services are part of the key scientific research topics of the WP8 demonstration. Further in-depth studies will be carried out to investigate this subject through simulation results and according to the experimental tests. It will also be necessary to further discuss with the system operators in order to better understand the performance required of different services as well as the related control methods proposed by the SOs. More results and conclusions on this topic will be presented in the next technical deliverables of WP8.

2. COMPONENTS AND STRUCTURE OF THE DEMONSTRATION

In this chapter, the main components and structure that will be used or developed to build the demonstration are presented, including the hardware and assets, the software modules and functionalities as well as the communication infrastructure and corresponding IT (Information Technology) solutions.

2.1 GENERAL STRUCTURE

As previously described, the portfolio of resources of the WP8 demonstration comprises a 12-MW wind farm, a 2.3-MW/1h lithium-ion battery system, photovoltaic panels and a variable load test bench, combined with power amplifiers. Most of the distributed resources are installed in the Concept Grid with the exception of the wind farm being at a distant location and connected to the public distribution grid. Detailed technical description of each asset and of EDF CG will be presented in Section 2.2.

The multi-service operation will be achieved using a dedicated two-level supervisory control as illustrated in a simple manner in Figure 7. First, a remote supervision will perform day-ahead scheduling of services allocation to maximize profitability by considering the variable renewable generation forecast results and market information such as energy and services prices, while satisfying different constraints (e.g., battery state of charge) and requests from the system operators. It will also make intraday adjustments of the schedule in order to limit the impact of the deviations due notably to RES forecast errors and take appropriate actions if any contingency occurs.

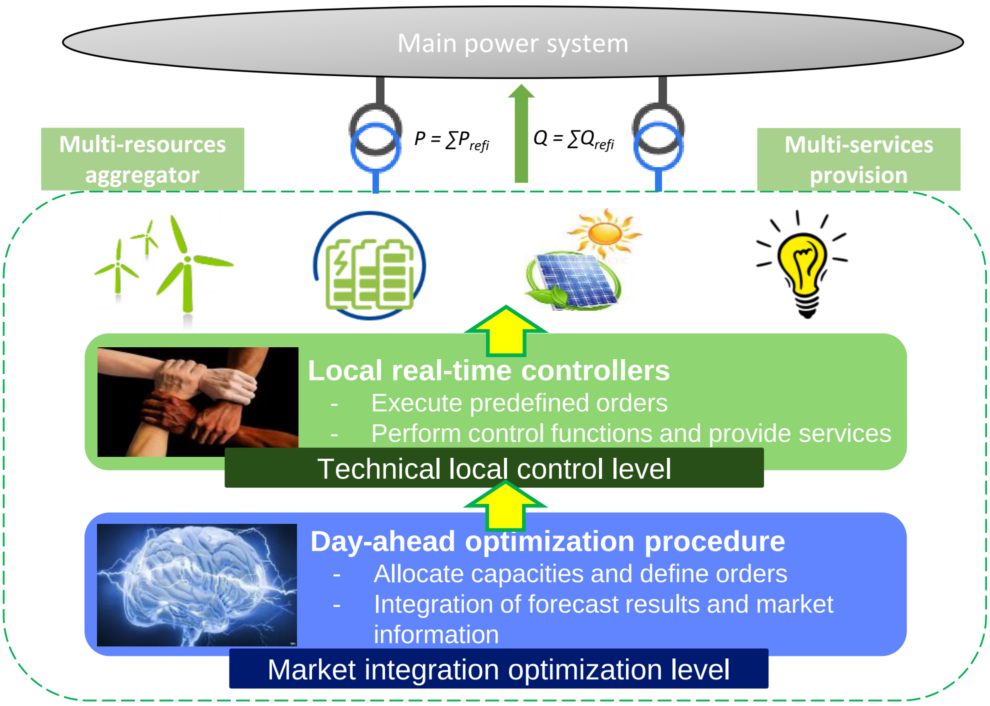


FIGURE 7. GENRAL OPERATING PRINCIPLE OF THE DEMONSTRATION

Secondly, local controllers of each resource will autonomously manage the execution of the optimized schedule in real time and provide allocated services by calculating the active and reactive power references according to local measurement such as frequency and voltage. To achieve a successful operation of the described functions, different software modules and controllers will need to be developed or enhanced for this demonstration. Their operating principles and technical specifications will be described in Section 2.3 of this chapter.

2.2 HARDWARE COMPONENTS

The hardware components of the demonstration, including ENERCON owned wind farm and BESS as well as EDF CG and several installed equipment, are described in detail in this section.

2.2.1 ANGLURE WIND FARM

For the demonstration, ENERCON will make available an owned wind farm, *Anglure 2* (or more officially *Les Vignottes 2*), located in the department of “Marne”, in the community of Saron-Sur-Aube, about 120km south-east of Paris (Figure 8).

FIGURE 8 : WIND FARM "LES VIGNOTTES 2"

Commissioned in September 2015, *Anglure 2* is producing 30 000 MWh/year, equivalent to the consumption of 10 000 households. It comprises 6 x 2000-KW turbine of type E82 (82-meters rotor diameter), for a total installed power of 12MW. Each wind turbine is based on a full converter technology with FACTS (Flexible Alternative Current Transmission System), which is a suitable solution for integration into the grid.

The wind turbines are connected to each other in parallel through an internal medium voltage grid, and to a substation materializing the point of connection to the public grid as illustrated in Figure 9.

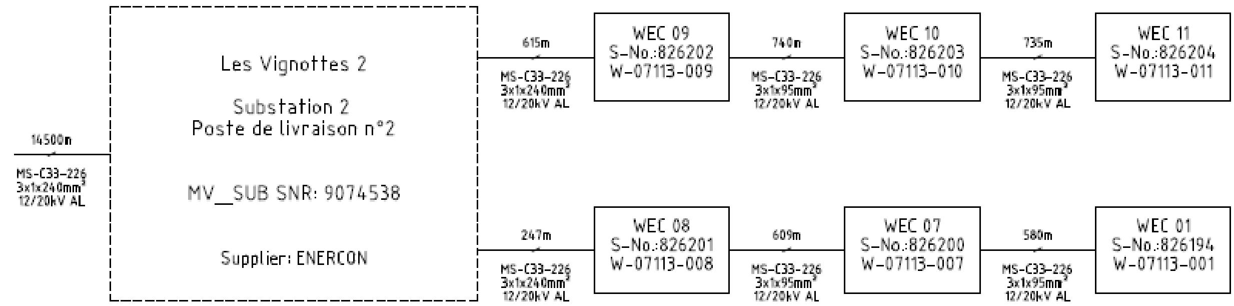


FIGURE 9 : SINGLE LINE DIAGRAM OF THE WINDFARM

The substation contains two separated rooms: the medium voltage room contains the medium voltage switchgear, all the protections and meters, whereas the low voltage room contains the SCADA (Supervisory Control And Data Acquisition) computer dedicated to communicate with the wind turbines, the Remote Terminal Unit (RTU) wind farm controller as well as an interface to communicate with the grid operator (Figure 10).

The RTU is used to monitor and to perform the following control:

- Limiting the maximum injected power to 12MW
- Providing the correct amount of reactive power by applying the single law Q/P=tan(Φ) as a constant as required by the French Distribution System Operator (DSO) ENEDIS

An additional interface DEIE [17] is used to respond to grid operators' requests (P or Q curtailment, wind farm stop/start).

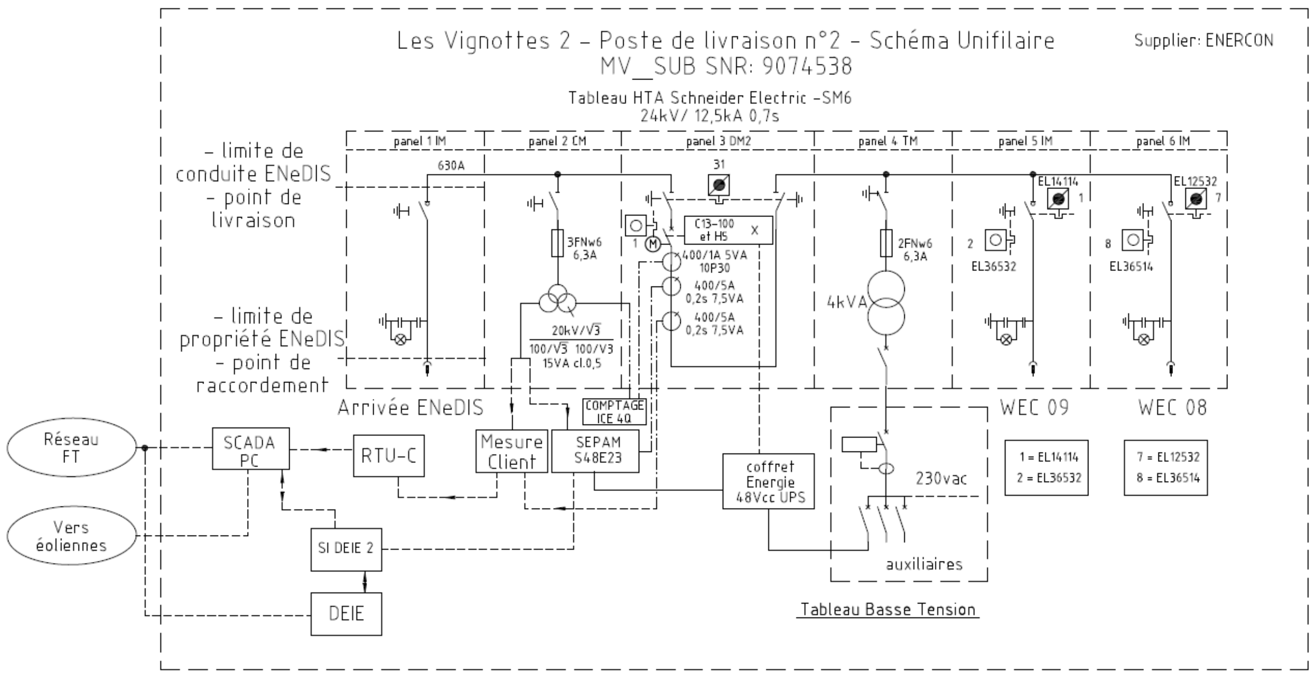


FIGURE 10 : SUBSTATION DIAGRAM

For the purpose of the demonstration, the RTU will be replaced by a Farm Control Unit (FCU), which can provide enhanced control capabilities dedicated to grid services. The FCU is a controller much faster than the RTU as it communicates directly with the wind turbines (and conversely to the RTU which communicates through the "slow" SCADA System). To allow such a direct communication between the FCU and the wind turbines, an additional Farm Control Interface (FCI) board will have to be installed inside each wind turbine. More details are described in Section 2.3.3.1 on FCU controllers.

In addition to the enhanced services that the FCU will provide, it will as well take over existing RTU roles (maximum power limitation and reactive power regulation). The DEIE interface will continue to work as usual to respond to grid operators requests.

2.2.2 BATTERY STORAGE – E-STORAGE 2300

2.2.2.1 E-STORAGE 2300

As a provider of system solutions for renewable energy technologies, ENERCON is driving renewable energy supply solutions on a global scale and is involved in technologies of the future such as battery energy storage, electric mobility and smart grids. It is the goal to provide more added value in relation to the core product, wind energy.

In the EU-SysFlex demonstration in WP8, the project team will make use of the newly developed E-Storage 2300 which is an intelligent interface technology for DC-batteries of all kind. Battery storage is already being used in a wide range of applications and it is continuing to increase in significance for energy supply. The ENERCON E-STORAGE 2300 serves as the power conversion system between a battery (low voltage / DC) and the electric grid (medium voltage / AC). It consists of a bidirectional inverter within a 40-foot container. The ENERCON E-STORAGE 2300 is based on proven ENERCON power components. Together with a battery and an ENERCON controller, the E-STORAGE 2300 can provide system services – such as primary frequency control and ramp rate reduction of active power variations from wind farms.

The battery used for the demo was pre-configured and procured along with the E-STORAGE 2300 according to the applying use patterns. A lithium ion battery with a capacity of 3.3 MWh was chosen, to reduce ageing during BESS operation, only less than 80 % of the battery will be used in the demonstration. The system topology is shown in Figure 11.

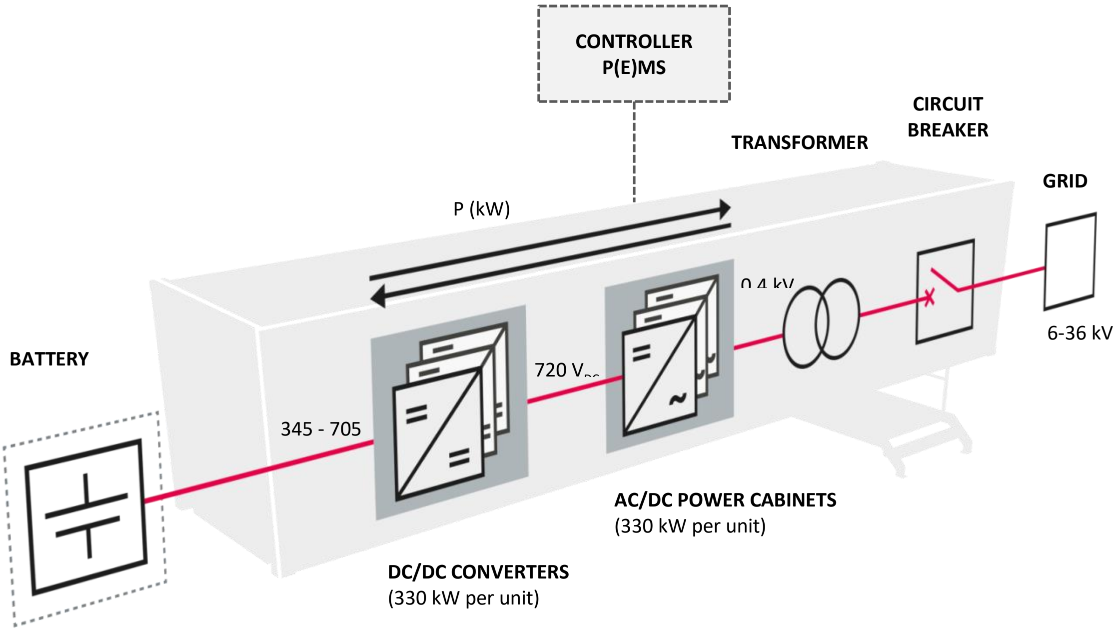


FIGURE 11: TOPOLOGY OF BATTERY ENERGY STORAGE SYSTEM (BESS)

The BESS consist of consists of the following main components:

- Battery container (45 feet)
- E-Storage 2300 container (40 feet)
- Subordinate control system P(E)MS (standard cabinet)

The E-Storage 2300 is connected to the medium voltage grid, thus containing the hardware interface between the electrical grid and the DC power storage. The E-Storage 2300 container ensures controlled charging and discharging. It contains the following components (among others) in the medium-voltage room:

- Transformer
- Medium voltage switchgear

The following components (among others) are found in the low-voltage room:

- Low-voltage distribution system
- Control cabinet
- 7 AC-DC inverter
- 7 DC-DC converter
- UPS (Uninterruptible Power Supply)

A drawing of the E-Storage 2300 container is shown in Figure 12.

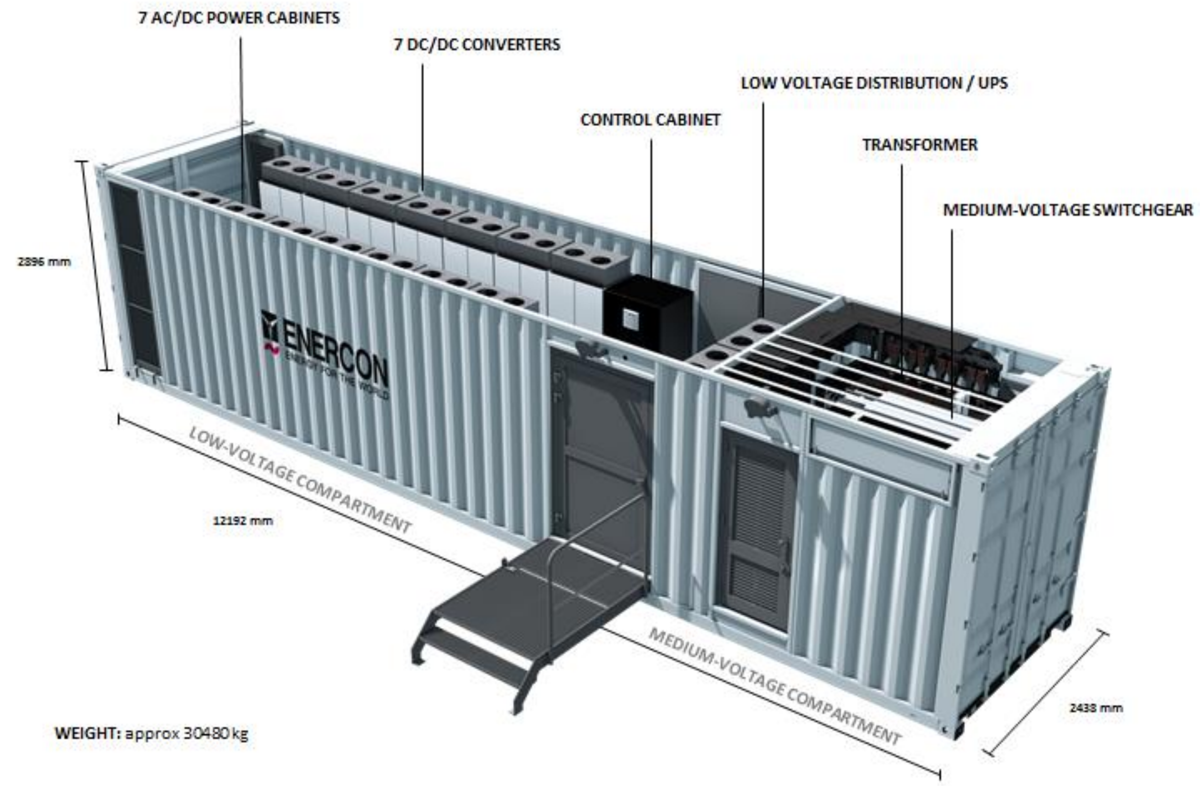


FIGURE 12: CAD OF THE E-STORAGE 2300

Notably the E-Storage 2300 features converter and control components which are also deployed in wind power plants (WPPs). The AC/DC converters are identical to those used in ENERCON wind turbine generators (WTGs), with the control cabinet and DC/DC converters having been adapted from existing wind turbine (WT) hardware.

The Technical data available, ambient conditions and communication interfaces available are given in Table 2, Table 3 and Table 4.

Nominal power	2300 kW
Reactive power range	-950 kVAr to 950 kVAr
Rated frequency	50 Hz / 60 Hz
Medium voltage range	6 kV to 36 kV
Rated voltage	400 V
Battery voltage range	345 V to 705 V
Charge/discharge efficiency	96 %
Connections for power supply to battery container auxiliary equipment	provided

TABLE 2: TECHNICAL DATA E-STORAGE 2300

Ambient temperature	-15°C to 35°C
Relative humidity	up to 95 %

Maximum operational altitude	2000 m a.s.l.

TABLE 3: AMBIENT CONDITIONS

Interface between battery and E-Storage 2300	CAN 2.0 Bus / Ethernet
Data interface for external control	IEC 60870-5-104
Remote monitoring	ENERCON SCADA

TABLE 4: COMMUNICATION INTERFACES

The BESS can be used for several applications like power ramp rate reduction in a wind farm, frequency regulation or reactive power injection. A selection of grid services for the EU-SysFlex WP8 demonstration is given in Table 1.

2.2.2.2 BATTERY CONTAINER

The Li-Ion-battery is located in a 45"-container, consisting of 45 racks. As the operational temperature range must be controlled in a narrow range, the battery container has an HVEC system. For safety reasons a fire detection and extinguishing system is implemented in the container based on aerosol material.

The cell chemistry is based on graphite and NMC, manufactured by LGChem. The container was constructed and manufactured as a turn-key unit by Hoppecke a well-known German battery manufacturer. Figure 13 shows the layout of this container.

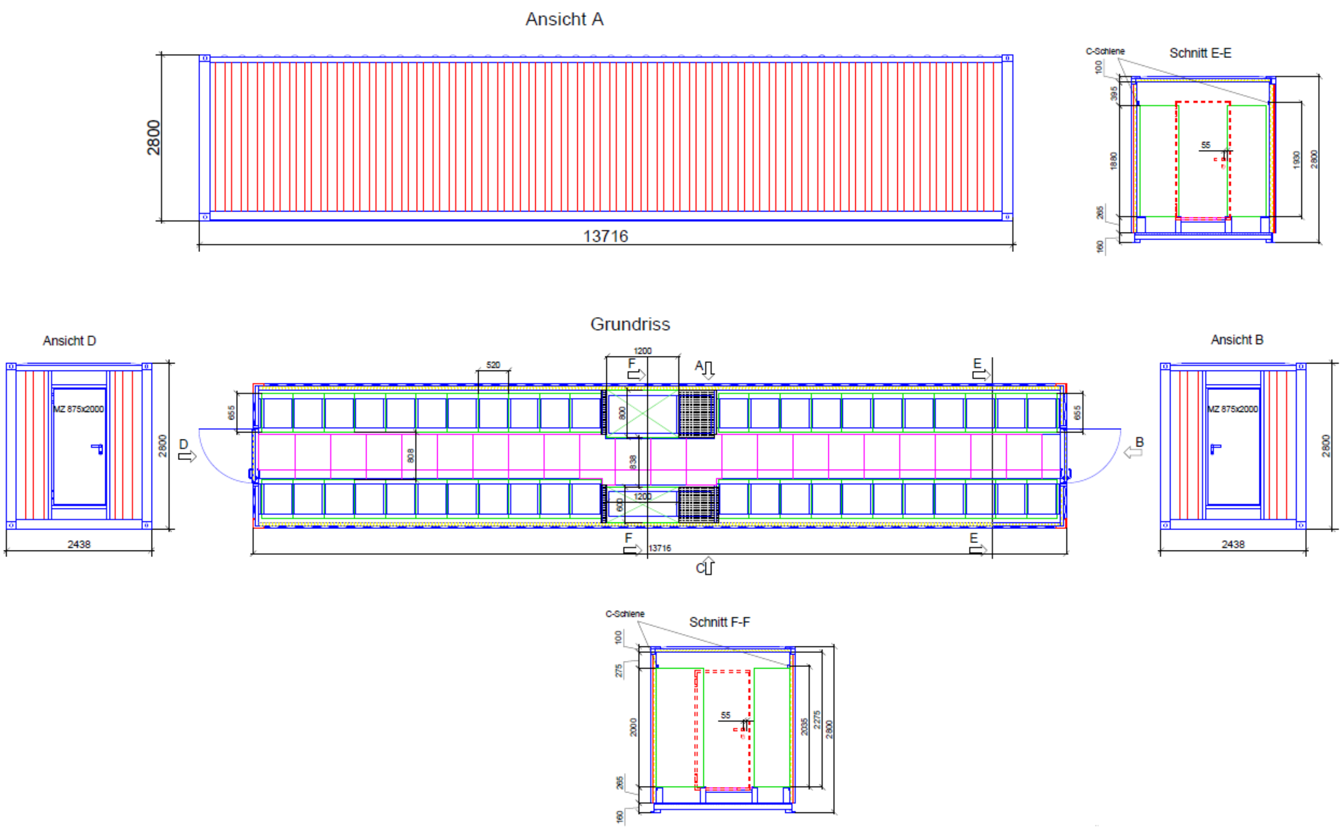


FIGURE 13: BATTERY CONTAINER LAYOUT

2.2.3 EDF CONCEPT GRID

2.2.3.1 GENERAL DESCRIPTION OF CONCEPT GRID

Concept Grid is a brand new laboratory dedicated to the test and validation of smart grid equipment, systems and functions. It has been developed to study and accompany the integration of renewable energy resources in the electric system, storage and new uses, e.g. electric vehicles or heat pumps (Figure 14). One of the goals for Concept Grid is to reproduce the real conditions of an electric system operation (Figure 15). For that purpose, it offers a wide range of equipment, from the primary substation to the customer. Moreover, Concept Grid is designed to take place midway between laboratory tests and experiments in the field, where it is possible to conduct, in complete safety, complex testing campaigns that would be impossible to perform on a real system. This open environment has been designed for many types of tests, becoming a privileged place for many stakeholders, from universities to equipment suppliers or network operators.

FIGURE 14. EXAMPLE OF EQUIPMENT TESTED AT CONCEPT GRID

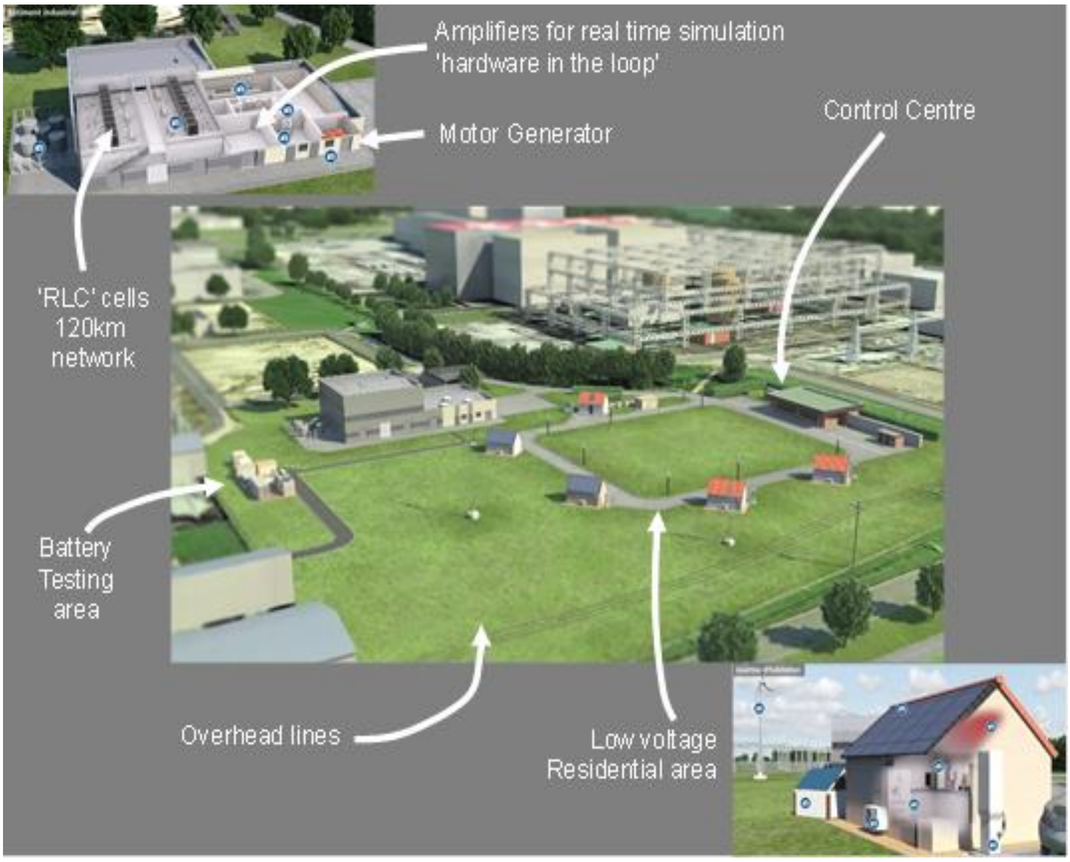


FIGURE 15. CONCEPT GRID, LOCATED AT EDF R&D "LES RENARDIÈRES SITE", SOUTH OF PARIS, FRANCE

Fed by a fully dedicated 63/20 kV transformer, Concept Grid includes 3 km of MV (Medium Voltage) network (Figure 16) (overhead lines, underground cables) supplying 7 km of LV (Low Voltage) network (Figure 17). The representativeness would not be effective in MV without additional network. To correct this, RLC cells have been added to make the equivalent of 120 additional kilometers. Chosen values perform a mix between overhead lines (two thirds) and underground cables (one third). Representativeness is also brought by a residential neighbourhood of five 20 m² houses, fitted with up-to date equipment: smart meters, remote controlled household appliances, micro wind turbine, reversible heat pumps, PV panels, terminal for electric vehicles, storage systems, etc. The experimental platform is mainly composed of a control center to operate the network and monitor the tests; a primary substation supplying MV and LV grids; a reduced-scale residential area; a protection and control system based on IEC 61850 standard; and a powerful four-quadrant amplifier (120 kVA source / 60 kVA load) coupled with real time simulation to perform complex power-hardware-in-the-loop (PHIL) experiments even in disturbed conditions. This infrastructure allows fast development on smart grids issues, by reproducing microgrids, islanded systems, and changing the topology according to users' needs.

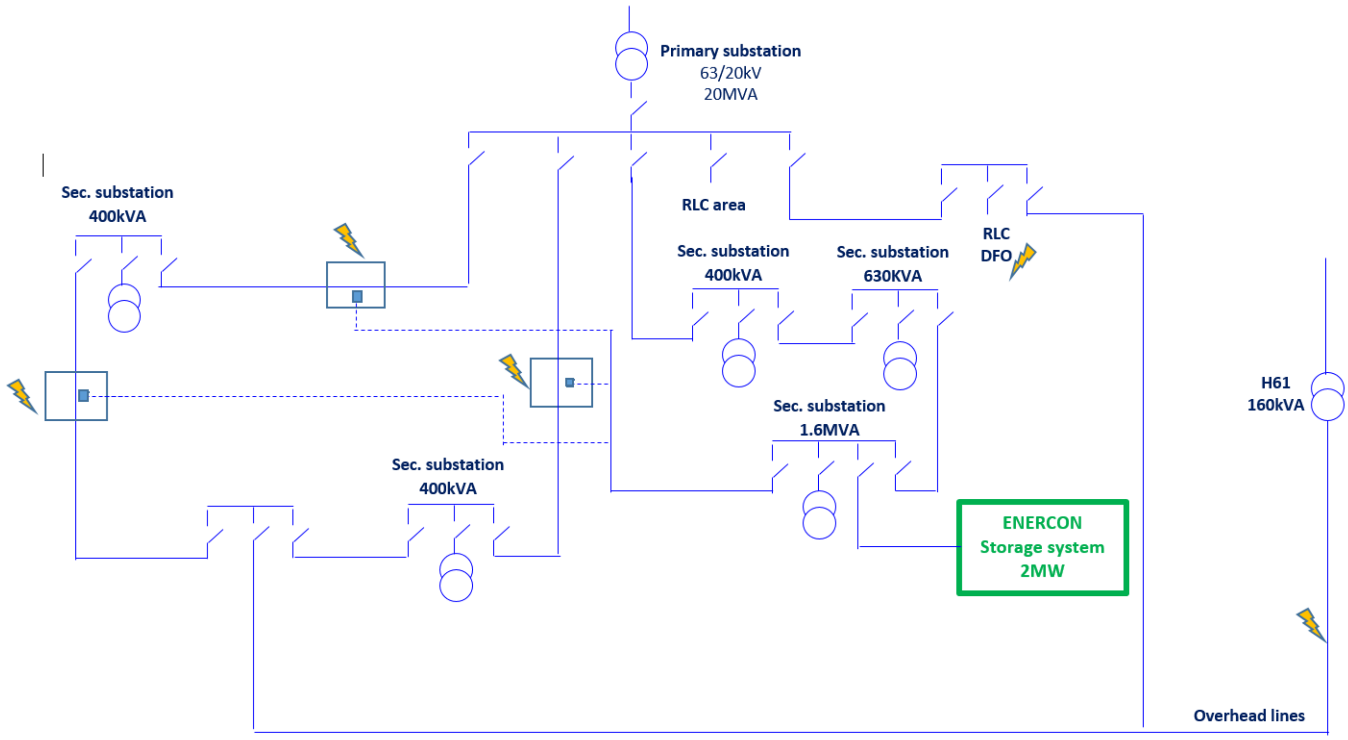


FIGURE 16. MEDIUM VOLTAGE DIAGRAM OF CONCEPT GRID

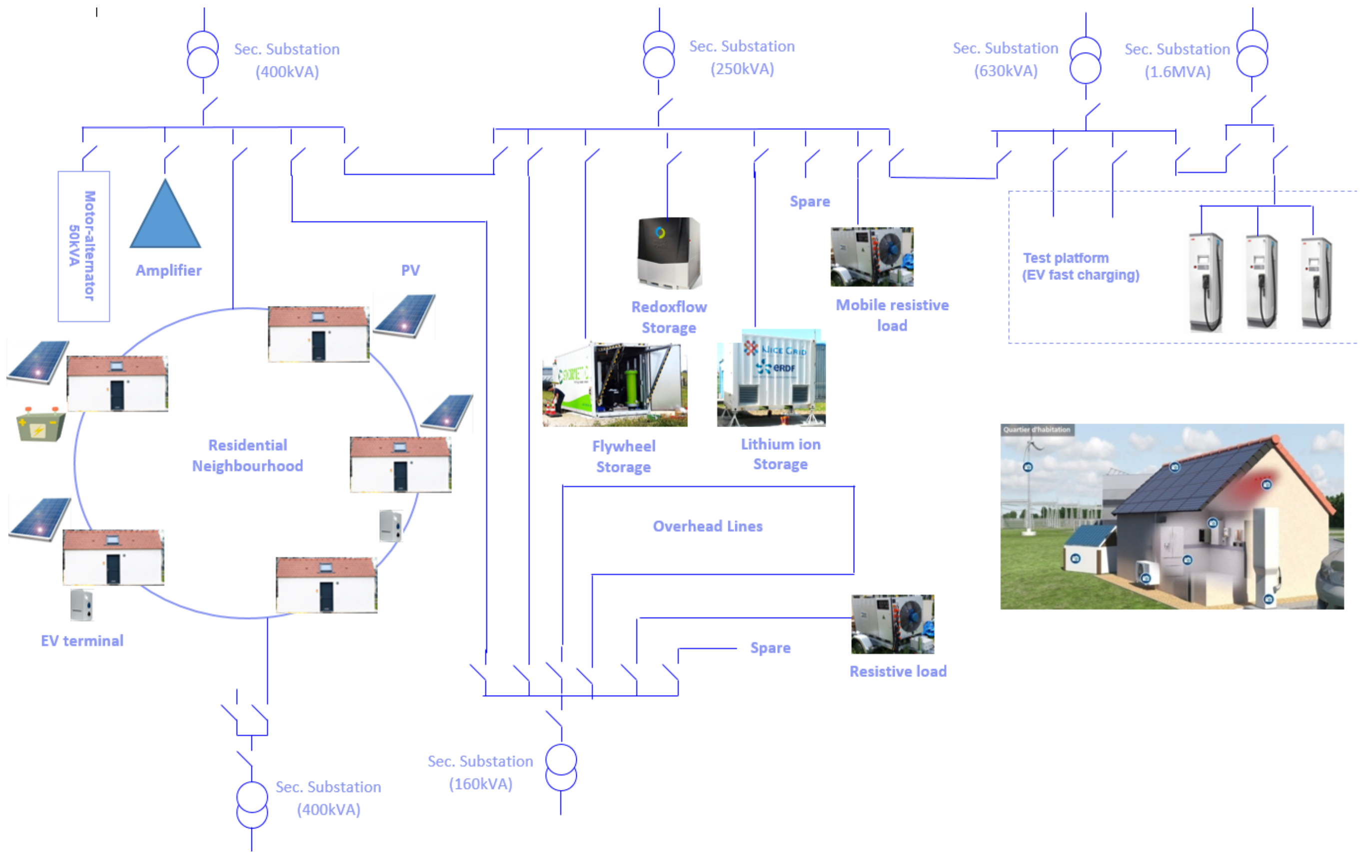


FIGURE 17. LOW VOLTAGE DIAGRAM OF CONCEPT GRID

Once done, these configurations can be challenged, performing functional test in normal conditions and disturbed conditions (MV and LV short-circuits, voltage dips, etc.).

2.2.3.2 PV PANELS

Table 5 describes the PV panels installed at Concept Grid (Figure 18).

Location	Mounting	Exposure	Brand	Model	Number of pannels	Power per panel	Total power	Inverter (brand and power)
T37 House	Roof	South	France Watt	RT6(x5)-RT3(x10)	15 (5 + 10)	(5*200W) + (10*165W)	2650W	DELTA SOLIVIA 2500W
T29 House	On the ground (Inclination angle of 40°)	South	Solarmodul	HS-PXL210	7	210W	1470W	SMA SB2.5-1VL-40 2500W
T31 House	On the ground (Inclination angle of 40°)	South	Solarmodul	HS-PXL210	6	210W	1260W	SMA SB2.5-1VL-40 2500W
T33 House	Roof	South	France Watt	RT6(x5)-RT3(x10)	15 (5 + 10)	(5*200W) + (10*165W)	2650W	DELTA SOLIVIA 2500W
Not installed	On the ground (installation in progress)	South	BYD	BYD230P6-30	8	230W	1840W	-
Not installed	On the ground (installation in progress)	South	CNPV	CNPV-295P	10	295W	2950W	-

TABLE 5. TECHNICAL DESCRIPTION OF CONCEPT GRID PV PANELS

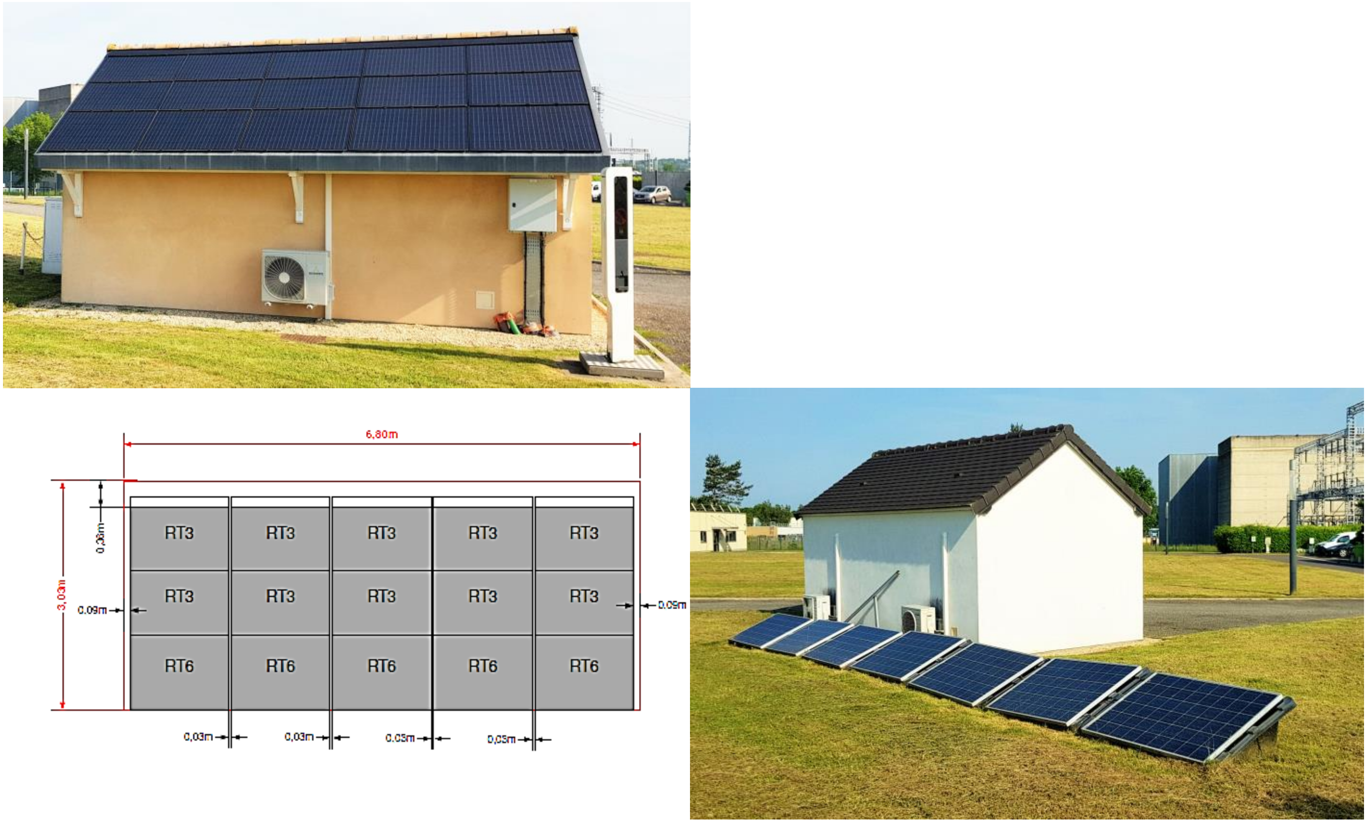


FIGURE 18. PV PANELS INSTALLED AT EDF CONCEPT GRID

The above mentioned power amplifiers will be used in the WP8 demonstration to simulate the power output of a real PV farm of MW size.

2.2.3.3 VARIABLE LOADS

Resistive load banks (Figure 19 and Figure 20) will be used as an aggregated consumption for the demonstration and amplified by the simulator (cf. Section 2.2.3.4) to a MW-size industrial load.

FIGURE 19. 600 KW RESISTIVE LOAD BANK

FIGURE 20. 400 KW RESISTIVE LOAD BANK

The simulator will control the resistive banks by using Modbus TCP/IP to create the load profile. During the demonstration, the centralised control of the aggregator will measure remotely in real time the active power at the output of the resistive loads using a dedicated measuring instrument.

2.2.3.4 REAL TIME SIMULATOR

The digital simulation represents the use of a program on a computer or on a network aiming to simulate real and complex physical phenomenon. Nowadays several scientific and technical domains use simulations as a mandatory step in the development of a process or a product in order to guarantee the security and to analyze the behavior over a large number of scenarios and events.

The real-time (RT) simulation represents a step forward of a non-real-time simulation towards the end of a development process. This kind of simulation that runs in real time has the possibility of being coupled with real-world assets, hardware and systems. One of the advantages of RT simulation is to allow experimental validation while the system tested still contains some prototype modeled in form of simulation. Hence the real time simulation is a part of the validation process while reducing the costs of prototyping multiple version of the end product.

EDF Concept grid contains a real time simulator (Figure 21) that interacts with the grids and the assets needed to perform various tests. The real time simulator is an OPAL-RT product that uses its “E-MEGA sim” license. The simulator uses an extension to control a 4 quadrants linear, 120 kVA power amplifier from Puissance Plus. The RT simulator has several cores, while 5 are activated. The different cores are used in parallel for more computation power.

FIGURE 21. REAL-TIME SIMULATION PLATFORM OF CONCEPT GRID

As mentioned in Paragraph 1.2, for the EU-SysFlex project the Concept Grid RT platform will be used in several steps of development. The first step starts the tests with all the assets simulated, in order to verify the compatibility between different models. A couple of real-time simulation steps will follow, where some of the assets will be real and some will remain simulated. All these steps prepare the final one by de-risking it as much as possible and assuring a step-by-step validation of each model and asset. The final step is the most real-world representative of all, where all assets are real physical equipment or controllable systems. In this final step the real-time simulation is not controlling anymore the assets, but used more as a support function, by gathering measured information and by helping create the wanted scenarios to be tested. Coupled with the RT simulator, the power amplifier will be used in Power Hardware In the Loop (PHIL) mode. For some of the steps, this will represent the "gate" between the virtual simulated world and the real world. The assets of the demonstration such as the wind farm, the storage system or the PV farm will be simulated in separated cores In order to optimize the performances of the real time simulation. Each element having a dedicated core will allow a better customization of the simulation around the needs of each element.

The real time simulation steps will involve several models from different code sources: ENERCON for the wind farm and storage models and EDF for the aggregator and Concept Grid platform. This represents a challenge as the models, some being black-boxes, will have to be adapted in order to respect the different conditions imposed by a real-time simulation. These conditions can be summed up to the simulation step size and the models' complexity as well as the models' content in terms of function and library choices.

2.3 SOFTWARE MODULES AND FUNCTIONALITIES

To operate the overall demonstration composed of a portfolio of resources of different nature as a whole and to ensure the optimal coordination of multi-services provision, existing local controllers of hardware components need to be improved or replaced by newly developed ones. Furthermore, centralised control functions will also need to be built for the whole aggregator's operation, including forecasting tools (for both wind and PV generation) as well as the centralised energy management system providing both day-ahead / intraday schedules and short-term program adjustment capacity under unexpected events.

2.3.1 FORECASTING TOOLS

2.3.1.1 WIND AND PV GENERATION FORECASTING

2.3.1.1.1 WIND POWER FORECASTING

Overview of the method

The method is based on a statistical model. Statistical relations between *Anglure 2* wind farm generation and meteorological forecast parameters are learned over a period of two years (2016-01-26 to 2018-01-28). These relations are then used daily to assess the output of the wind farm over the following days when a new meteorological forecast is available. Meteorological forecasts are provided by Météo France and the European Centre for Medium-Range Weather Forecasts (ECMWF). Real-time wind farm generation is used to correct the meteorological forecasts over a short horizon of 2 hours. The general approaches applied during the training and operational processes are summarized in Figure 22.

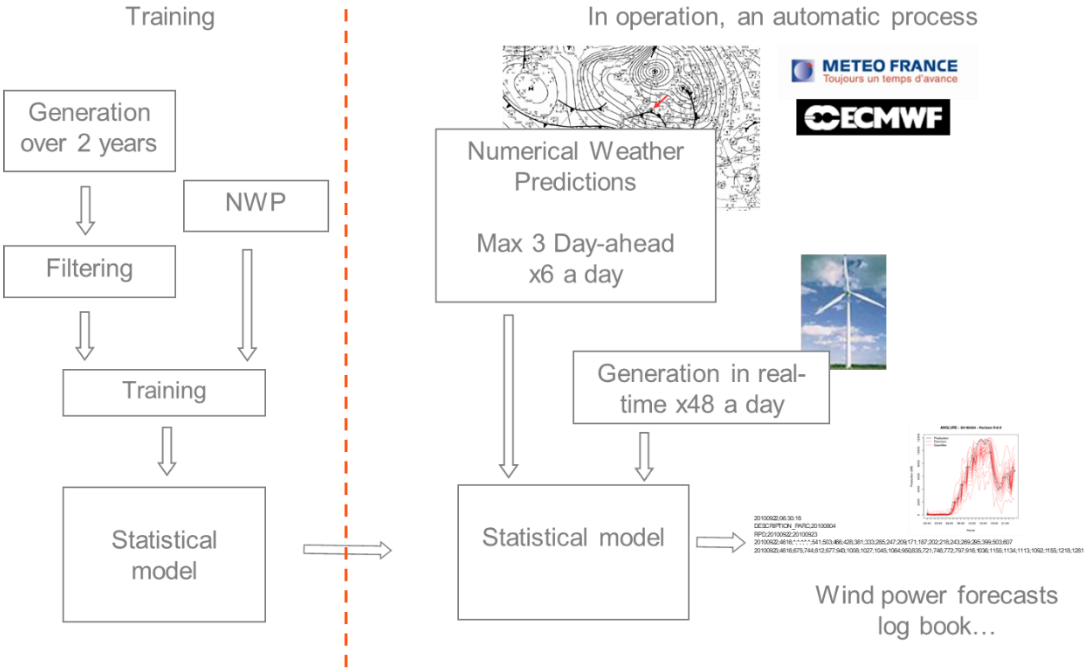


FIGURE 22. OVERVIEW OF THE WIND POWER FORECASTING TOOL, AT LEFT THE TRAINING PROCESS, AT RIGHT THE OPERATIONAL PROCESS

Forecasts delivery

As shown in Figure 23, the forecasts are updated every 30 minutes when a new meteorological forecast and/or a new real-time wind farm generation are available. When a new meteorological forecast is available at 03:30, 06:30, 10:00, 15:00, 20:00 and 22:00, the forecast covers 1 to 3 days. Otherwise, the forecast covers only 2 hours.

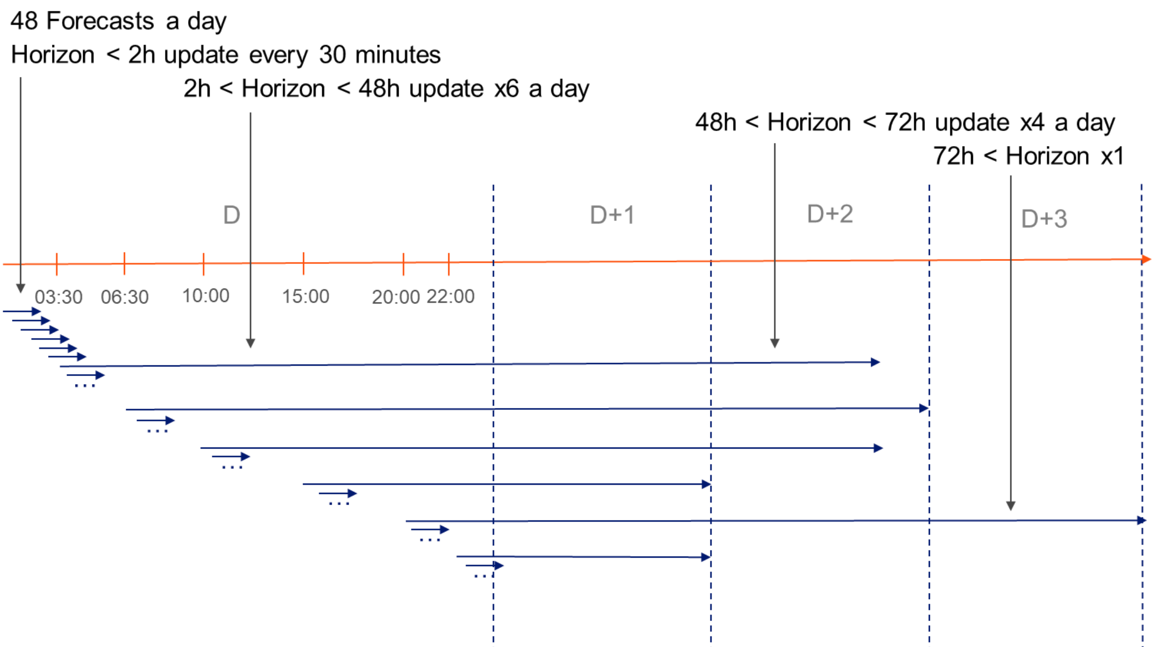


FIGURE 23. DAILY FORECASTS DELIVERY: FORECASTS ARE REPRESENTED BY ARROWS WHICH START AT THE TIME THE FORECAST IS PUBLISHED AND END AT THE FORECAST HORIZON

Two types of forecast are computed: a deterministic one and a probabilistic one. The deterministic forecast is provided by the statistical model described above. The probabilistic forecast takes into account not only the result of the statistical model but the distribution of the forecast errors of the model over the training period. This forecast is compose of 21 quantiles: 1%, 5% … 95% and 99%: the wind farm generation has X% of chance to be below the X% quantile. The strength of the probabilistic forecast is to describe all the possible futures and their likelihood. Moreover, the 50% quantile of the probabilistic forecast is more accurate than the deterministic forecast.

Forecasts examples

Figure 24 illustrates an example of wind forecast on February 4th 2018, which is a day showing a large variation of wind farm generation. One day ahead, the probabilistic forecast covers a large range of values for the afternoon and the deterministic forecast shows a moderate increase of the generation. 30 minutes ahead, the area covered by the probabilistic forecast narrows (the confidence increases) and the deterministic forecast predicts the sharp increase of the generation. When the forecast is near zero, e.g. during the night, even the 99% quantile of the probabilistic forecast predicts weak generation. The confidence is high in this type of situation.

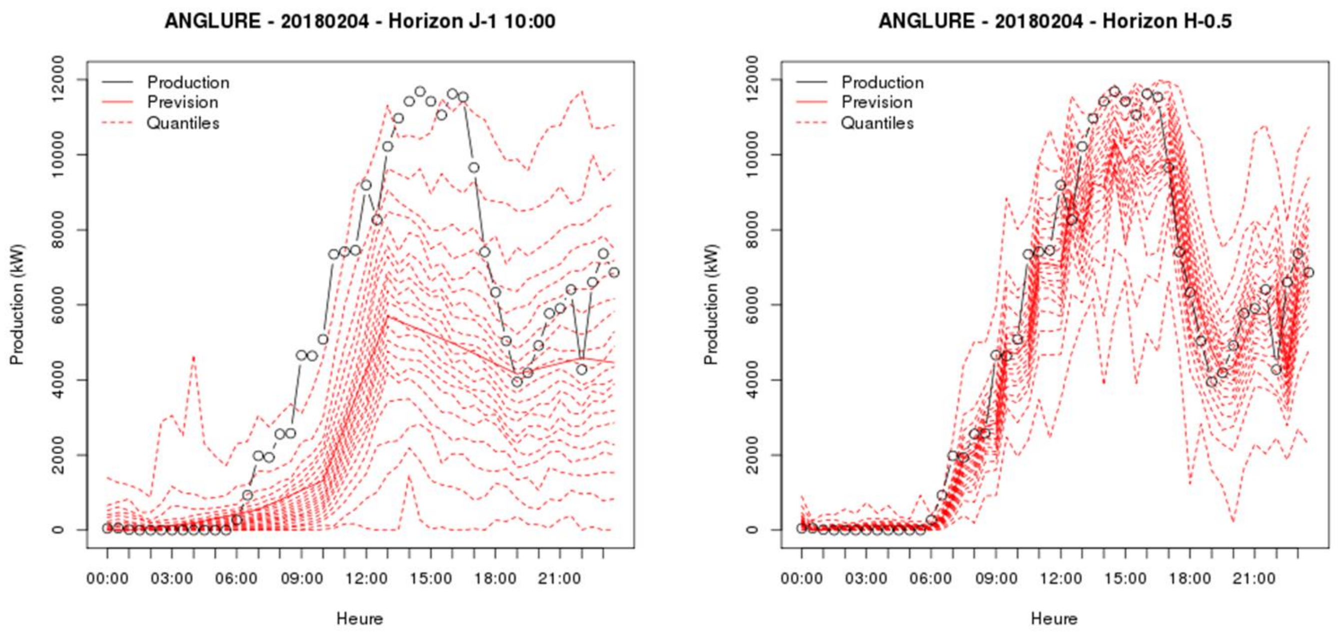


FIGURE 24. DETERMINISTIC FORECAST (RED LINE) AND PROBABILISTIC FORECAST SHOWING THE 1%, 5% … 95% AND 99% QUANTILES OF THE FORECAST (RED DOTTED LINES) AND WIND FARM GENERATION (BLACK LINE WITH CIRCLES) OVER THE DAY OF 2018-02-04: 1 DAY AHEAD FORECAST (LEFT) AND 30 MINUTES AHEAD FORECAST (RIGHT)

2.3.1.1.2 PV POWER FORECASTING

Quick overview of the method

As with the wind generation forecast, PV production forecasting methods are based primarily on statistical learning between PV production data and meteorological data. The diagram in Figure 25 represents the meteorological data used in the state of the art to obtain the best forecasts in PV according to the predicted horizon. The longer the time horizon gets, the farther the error grows.

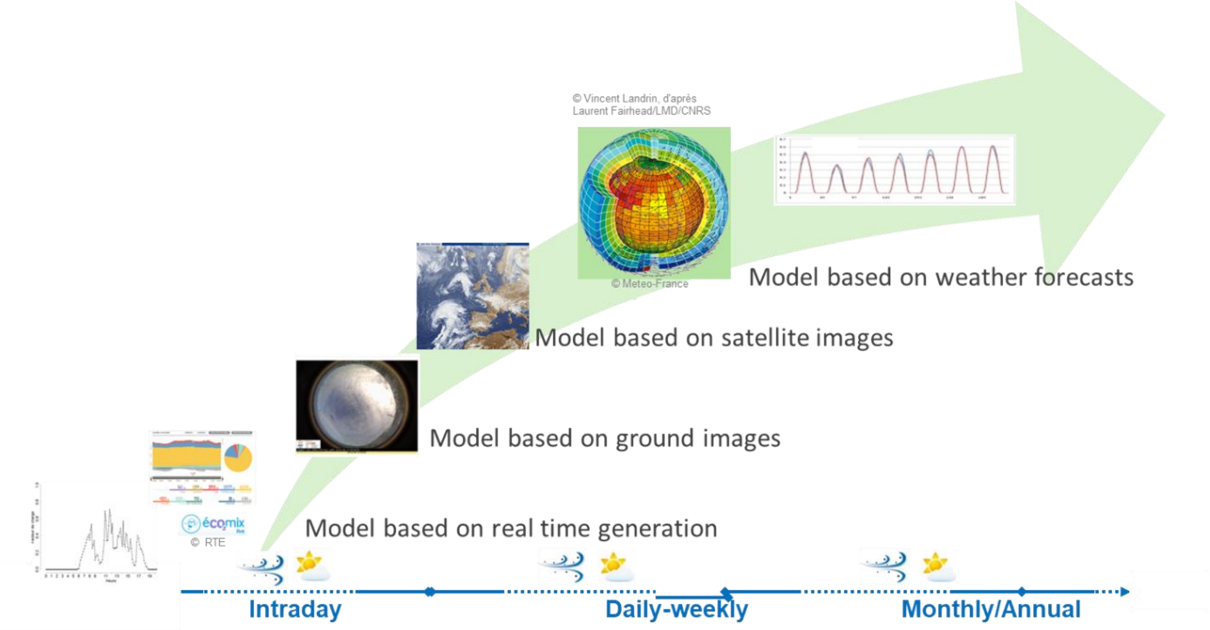


FIGURE 25. PV FORECASTING MODELS

<u>Forecasts delivery</u>

For the EU-SysFlex WP8 demonstration, PV production forecasts will be built for two types of horizon:

- Very short term horizon: a horizon covering a + 15minutes to + 3 hours period.
  This very short term forecast will be built using satellite imagery from Meteosat 10 and Meteosat 11 and can be refreshed every 15 minutes.
- Short term horizon: a horizon covering the day and the next day period.
  This short-term forecast will be constructed from Météo France's numerical weather forecast model named ARPEGE. It will be refreshed every day at 0h UTC and will cover the horizon from + 1 hour to + 48 hour.

As with the wind generation forecasts, both deterministic and probabilistic forecasts will be delivered for this project. The quantiles for probabilistic forecasts will be the same as for the wind probabilistic forecasts.

<u>Forecast examples</u>

Figure 26 represents some short term forecasts for a single PV plant with both deterministic (blue line) and probabilistic forecasts (grey band). For the probabilistic ones, only the 90% confidence band is shown here.

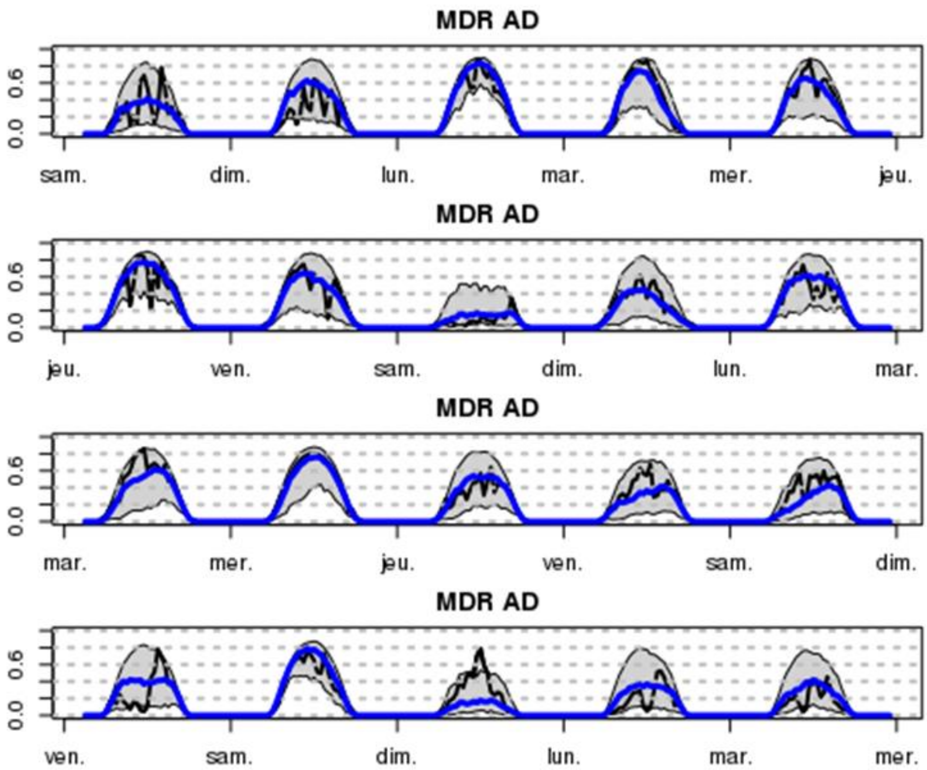


FIGURE 26: PV LOAD FACTOR (BLACK LINE) OF SEVERAL DAYS FOR A SINGLE PV PLANT: DETERMINISTIC DAY-AHEAD FORECASTS (BLACK LINE) AND PROBABILISTIC FORECASTS (GREY BAND).

2.3.1.2 SERVICES PRICES FORECASTING

Most tested services are expected to have time-varying prices, depending on supply and demand and on grid operation situations. It is therefore necessary to have the “knowledge” of the prices of different services before the real time to be able to perform day-ahead scheduling and intraday re-scheduling by maximizing the profitability of the aggregated resources at different time scales. In practice, a forecasting tool of different services prices will need to be developed, according to mathematic models and to robust knowledge on historical data, to ensure the well-functioning of the aggregator’s scheduling.

However, the design of such a forecasting tool is out of scope of the present demonstration, whose main objective is to assess the practical feasibility of a multi-services/multi-resources control scheme. Furthermore, for some of the services that will be tested, the corresponding markets do not yet exist in France. No historical data of services prices is available for the development of the forecast.

In the first instance, the services prices forecast will be therefore assumed to be perfect. In other words, only the uncertainties due to wind and PV generation will be addressed when scheduling the services. Moreover, the economic gain from the services provision will be estimated using historical prices when available and simplified assumptions on the prices and markets for the service products that have not existed yet. For want of anything better, it may be assumed that:

- all the services have hourly prices at best, which are provided by hourly-based markets;

- the gate closure time of the day-ahead markets is at 12:00;
- an intraday market exists to allow the resources aggregator to adapt its offers on the hour of the day according to the updated generation forecasts and latest measurement.

2.3.2 CENTRALISED CONTROL – ENERGY MANAGEMENT SYSTEM (EMS)

The centralised energy management system of the aggregator is mainly composed of 2 functions: the operational day-ahead and intraday scheduling as well as the short-term control and re-dispatch. The outputs of the previously presented forecasting tools as well as all the necessary local measurement will be collected by the centralised EMS as the inputs for the calculation of the scheduling program and short-term control algorithms.

2.3.2.1 OPERATIONAL PLANNING SCHEDULER

General description and main issues

The operational planning scheduler aims at defining the services to be provided by each resource (PV farm, wind farm, BESS and controllable load) in the coming hours with a fixed sampling interval (e.g., in the following 48 hours with a 30-minute interval). More precisely, it will determine the sequence of the service set points for all the resources and sampling intervals considered. For instance, it will define the upward and downward power reserves of the battery from 8:00 to 8:30 if it is expected to deliver the FCR service.

The operational planning of services will be designed so as to maximize profitability while satisfying requests from stakeholders (e.g., wind power limitation demanded by the DSO) and a set of constraints (e.g., service parameter ranges, material limits, network issues, regulatory framework, market closure…). To design such a planning, the scheduler will use at least the following data:

- The wind and PV generation forecasts (see Section 2.3.1.1),
- The services prices forecasts (see Section 2.3.1.2),
- Some data measured on the resources such as the state of charge of the battery,
- A set of parameters provided by the user and related to the services and optimization algorithm considered.

The scheduler will update the planning of services several times a day, e.g., every 30 minutes, in order to consider the most recent forecasts and measures available.

Note that several issues have to be addressed when designing the scheduler. The most significant ones are to assess the potential shortfall of the services planning due to forecast errors, and to define appropriate risk measures for guiding the optimization process.

Ongoing development

The software used for scheduling is based on a planning software for production systems, developed entirely by EDF R&D. Initially designed for optimal management of power plants, it can as well be used for industrial (heat networks, drinking water networks…), residential or tertiary sites. It was also conceived to ensure that evolutions can be updated quickly.

The optimization method used is Mixed Integer Linear Programming (MILP). Linear programming is more efficient than non-linear programming but it implies that all the equations from the optimization problem are linear. Battery losses or motor performance must therefore be approximated by linear functions.

Several developments are in progress to adapt this software to the demonstration case, and thus to schedule several services provided by a portfolio of resources. In particular, recent improvement was made to enable stochastic programming with scenarios under different probabilities. Such kind of improvement could help schedule the services taking into account several renewable energy generation scenarios, which would be built from the probabilistic generation forecasts.

2.3.2.2 SHORT-TERM CONTROL

As described in 2.3.2.1, the operational planning scheduler defines the services to be provided by every resource of the aggregator, with a time resolution between 15-30 minutes. However, since some services are assessed on smaller time resolution (e.g., 10-second average of active power for FCR according the French TSO's requirement [22]), the performances of these services will be impacted by the phenomenon that occur within each scheduling time step and thus the operational planning scheduler cannot "see".

We can distinguish different time scales:

- Instantaneous: contingency events, e.g., loss of a resource, loss of communication.
- A few seconds: fast fluctuations of wind and solar generation, of the grid frequency, etc.
- Several minutes: generation deviation from forecast of wind and solar power.

Thus, another layer of control is necessary to handle these events and ensure proper operation of the aggregator, which is called herein the short-term control. Its goals are: 1/ to monitor the real-time performance of the aggregator in regard to the services that are scheduled to be provided; and 2/ to monitor the state and availability of the system and, if necessary, switch to another operational scenario in case of unexpected events (detailed descriptions can be found in 3.2).

2.3.3 ADVANCED WIND FARM CONTROL

As mentioned in Section 2.2.1, for the purpose of the demonstration, the control system of the *Anglure 2* wind farm currently under operation will be enhanced by implementing a more advanced controller called FCU. A supplementary device called GED-W will also be installed to ensure the communication between the wind farm and the centralised EMS.

2.3.3.1 FCU CONTROLLER

The ENERCON SCADA Farm Control Unit (FCU) will be installed in the *Anglure 2* wind farm. The FCU cabinet is depicted in Figure 27.

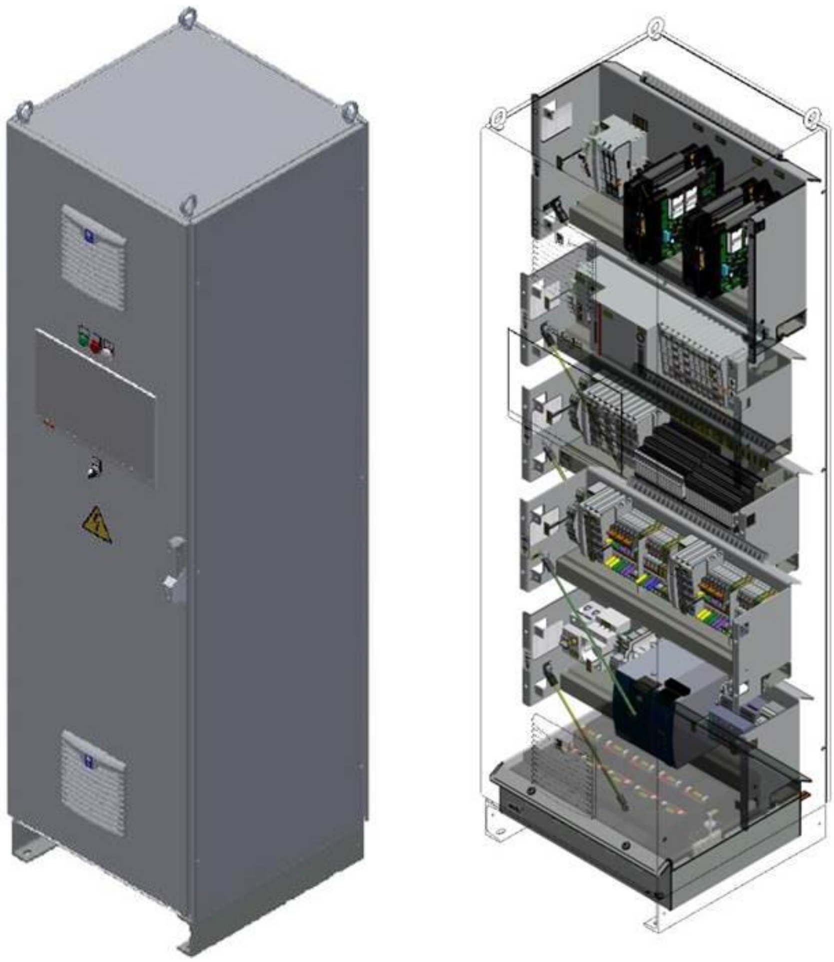


FIGURE 27 : VIEW OF THE FCU CONTROLER

As presented before, the FCU E2 will replace the currently installed ENERCON SCADA Remote Terminal Unit (RTU). The FCU will be the only entity directly controlling the wind turbines. In parallel with the FCU, there will be an SAI (SCADA Application Interface) for the system operator ENEDIS, which will only be used to stop the wind farm in case of a grid fault. The wind farm communication structure is illustrated in Figure 28.

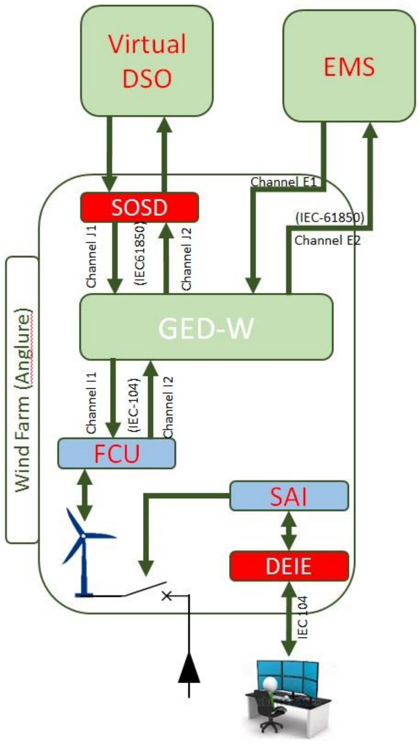


FIGURE 28 : COMMUNICATION STRUCTURE (THE FARM IS CONTROLLED BY THE FCU)

<u>General functionality of the FCU</u>

The FCU can be used to implement a fast and constant central closed-loop control system in the wind farm. The reference point for this closed-loop control system is not the individual wind energy converters (WECs), but rather a defined project-specific reference point. The reference point is usually the same as the wind farm's network connection point to the high or medium-voltage grid.

The FCU system consists of central hardware and software components close to the network connection point (in the transmission substation or the substation), additional hardware in each WEC, and a dedicated data bus connection to be installed separately using fibre-optic cables between the WECs and the FCU. Fibre-optic cables (FOC) are essential for achieving the desired fast control properties of the FCU.

<u>FCU controller modes</u>

The control algorithms implemented in the FCU can be used to control the active power infeed at the coupling point as well as the reactive power, the voltage or the power factor. To control active power infeed, the FCU sends an active power actuating signal to the wind energy converters. A reactive power actuating signal is sent to control the other parameters. Active power closed-loop control can be combined with any one type of reactive power closed-loop control. Setpoints can either be fixed parameters or transmitted online via an appropriate interface. In the *Anglure 2* wind farm, the GED-W device (as described in the next section) will be communicating to the FCU via the IEC-104 protocol.

The following active power controllers are available in the FCU:

- Active power open-loop control
- Active power limitation controller
- Active power gradient limitation controller
- Power frequency controllers
- Wind inertia-based FFR

Reactive power controllers available in the FCU:

- Reactive power open-loop control
- Voltage closed-loop controllers
- Voltage droop controllers
- Reactive power closed-loop controllers
- Power factor controllers
- Voltage-dependent reactive power closed-loop controller: Q(ΔU)

For the demonstration of frequency services, active power controllers - depending on the balancing market product to be demonstrated - will be used. Reactive power controllers will not be tested, even if it is technically feasible, as the wind farm is connected to the French distribution grid via a dedicated feeder with an agreed reactive power injection plan with the DSO. Therefore the reactive power management will not be possible during the experiments.

<u>Control strategies for balancing services</u>

For the balancing market system services, which are a major part of the services to be demonstrated in WP8, different control strategies will be needed.

- For the very fast response, such as FFR, wind inertia-based FFR will be needed. This control strategy allows the wind farm to provide under frequency response within 0.5-2s, but with magnitude and duration limited to the order of 5-10% of rated power over 10-15s.

- For FCR, power-frequency controller will be used. This controller controls the active power, which is calculated from a setpoint of the allocated reserve capacity (which is a controller's parameter). This ensures that the required reserve is available at any given time. The reserve capacity is always based on the current available power of the WEC. This controller mode reacts to frequency changes automatically. As of today FCR service is said symmetrical, meaning that the providing unit must be able to provide both positive FCR (i.e. increasing the active power in case of under-frequency) and negative FCR (i.e. decreasing the active power in case of over-frequency).

  In the future, it would be possible to separate the positive and negative FCR provision. This distinction is essential for the demonstration as, conversely to conventional synchronous generation, new generation means such as PV or wind are more suitable to provide negative FCR only. Providing positive FCR is technically possible, but from an economical point of view, it requires the curtailment of the generation, leading to a loss of the primary energy. For this reason, a priori only negative FCR will be demonstrated with the wind farm. Positive FCR can be tested but only for a limited duration.

- For FRR, active power limitation controller will be used. This controller regulates the active power infeed at the reference point to a setpoint specified e.g. by the grid operator. The active power fed in at the reference point is captured and, provided that there is sufficient wind power, adjusted to the specified setpoint. Setpoint changes can be specified in steps or using an adjustable gradient. In this case, the setpoint will be sent to the FCU via the GED-W device from the centralised control system of the aggregator. This means that the controller will not be reacting automatically to the frequency changes, but rather the FCU will receive an active power setpoint from the EMS. As for the FCR service, a distinction between positive aFRR and negative aFRR has to be considered, and a priori only negative aFRR will be tested with the wind farm.

Functionality to be implemented

Normally, only one control strategy for one system service is needed in a wind farm, depending on the grid operator's requirements in the corresponding country. The behaviour of the controller can be parameterized to meet such requirement. For the purposes of demonstration of services corresponding to different European markets, it is necessary to be able to switch between such parameter sets for the same controller type or to dynamically adjust those via the communication interface between the EMS and the FCU. This functionality is yet to be implemented into the FCU and is part of the WP8 development of the EU-SysFlex project.

2.3.3.2 GRID EDGE DEVICE – WIND FARM (GED-W)

As can be seen from Figure 28, the grid edge device – wind farm (GED-W) is the device which assures the communication between the wind farm control unit (FCU) and the distributed energy resources management system of the aggregator (EMS) and also with the system operator supervision device (cf. Section 2.3.3.3). This device is owned by the aggregator and can incorporate several functions allowing the required services. In the present demonstration, the GED-W will integrate the following functions:

- Sending all the measurements provided by the FCU concerning the wind farm to the aggregator EMS. This information should be provided in the required format and time frames;
- Sending all the control signals (services activation/deactivation and other necessary control parameters) provided by the EMS to the FCU;
- Storing information of one day (measurement, alarms and control set-points);
- Performing the autonomous control of the FCU in case of loss of communication during a defined period;
- Managing the alarms provided by the FCU;
- Managing and giving priority to the orders provided by the EMS and by the system operator through the system operator supervision device (SOSD).

The GED-W is a hardware agnostic solution proposed and developed by EDF R&D that will be installed in the *Anglure 2* wind farm. Ongoing work concerns the specification of the information managed by the GED-W and exchanged with the FCU, the SOSD and the EMS. In case of real action of ENEDIS, sent through DEIE device, the wind farm should be stopped and an information of P_{max}=0 should be sent to the GED-W. This action is managed by the ENERCON FCU device.

2.3.3.3 VIRTUAL SYSTEM OPERATOR SUPERVISION DEVICE (SOSD)

The system operation supervision device (SOSD) is the device of the SO to interact with the wind farm. The SOSD can have different functions such as send the measurements of the production to the SO and the activation/deactivation of some services requested by the SO. The most common services are the total or partial generation curtailment. However, in the future, other services can be imagined and implemented.

In the present demonstration, the SOSD will be operated by a virtual SO allowing to analyse the impact of the orders of the SO when the aggregator is providing other services. As the GED and the SOSD are based on a hardware agnostic solution proposed and developed by EDF R&D. The main advantage of the proposed approach is that the owner can easily change remotely the firmware and the configuration of the SOSD. All the aspects concerning the interoperability IEC 61850 and cybersecurity are considered in the proposed solution.

2.3.4 STORAGE CONTROL

2.3.4.1 E-STORAGE 2300 CONTROL

The hardware of the subordinate control of the BESS is based on a commercial PLC (Programmable Logic Controller). So far, the implemented services are ramp rate reduction (RRC) and frequency control along with reactive power injection.

2.3.4.1.1 RAMP RATE REDUCTION

Figure 29 shows the SLD (Single Line Diagram) of possible grid connection of the E-Storage 2300 based on a project on the Faroe Islands.

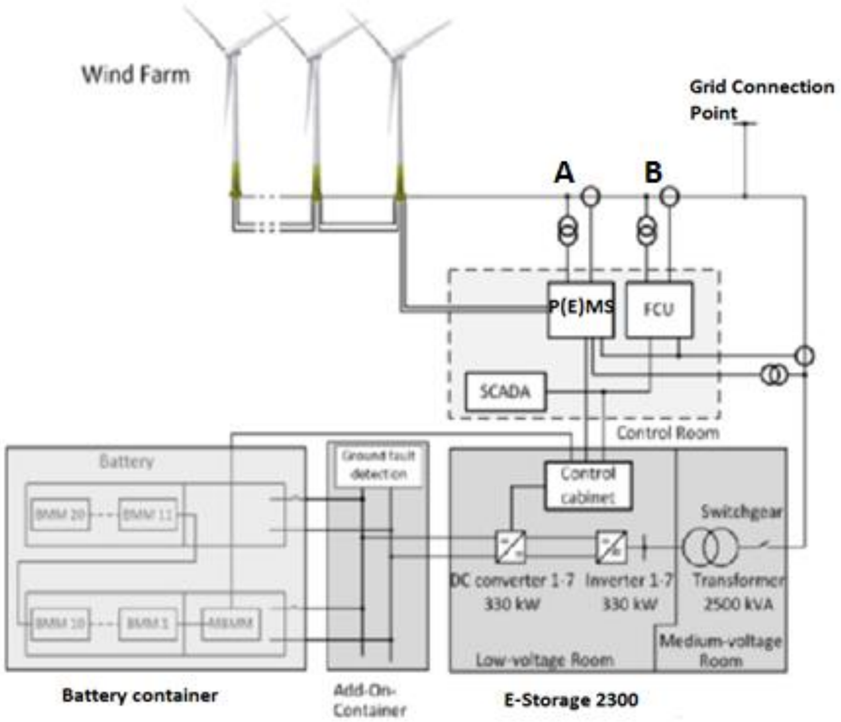


FIGURE 29 : SLD FOR E-STORAGE GRID CONNECTION MAKING USE OF RAMP RATE REDUCTION AND FREQUENCY CONTROL

The control is based on the measurement of current and voltage as well as the calculation of the grid frequency and power at the point connection of the wind farm and the battery system. As shown in Figure 29, the PEMS (Power Energy Management System) of the storage system includes current and voltage transducers for measurement of the power flows from the WTGs and the BESS individually, at points “A” and “B” respectively. It controls BESS power output by sending setpoints to the E-Storage 2300 Container, and can control the WTGs’ collective power output via their Farm Control Unit (FCU). It also receives internal feedback and status signals from the BESS and the WTGs via these interfaces. The PEMS has a remote interface with the SO’s control centre, for exchange of setpoints and status signals.

If the ramp rate reduction mode (RRC) is chosen, two main parameters must be adjusted:

- dP/dt_{set}: Power gradient setpoint (value range 0-300 kW/s)
- SoC_{set}: State of charge (SoC) setpoint (value range 0-100%)

RRC defines the power setpoint to the BESS according to three algorithms:

- Gradient Control
- State of Charge Control
- Power Control

Gradient Control

An adjustable power gradient setpoint dP/dt_{set} is defined within the PEMS. The gradient controller produces a power setpoint opposite to the WTGs’ active power, to ensure that the overall WPP’s power gradients stay within

$\pm dP/dt_{set}$. Based on this, a "triangle" of allowable P values around the WTGs' current active power output is calculated continuously as shown in Figure 30.

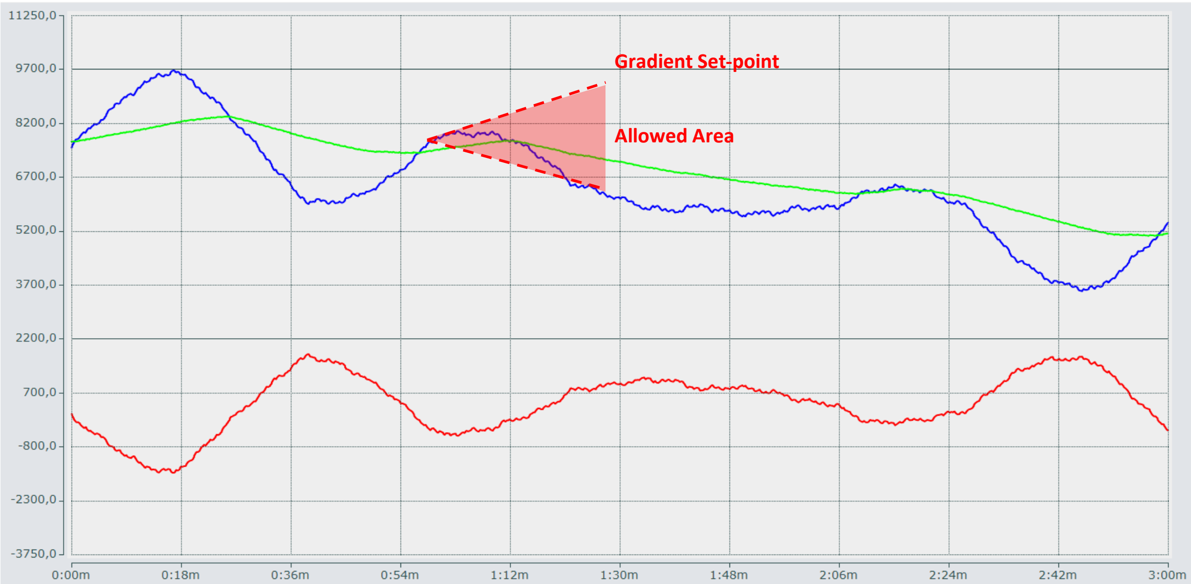


FIGURE 30. GRADIENT CONTROL EXAMPLE (RED: BATTERY POWER, BLUE: WIND FARM POWER, GREEN SMOOTHED POWER)

The control software, which was originally implemented in the ENERCON BESS controller for RRC service, works with very high resolution data (range of 10 ms) of wind generation measurement. In the EU-SysFlex demonstration, the control algorithm must be based on the total generation measured from the wind farm Anglure as well as from the emulated PV farm. Only data measured in a time step of 1-5 seconds are available in this demonstration, the controller of the storage will need to be adapted to consider this technical constraint.

State of Charge Control

State of Charge (SoC) Control keeps SoC close to an adjustable setpoint, SoC_{set}. If the current SoC is not equal to SoC_{set}, then the SoC control adjusts the positive or negative power gradient limits, using the "excess" power from the WTGs to bring the SoC back towards SoC_{set}. The Gradient Control takes priority over the SoC Control, in that the SoC Control can charge the battery only when the wind is ramping up, and discharge it only when the wind is ramping down.

Power Control

The Power Control modulates the power setpoint to the BESS, in order to reduce losses and minimise battery usage, without affecting the WPP's overall power gradient.

The PEMS is programmed to balance the ramp rate and SoC requirements (as defined by their parameter settings) with the operating limits of the BESS components. Under normal conditions, the PEMS will first use BESS charging and discharging to comply with dP/dt_{set}, and use any "excess" power from the WTGs to maintain the desired value of SoC_{set}. However, if the charging power of the BESS is not enough to comply with dP/dt_{set} (e.g. due to an extreme ramp-up by the WTGs), the PEMS can also instruct the FCU to reduce the positive power gradients of the WTGs.

To comply with the battery's design limits, the PEMS automatically adjusts its operation in real time to keep the BESS within a specified energy throughput limit, as well as upper and lower SoC limits.

2.3.4.1.2 FREQUENCY CONTROL

The *P*(*f*) block, calculates the active power to inject to the grid depending on the actual frequency and the configured *P*(*f*) curve, as shown in Figure 31.

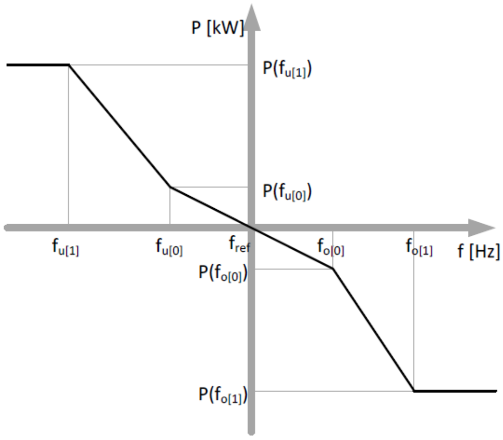


FIGURE 31: E-STORAGE 2300 *P*(*F*) CONTROL CHRACTERISTIC

A moving average of the actual frequency is used as reference; in this way the controller reacts only to grid events, and not to long term frequency deviations that could completely discharge the battery. In Figure 31 is represented how the points of the *P*(*f*) curve work in relation to the moving average frequency reference (f_{ref}).

The Power and frequency parameters can be freely configured according to Table 6. It is recommended that the parameters $P(f_{u[0]})$ and $P(f_{o[0]})$ are be set to zero to create a dead band that allows the gradient controller to operate accurately under normal conditions.

Parameter	Range	Resolution
$f_{u(1)}$	[0…50 Hz]	0,01 Hz
$P(f_{u(1)})$	[0…P_n(+)]	0,01 kW
$f_{u(0)}$	[0…50 Hz]	0,01 Hz
$P(f_{u(0)})$	[0…P_n(+)]	0,01 kW
$f_{o(0)}$	[0…50 Hz]	0,01 Hz
$P(f_{o(0)})$	[0…P_n(+)]	0,01 kW
$f_{o(1)}$	[0…50 Hz]	0,01 Hz
$P(f_{o(1)})$	[0…P_n(+)]	0,01 kW

With $f_{u(1)} < f_{u(0)} < f_{ref} < f_{o(1)} < f_{o(1)}$

TABLE 6: PARAMETER LIST POWER AND FREQUENCY

FIGURE 32: PEMS CABINET FOR SUBORDINATE BESS CONTROL

Figure 32 shows a CAD of the storage PEMS cabinet which needs to be installed in addition to the E-Storage container at EDF CG.

2.3.4.1.3 OTHER SERVICES

In the EU-SysFlex demonstration, the storage could be used to provide other services such as FFR or FRR as defined in Table 1. The corresponding control algorithms have not been implemented in the existing storage PEMS. This option is still under discussion, in case that these services will be demonstrated using the storage, further development will be needed to equip the controllers with the necessary functions for the services provision.

Furthermore, as previously mentioned, ENERCON wind turbines are able to provide reactive power services; however, the tests would be complex as, for example, a real fault into the system has to occur in order to trigger the response of dynamic reactive response. Therefore for the WP8 demonstration, this kind of service will be tested only on the storage system which is connected to EDF Concept Grid.

2.3.4.2 GRID EDGE DEVICE – STORAGE (GED-S)

Similar as for the GED-W, the grid edge device – Storage (GED-S) is the device which assures the communication between the battery control unit (BCU) to the centralised control of the aggregator (EMS) and to the Concept Grid control center. This device is owned by the aggregator and can incorporate several functions allowing the required services. In the present demonstration, the GED-S will integrate the following functions:

- Sending all the measurements provided by the BCU concerning the storage system to the aggregator EMS. This information should be provided in the required format and time frames;
- Sending all the control signals (services activation/deactivation) provided by the EMS to the BCU;
- Storing information for one day (measurement, alarms and control set-points);

- Performing the autonomous control of the BCU in case of loss of communication during a defined period;
- Managing the alarms provided by the BCU;
- Managing and giving priority to the orders provided by the EMS and by the Concept Grid operators.

The GED-S is a hardware agnostic solution proposed and developed by EDF-R&D that will be installed in the Concept Grid laboratory in EDF-Lab Les Renardières. Ongoing work concerns the specification of the information managed by the GED-S and exchanged with the BCU. The CG control and supervision can impose some limits in the use of batteries to avoid some constraints in the laboratory network as well as to simulate the action of a system operator.

2.3.5 CONCEPT GRID CONTROL

2.3.5.1 CONCEPT GRID CONTROL CENTER

As described before, the PV panels and loads are already installed at Concept Grid. The 2.3-MW storage system provided by ENERCON will be installed at Concept Grid on the MV network before the end of 2018.

Concept Grid will be able to remotely operate and monitor the storage system during the following phases:
- the commissioning phase (specifically for the storage system),
- the simulation phase,
- the operation phase excepted during the official testing campaign,
- emergency situation and/or request from the manufacturer,

During the above-mentioned phases, the Concept Grid controller (Figure 33) will make possible at least
- to start and shut down the storage system,
- to request active and reactive power set point,
- To monitor
    - alarms, alerts,
    - SoC,
    - active and reactive power,
    - DC and AC voltage and current,
    - operating state
    - …

The Concept Grid controller will be communicated remotely:
- directly to the storage using Modbus TCP/IP (to be confirmed by ENERCON) or
- via an GED as the interface able to convert Modbus TCP/IP to IEC 104.

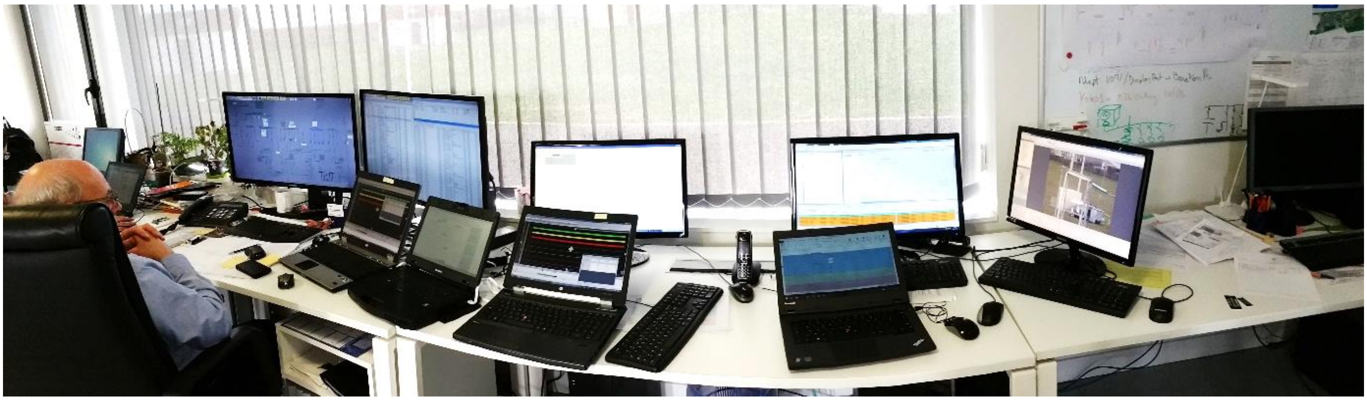


FIGURE 33. CONCEPT GRID CONTROL CENTER

For safety reasons, the EMS operators (EDF R&D in Saclay site in the EU-SysFlex demonstration) and the manufacturer (ENERCON) will not be able to access remotely to the assets without Concept Grid's authorization. All the remote operation will be scheduled in advance with Concept Grid team, who has the responsibility to manage all the remote access in order to avoid unscheduled assets' behaviour and/or unexpected power flow on the overall experimental grid.

During the official test campaigns using the overall network architecture, only the EMS will operate the storage and the other assets. The Concept Grid's controller will be disconnected physically to the communication network in order to have only one controller dedicated to operate and monitor the assets at any time.

Concept Grid team will not be allow to perform electrical and mechanical work inside the storage and inverter containers. Only ENERCON staff or a contractor mandated by ENERCON can work inside the storage system for the maintenance, repairs work, etc…

In case of fire or any electrical issue inside the containers, the storage has to be internally equipped of all the safety features in order to ensure its own safety (fire extinguisher, smoke detector, DC and AC breaker and/or fuses protection). The storage should be equipped externally of lights and audible alarm allowing Concept Grid team to know the system state at any time. In case of smoke and fire detection inside the containers, Concept Grid has to be alerted via an alert message to a mobile phone or a feedback has to be transmitted to a fire panel operated by EDF (technical solutions under discussion).

2.3.5.2 GRID EDGE DEVICE – PV AND LOAD (GED-P AND GED-L)

The grid edge device – PV (GED-P) is the device which assures the communication between the PV systems with the EMS of the aggregator. In the present demonstration is not foreseen the control of the PV system and the measurement will be provided by a mobile measurement bank. This architecture allows the use of different PV systems installed at Concept Grid Laboratory.

The grid edge device – Load (GED-L) assures the communication between the EMS of the aggregator and the loads. The GED-L will not control directly the loads. The GED-L should communicate the load set-points (load shedding) to the CG control center. The measurement of load consumption will be performed by a mobile measurement bank and transferred to GED-L using Modbus protocol.

In the present demonstration, the GED-P and GED-L will be installed in the same hardware, which is possible because both of the resources (PV system and loads) are installed in Concept Grid laboratory. This will allow to demonstrate the versatility of the proposed solution as well as to reduce the costs of the demonstration. In the present demonstration, the GED-P and GED-L will integrate the following functions:

- Sending all the measurement provided by the mobile measurements bank concerning the PV system production and load consumption to the EMS. This information should be provided in the required format and time frames;
- Sending all the control signals (services activation/deactivation) provided by the EMS to the CG control center: in the present demonstration only the load modulation will be considered;
- Storing information of one day (measurement, alarms and control setpoints);
- Performing autonomous control of the loads in case of loss of communication during a defined period.

The GED-P and GED-L are a hardware agnostic solution proposed and developed by EDF-R&D that will be installed in the Concept Grid laboratory in EDF-Lab Les Renardières.

2.4 COMMUNICATION INFRASTRUCTURE AND INTERFACES

The communication and control architecture is an important aspect in the aggregator's operation. To participate in the proposed services, fast and accurate communication solutions must be adopted. Considering the performance control requirement of certain services that will be demonstrated, it is necessary that data and information will be exchanged in a continuous and bidirectional way between the EMS and all GED devices within a time step of 5 seconds. This specification has been carefully considered to build the global communication infrastructure of the demonstration. Detailed description of the infrastructure and corresponding IT (Information Technology) solutions can be found in the next sub-sections.

2.4.1 ADVANCED ARCHITECTURE BASED ON HARDWARE-AGNOSTIC SOLUTIONS

To assure the interoperability and scalability of the proposed solutions in the present demonstration, a new full IEC 61850 based and hardware-agnostic R&D software and platform developed by EDF R&D will be used. This R&D software and platform present several advantages, when compared with the traditional ones, such as the flexibility to manage the software, firmware and configurations on intelligent electronic devices (IED) with an increased level of cybersecurity. Another important aspect is the evolutivity of the proposed solution since the evolutions of the software and the hardware are mostly independent. This aspect also has a significant impact on the asset management strategies. It is important to manage the increasing number of smart grid devices being deployed on the field for automation and DER (Distributed Energy Resources) on all voltage levels, with solutions based on IEC Core Standards (such as IEC 61850, IEC 62351 and IEC CIM), in order to test several services, different control strategies and different optimization methods.

Before the deployment in real operation conditions, all the devices will be tested both in EDF Lab Paris-Saclay in a HIL platform specially conceived for this purpose. The EDF-owned A2R (Advanced Power Grid Automation) platform provides great conditions to develop IEC 61850 and IEC 61131 based solutions meeting projects' needs, to carry out studies on IEC 61850 compliant materials and tools, and perform tests of interoperability between different equipment.

2.4.2 CONTROL INFRASTRUCTURE OF THE DEMONSTRATION

Different hardware components as well as software and control modules of the demonstration have been presented in previous sections of this chapter. The proposed architecture here intends to represent a real and global control architecture that can be used by any large industrial-scale aggregator to manage the aggregated resources. Additionally, as previously mentioned, in order to be closer to real operation conditions, the SOSD device emulating virtual SO advanced control orders will also be installed in the wind farm. It will be operated in parallel with the real devices currently under operation (DEIE device of ENEDIS). The orders given by ENEDIS should have priority compared with the orders of the services tested in the demonstration. The overall communication architecture of the demonstration is presented in Figure 34.

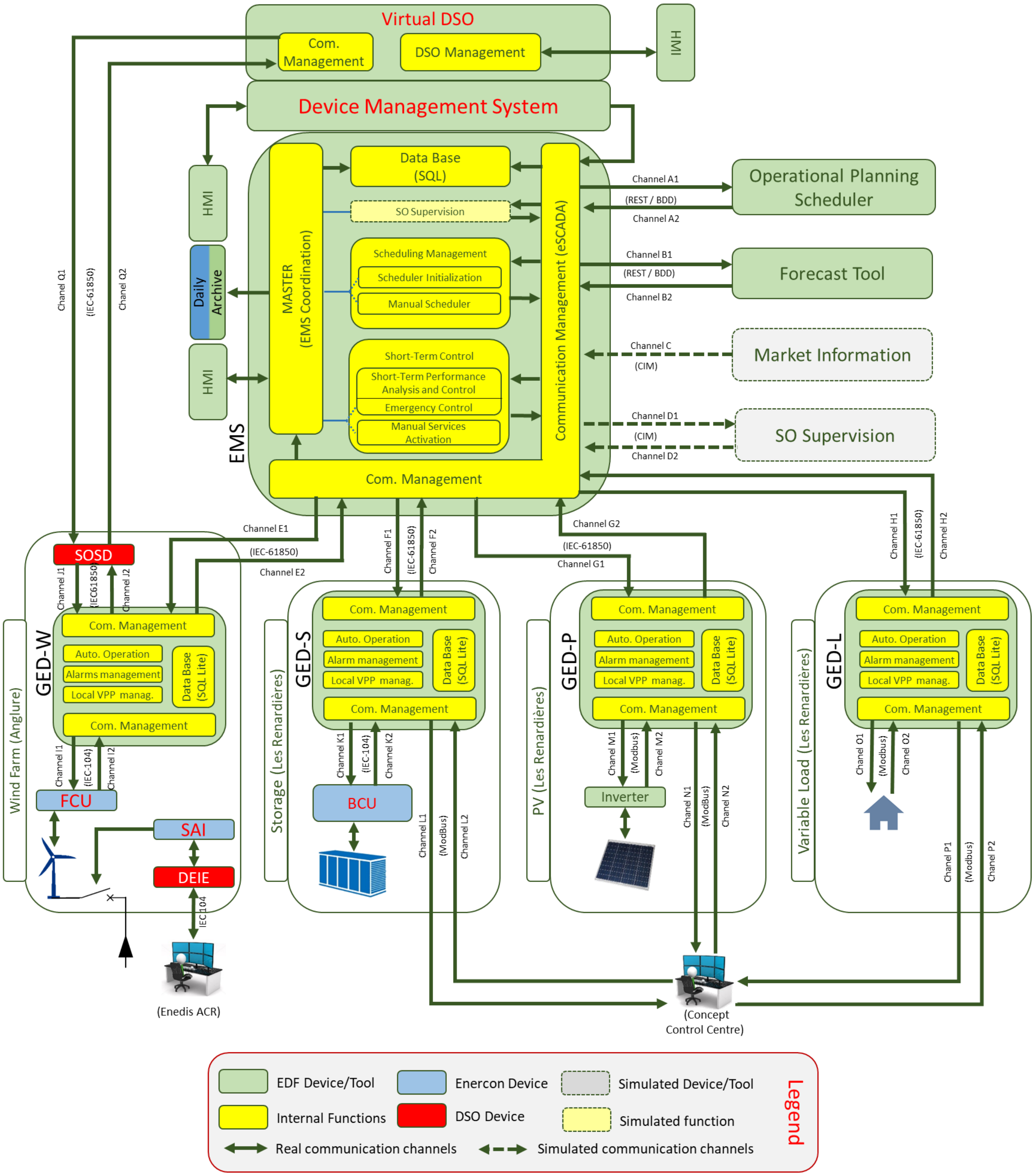


FIGURE 34: DEMONSTRATION CONTROL ARCHITECTURE

The control system should assure the interactions between the EMS and the 4 aforementioned GEDs. As described, the GEDs play the role of interface between the EMS and all the distributed resources. The use of the proposed solution allows the interaction with a wide range of DER using different protocols. In the present demonstration, the communication between the EMS and the GEDs will be made in IEC 61850. Between the GEDs and the FCU and BCU, the communication will be made using IEC 60870-5-104. The communications with the Concept Grid devices will be performed using ModBus protocol.

To guarantee the expected performance of the EMS giving orders to activate and deactivate flexibility services, it is necessary to communicate with two external servers to obtain respectively the updated generation forecasts (wind and PV) and the operating program calculated by the operational planning scheduler. The communications with these two servers will be implemented using REST (REpresentational State Transfer). The interactions with the markets and with the SO can be tested using IEC CIM when the proposed architecture is applied in a real environment interfaced with real market operators. In the present demonstration, the markets and the system operator will only be emulated.

A human machine interface (HMI) will be specifically developed for the demonstration. The HMI should provide all the relevant information concerning the resources performance and the services participation levels. Additionally, the HMI should allow the manual activation of the services and the manual definition of the global scheduling for the purpose of pre-testing and proof of concept.

The device management system (DMS), allows the update of firmware and configuration of the algorithms in the GEDs. The DMS is used for maintenance purposes in real equipment. In the present demonstration, the DMS will be particularly useful to test different algorithms and parameter settings which can be deployed in the GEDs remotely.

A very simplified energy management system of the system operator will be developed only to simulate the activation of some services in the wind farm. These services will be activated through the SOSD. As it is also possible to see in Figure 28, the orders sent by ENEDIS through the DEIE device preinstalled in the wind farm will operate directly the circuit breaker of the evacuation substation.

2.4.3 IT INTERFACES AND SOLUTIONS

One of the main challenges in the proposed architecture is to assure the cyber-security in all equipment and sites (Three EDF laboratories at Saclay / Chatou / les Renardères, *Anglure 2* wind farm, etc.). Each site is a confident zone that is interconnected by public Internet, which is a less confident zone. Therefore, data passing through Internet need to be secured (guarantee of confidentiality and integrity). In addition, a gatekeeper can be installed to control the boundary between “trust” and “untrust” zone.

The technical approach for the gatekeeper is installing a firewall allowing only white list IP address (and with the authorized protocol identified by the TCP/UDP port number). We may use the firewall embedded in the GEDs devices if third-party hardware is not available (all data flow must pass through the GED to go to/back Internet) or the gateway to Internet does not have secured functions. Regarding data protection, it is suggested to use a Virtual Private Network (VPN), based on IPSec technology. The encryption will prevent from data confidentiality and integrity violation as long as the encryption key of each site keeps secret. Once more, GEDs support IPSec if third-party hardware is not available. The global IT architecture of the demonstration is presented in Figure 35.

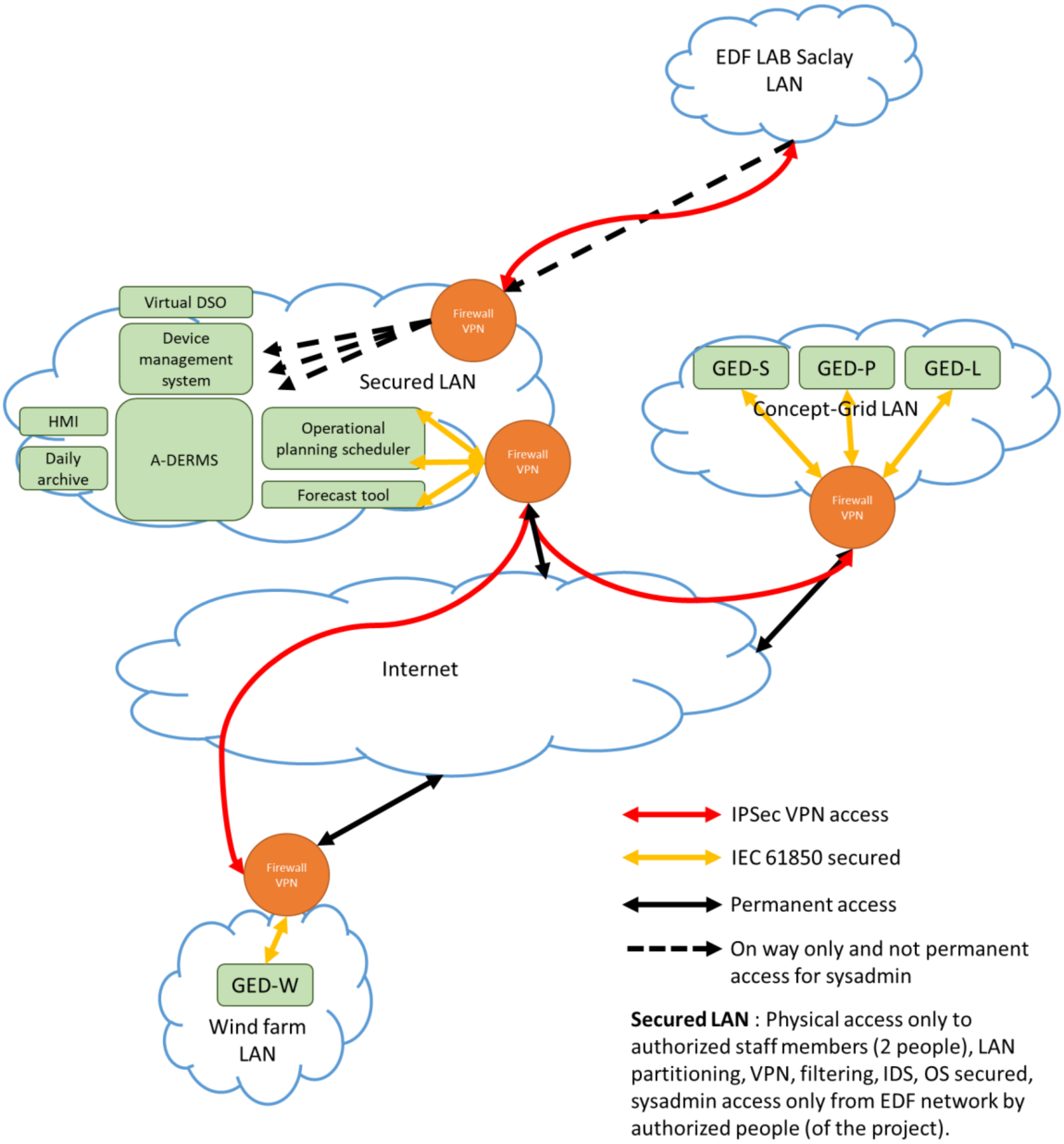


FIGURE 35: DEMONSTRATION IT ARCHITECTURE

3. SYSTEM USE CASES (SUC) DEFINITION

The use case methodology has been initially proposed in the smart grid mandate M/490 handed over to CEN/CENELEC/ETSI Smart Grid Coordination Group [18]. In the document is proposed the smart grid model architecture (SGAM) framework, presented in Figure 36, proposing the organization of the design of new Smart Grid architecture components on a 3-axe basis.

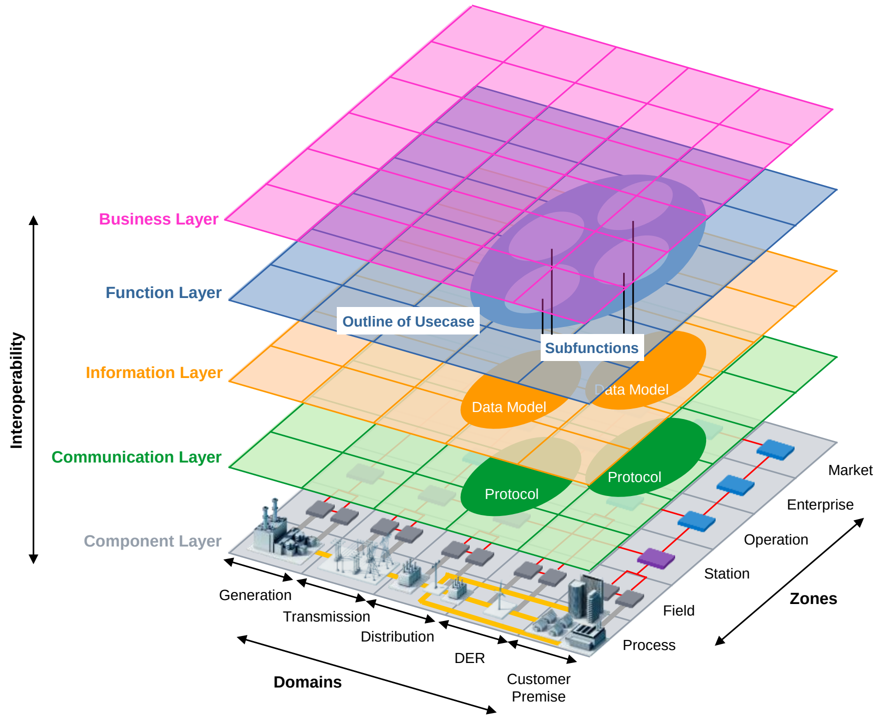


FIGURE 36 THE SMART GRID ARCHITECTURE MODEL [18]

Every Smart Grid component to be deployed on the field has to be firstly specified through different layers of abstraction from the business, down to the component implementation. In order to facilitate the high-level specifications, IEC decided to leverage an approach based on the design of Use Cases capturing the Smart Grid requirements [18]. This approach is used in the present demonstration to specify the functions (Function layer) and the interactions (Information layer) between the equipment (Component layer) using the respective protocols (communication layer).

3.1 METHOD AND APPROACH

In the proposed approach, the system use case (SUC) is defined using the Use Case methodology through key concepts: Roles, Business Processes, Activities, Systems and Functions. The methodology is exemplified in Figure 37 [19].

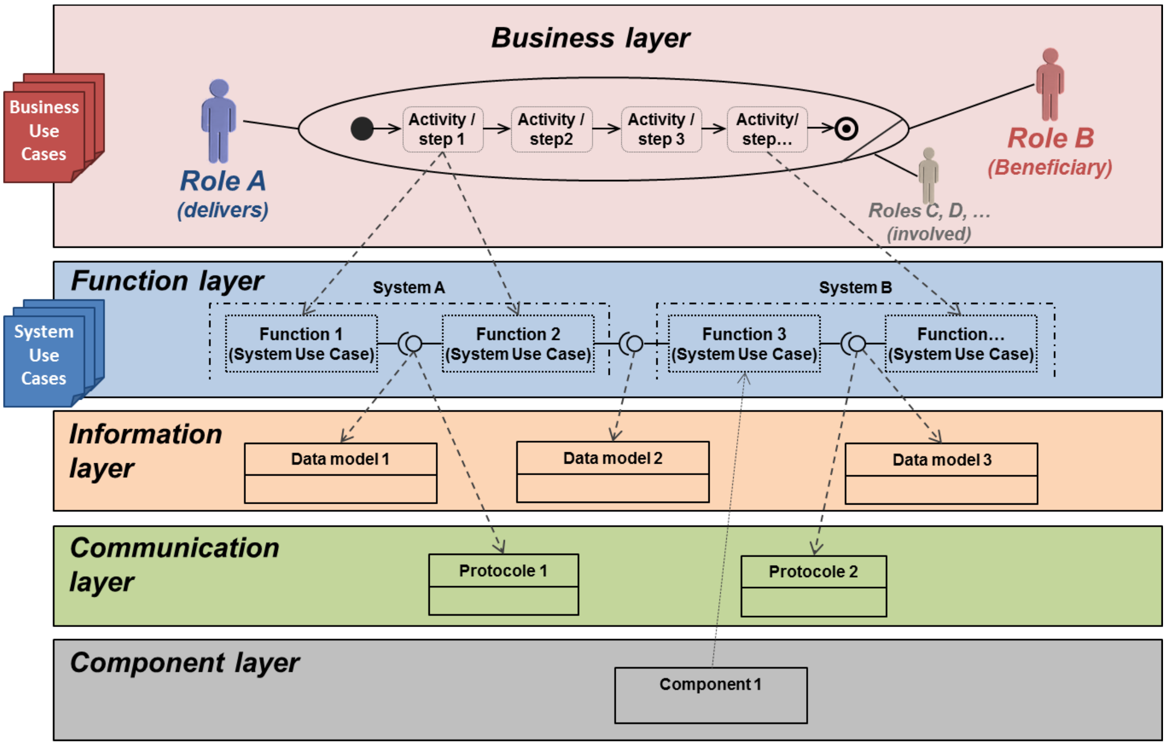


FIGURE 37 INTERACTIONS BETWEEN THE USE CASE METHODOLOGY AND THE SMART GRID ARCHITECTURE MODEL [19]

The Figure presents the relation between the layers of the SGAM (Smart Grid Architecture Model) and the interactions with the key concepts of the Use Case methodology. In the figure, it is possible to see how a given role provides a service to another role, through the execution of a business process composed of different activities. Moreover, a business process needs to be implemented in various systems. These systems also have different processes (named functions) that can be described through activities. The Use Case methodology prescribes that Business Use Cases (BUC) are developed at the Business Layer, and System Use Cases are developed at the Functional layer [20].

WP8 focuses on testing at a reduced scale in EDF's laboratory distribution grid several innovative products or different existing services but provided by "new" assets (e.g. from variable renewable generation). Some of these products do not exist in the current French ancillary services market but could be required by the future grid codes, as their procurement will help to meet future European system needs at high renewable penetration rates. At this stage, specific processes of those services from the "market" perspective cannot be fixed yet and detailed BUC description taking into account the regulatory framework and roles of stakeholders cannot be described and should be further explored during project execution.

3.2 OVERVIEW OF OPERATIONAL SCENARIOS

As explained in 2.3.2.2, the way the aggregator is operated may vary depending on its operating state (for instance, presence of contingency). The aim of this section is to briefly present these different ways (called "operational scenarios") and explain:

- why control strategies should be defined under different operational scenarios;

- when each operational scenario is activated
- how the aggregator is operated under different scenarios.

Detailed step-by-step description can be found in the SUC document in Annex II.

3.2.1 NORMAL OPERATION

This is the main operation mode of the aggregator. The operational planning scheduler chooses the services to be provided, that are then allocated to the available resources. The short term control monitors the system performance and availability and can switch the operation to another operational scenarios if needed.

This operational scenario is activated when:

- No alarms: no alarms sent by the GEDs.
- No limitations imposed by SO: the system operator does not impose any limitation.
- Manual Operation mode deactivated.
- Communication with GED without problems.

3.2.2 DIRECT RESOURCES CONTROL

In this mode the services of each resource can be manually activated through the EMS HMI by the user. This mode is used either to test services provided by a single resource (e.g., to assess the performance of the FCR provided by only the wind farm) or to set the system in a given state (e.g., sending an active power setpoint to the battery in order to reach a given state of charge).

The manual mode is activated and the operator send the control orders to the DER manually, which means:

- No Alarms: no alarms sent by the GEDs.
- No limits imposed by the SO: the system operator does not impose any limitation.
- **Manual Operation mode activated**.
- Communication with GED without problems.

3.2.3 MANUAL OPERATIONAL PLANNING

In this mode the planning of services is provided by the user in advance instead of being computed by the operational planning scheduler during operations. The rest of the operations (dispatch, short-term control, etc.) is the same as in the *normal operation scenario*. This mode is to be used during the development of the operational planning scheduler.

The manual mode is activated and the operator define the services' schedules manually. In this case the performance analysis control is activated and should guarantee the participation in the services defined manually by the operator. The activation conditions are as follows:

- No Alarms: no alarms sent by the GEDs.
- No limits imposed by the SO: the system operator does not impose any limitation.
- **Manual Operation mode activated.**

- Communication with GED without problems.

3.2.4 AUTONOMOUS OPERATION OF GED

In this under-contingency operational scenario one or several communication links are lost between the EMS and the GEDs. Depending on the services initially dispatched, some GEDs should continue to autonomously provide some services for a certain time while the EMS will re-dispatch the remaining services if possible.

This operational scenario is activated when:

- No alarms: no alarms sent by the GEDs.
- No limitations imposed by SO: the system operator does not impose any limitation.
- Manual Operation mode deactivated.
- **Communication with GED with problems (loss of communication).**

3.2.5 OPERATION UNDER A SO EXTERNAL ORDER

This mode will be activated if one resource (wind farm, storage system or PV unit) receives an external order from the SO (ENEDIS) or the virtual SO (SOSD). The EMS should re-schedule the services while the GED of resource should follow the external order.

The orders sent by the system operator should have priority regarding the ones sent by the aggregator's EMS. The information of the SO order should be also transmitted to the EMS through the GEDs. This operational scenario is activated when:

- No alarms: no alarms sent by the GEDs.
- **Limits imposed by the SO in form of external active or reactive power references**
- Manual Operation mode deactivated.
- Communication with GED without problems.

3.2.6 OPERATION UNDER ALARM

If an alarm occurs on a resource (wind farm, storage system or PV unit), the EMS will try to re-dispatch the services provided by the resource until the operational planning re-schedule the services based on the new state of the system.

This operational scenario is activated when:

- **Alarm: one or more GED sent an alarm information**
- No limits imposed by the SO: the system operator does not impose any limitation.
- Manual Operation mode deactivated.
- Communication with GED without problems.

The control strategies defined under different operational scenarios should allow the aggregator to provide the pre-allocated services within the maximum allowable time, even during some unexpected events, by respecting the operating constraints of the resources as well as the required performance of the services. The development of the most suitable control strategy and the corresponding algorithms in different operational mode is part of the key research topics of WP8. Further in-depth studies will be carried out to investigate this subject through simulation results and according to the experimental tests. More results and conclusions on this topic will be presented in the next technical deliverables of WP8.

3.3 PROPOSED KEY PERFORMANCE INDICATORS (KPI)

A first list of key performance indicators (KPIs) of WP8 as well as their calculation methods is proposed in Table 7. These KPIs allow to assess the performance of the demonstration and the success of the different functions developed and are integrated in the detailed SUC definition presented in Annex II.

<table>
<tr><th colspan="4">KPI n°1</th></tr>
<tr><td>KPI name</td><td>Increase in revenue of the multi-resources aggregator for multi- services provision</td><td>KPI ID</td><td>IR</td></tr>
<tr><td>Main objective</td><td colspan="3">Assess the increase in revenue due to the use of an optimization procedure based on determinist or stochastic approaches within the scheduler.</td></tr>
<tr><td>KPI Description</td><td colspan="3">In a context of aggregation of various assets, the use of an optimizer will help maximize the revenue of the aggregator when providing multi-services by taking account generation forecasts, market prices, service remunerations, etc. This will encourage new players to participate in ancillary service markets.</td></tr>
<tr><td>Unit</td><td colspan="3">%</td></tr>
<tr><td>Formula</td><td colspan="3">$IR[\%] = \frac{G_{EUSysFlex} - G_{BaU}}{G_{BaU}} \times 100\%$
Where:
$G_{EUSysFlex}$ [€] is the estimated or simulated aggregator revenue when EU-SysFlex solutions are applied (while the WP8 demonstration is operated with the scheduler developed).
G_{BaU} [€] is the simulated aggregator revenue in the BaU (Business as Usual) scenario (without optimal use and economic dispatch of the aggregator's assets).</td></tr>
<tr><th colspan="4">KPI n°2</th></tr>
<tr><td>KPI name</td><td>Forecast accuracy evaluation</td><td>KPI ID</td><td>FO</td></tr>
<tr><td>Main objective</td><td colspan="3">Evaluate the quality of the forecast methods and tools considering real measurement of the wind and PV generation.</td></tr>
<tr><td>KPI Description</td><td colspan="3">The performance of generation forecasting will be a key factor for the multi-resources aggregator's operation and will have significant impacts on the quality of the services provided by variable renewables as well as on the market integration possibility of those services. This KPI can be determined by different indexes such as MAPE, RMSE, sMAPE, etc. The proposed approach is to use the RMSE (root-mean-square error) for performance evaluation.</td></tr>
</table>

Unit	%		
Formula	$FO[\%] = \frac{1}{P_{nom}} \sqrt{\frac{\sum_{t=1}^{T}(Forecast_t - Generation_t)^2}{T}} \times 100\%$ Where: $Forecast_t$ [kW] is the wind or PV generation forecast at each time step t. $Generation_t$ [kW] is the measured wind or PV generation produced at each time step t. T [min] is the considered total period. P_{nom} is the installed capacity of the wind or PV farm.		
KPI n°3			
KPI name	Availability of the communication infrastructure	KPI ID	AV
Main objective	Evaluate the performance of the communication infrastructure and the IT solutions applied in the WP8 demonstration.		
KPI Description	To ensure the interoperability and scalability of the WP8 demonstration, a new full IEC 61850 based and hardware-agnostic R&D software and communication platform is developed. The availability of this ICT (Information and Communication Technology) infrastructure and interface is essential to ensure the constant exchanges between the centralised control and all the assets, so as to guarantee a proper functioning of the aggregator and its full services delivery capacity. This availability can be measured in percentage of the time during which the communication infrastructure is working as expected.		
Unit	%		
Formula	$AV[\%] = \frac{T_{com}}{T_{op}} \times 100\%$ Where: T_{com} [s] is the total duration in which all the communication platform is working correctly as defined in the demonstration specifications. T_{op} [s] is the total operational time of the aggregator.		
KPI n°4			
KPI name	Performance and reliability of existing services provision	KPI ID	PES
Main objective	Evaluate the performances and reliability of the services provided by the aggregator corresponding to the existing products in the current ancillary services market or grid codes of continental Europe.		
KPI Description	The WP8 demonstration will provide multi-services to the power system. The idea is to analyse the performance and reliability of some of the services corresponding to the existing products in the current system, such as FCR, aFRR and voltage controls. The current and updated ENTSO-E grid codes, although initially defined for the qualification and performance control of the services provided by conventional generators, will be used as references for this KPI evaluation. New adaption methods or suggestions could be given		

	to assess the performance of the corresponding services procured from renewables or storage according to the experimental results analyses and field tests feedback.		
Unit	-		
Formula	Detailed description of the TSO requirement, performance measurement methods and approaches as well as the performance control formula for the different existing services can be found in the ENSTO-E guidelines [13] [21] and in the French and German grid codes [22] [23] and will be applied.		
KPI n°5			
KPI name	Performance and reliability of "new" services provision	KPI ID	PNS
Main objective	Evaluate the performances and reliability of the services provided by the aggregator which do not yet exist in the current ancillary services market or required by the grid codes of continental Europe.		
KPI Description	The WP8 demonstration will provide multi-services to the power system. The idea is to analyse the performance and reliability of some "new" services that could be provided by the aggregator, such as FFR and flexibility solutions (ramp rate control or peak shaving). These services have not been required in the current continental grid codes. The performance measurement methods will be defined at a later stage through discussions with the system operators that have already investigated the qualification approaches of these services (e.g. EirGrid) and according to the experimental results analyses.		
Unit	-		
Formula	To be defined.		
KPI n°6			
KPI name	Services re-dispatch success rate	KPI ID	SRR
Main objective	Evaluate the performance of the developed short-term control module regarding its capability of services re-dispatch.		
KPI Description	One of the functionalities of the short-term control is to re-dispatch the allocation of services during unexpected operational events (e.g. loss of one unit, unavailability of a variable resource, etc.) to make sure that the programmed services can be delivered constantly with limited impact on the expected performance of service provision. The proper functioning of the short-term control can be assessed using the re-dispatch success rate, which is determined by considering the percentage of time during which the services re-allocation is successful when needed.		
Unit	%		
Formula	$SRR[\%] = \frac{T_{redispatch\_suc}}{T_{redispatch\_act}} \times 100\%$ Where: $T_{redispatch\_suc}$ [s] is the time duration in which the short-term control succeeds in re-allocating the capacities and services to available resources or units during unexpected		

	operational events. $T_{redispatch\_act}$ [s] is the total operational time during which unexpected events occur and services re-dispatch is technically possible (i.e. the corresponding function of the short-term control is activated).

TABLE 7. WP8 DEMONSTRATION KPI DESCRIPTION

The above-mentioned KPIs will be considered in WP10 ("*Pan-European Scalability and Replicability Analysis and Flexibility roadmap*") of the project and integrated into the cross-analyses of the demonstrations' KPIs within the EU-SysFlex project. The proposed WP8 KPIs could further evolve following the recommendations given by the WP10 cross-analyses' results and the progress state of the demonstration work.

4. CONCLUSION AND PERSPECTIVES

This report gives an overview and presents the technical specifications of the EU-SysFlex WP8 demonstration based on an aggregation approach for multi-services provision from a portfolio of distributed resources. The following information has been described in detail in the present report, including:

- Objectives and scientific approaches of the demonstration work (Chapter 1);
- Services that will be demonstrated and provided by the demonstration (Chapter 1);
- Hardware components and distributed resources of the aggregator (Section 2.2);
- Controllers, software modules as well as their functionalities (Section 2.3);
- Communication infrastructure and SI interface (Section 2.4);
- System use cases of the demonstration and WP8 KPIs (Chapter 3).

Next steps within WP8 mainly concern the set-up of the hardware components to build the demonstration as well as the development and integration of different tools allowing its operation. In the next months, the WP8 team will:

- Install the storage containers[3] at EDF Concept Grid and perform the commissioning tests;
- Prepare the models of different assets and controllers in order to build the real time simulation platform of the demonstration;
- Develop the algorithms of the EMS of the aggregator and perform first tests. A milestone report will be prepared in M14 to present the progress state of the development of the operational planning scheduler as well as the test results for its validation.

[3] Currently under construction and preparation

5. COPYRIGHT

Copyright © EU-SysFlex, all rights reserved. This document may not be copied, reproduced, or modified in whole or in part for any purpose. In addition, an acknowledgement of the authors of the document and all applicable portions of the copyright notice must be clearly referenced.

Changes in this document will be notified and approved by the PMB. This document will be approved by the PMB.

The EC / Innovation and Networks Executive Agency is not responsible for any use that may be made of the information it contains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under EC-GA No 773505.

6. BIBLIOGRAPHY

[1] Y. Wang, V. Silva and M. Lopez-Botet-Zulueta, "Impact of high penetration of variable renewable generation on frequency dynamics in the continental Europe interconnected system," in *IET Renewable Power Generation*, vol. 10, no. 1, pp. 10-16, 1 2016.

[2] A. Rousis, G.Strbac, N. Cunniffe, S. Nolan, H. Holtinnen, C. Bono, Y. Wang, MA. Evans, E. Padrón, W. Jaworski, P. Kacprzak and B. Silva, "State-of-the-Art Literature Review of System Scarcities at High Levels of Renewable Generation", D2.1 report of EU-SysFlex project, 2018. [Online]. Available: http://eu-sysflex.com/.

[3] EirGrid Grid Code v6.0, Eirgrid, 22nd July, 2015. [Online]. Available: http://www.eirgrid.com.

[4] National Grid grid code issue 5, 16 May, 2018. [Online]. Available: https://www.nationalgrid.com/uk.

[5] D. Colin *et al.*, "Enhancing the business model of distributed storage through optimized multi-service operation for TSO, DSO and generation owners: The VENTEEA real example," *CIRED Workshop 2016*, Helsinki, 2016, pp. 1-4.

[6] M. Lippert, T. Nielsen, B. Lenz and E. Quitmann, "Managing Massive Wind Integration in Electricity Grids with Lithium-Ion Energy Storage," *Power-Gen Europe 2017*, Germany, 2017.

[7] Elia, "Delivery of downward aFRR by wind farms," Elia report, October 2015. [Online]. Available: http://www.elia.be/.

[8] R.N. Andriamalala, Y. Wang, F. Colas and B. Francois, "Experimental assessment of the wind turbine contribution to the primary frequency control in an isolated power system", *IEEE PowerTech*, 16-20 June 2013, Grenoble, France.

[9] A. Rossé and G. Delille, "Commande en puissance d'onduleurs d'une installation photovoltaïque pour la participation au réglage en fréquence du réseau de distribution électrique", *French patent FR3060229*, 15 June 2018.

[10] B. PULUHEN *et al.*, "Concept Grid: a new test platform for smart grid systems general presentation & experiments," *23rd International Conference on Electricity Distribution*, Lyon, 2015.

[11] Y. Wang, G. Delille, X. Guillaud, F. Colas and B. François, "Real-time simulation: The missing link in the design process of advanced grid equipment," *IEEE PES General Meeting*, Providence, RI, 2010, pp. 1-8.

[12] W. Li, G. Joos and J. Belanger, "Real-Time Simulation of a Wind Turbine Generator Coupled With a Battery Supercapacitor Energy Storage System," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 4, pp. 1137-1145, April 2010.

[13] ENTSO-E, "Commission regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation", 2 August, 2017. [Online]. Available: https://www.entsoe.eu/.

[14] EirGrid, "Recommendation on DS3 System Services Volume Capped Competitive Procurement", 6th September 2018. [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/DS3-System-Services-Volume-Capped-Recommendation-Paper-FINAL.pdf.

[15] D. McMullin, B. Lenz, D. Gamboa, E. Quitmann, J. Anderlohr and T. Nielsen, " Integrating Energy Storage Solutions into Wind Power Plants: the Faroe Islands Case Study," *16th International Workshop on Large-Scale Integration of Wind Power into Power Systems*, Berlin, Germany, 2017.

[16] WECC, "Standard Wind Turbine-Generator Models", *IEEE PES 2006*, Montreal, Quebec, 2006. [Online]. Available: http://sites.ieee.org/pes-resource-center/files/2014/02/kehler.pdf.

[17] ENEDIS, "Présentation du Dispositif d'Échange d'Informations d'Exploitation (DÉIE) entre Enedis et un Site Producteur raccordé en HTA sur le Réseau Public de Distribution", March 2017. [Online]. Available: https://www.enedis.fr/sites/default/files/Enedis-NOI-RES_14E.pdf.

[18] CENELEC, "CEN-CENELEC-ETSI Smart Grid Coordination Group Smart Grid Reference Architecture", November, 2012. [Online]. Available: https://ec.europa.eu/energy/en.

[19] IEC, "IEC TS 62913-1 ED1: Generic Smart Grid Requirements - Part 1: Specific application of the Use Case methodology for defining Generic Smart Grid Requirements according to the IEC System approach", August, 2014. [Online]. Available: http://www.iec.ch/.

[20] Morais, H. *et al*. "Agreed models, Use Case list, and Use Case description in UML", TDX-ASSIT project deliverable D1.2, 30th March, 2018. [Online]. Available: https://cordis.europa.eu/project/rcn/211959_en.html.

[21] ENTSO-E, "Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing", 23 November, 2017. [Online]. Available: https://www.entsoe.eu/.

[22] RTE, "Documentation technique de référence", 5 July, 2018. [Online]. Available: https://www.rte-france.com/.

[23] Deutsche ÜNB, "Anforderungen an die Speicherkapazität bei Batterien für die Primärregelleistung", 29 September, 2015. [Online]. Available: https://www.regelleistung.net/ext/download/anforderungBatterien.

ANNEX I. WIND FORECASTS FILE STRUCTURE

An example of wind forecasts file structure

The first lines of the forecast published 2018-01-29 at 03:30 UTC is shown below. The 47th other forecasts published daily have the same file structure. Only files length varies due to the different forecasts horizon.

File name: prev_ANGLURE_20180129033000_IJ_01.txt

```
date.prevue;date.prevision;prevision;q0.01;q0.05;q0.1;q0.15;q0.2;q0.25;q0.3;q0.35;q0.4;q0.45;q0.5;q0.55;q0.6;q0.65;q0.7;q0.75;q0.8;q0.85;q0.9;q0.95;q0.99
2018-01-29 04:00:00;2018-01-29 03:30:00;2345;312;1060;1427;1583;1736;1858;1968;2024;2111;2174;2267;2356;2423;2498;2575;2671;2748;2933;3202;3668;4826
2018-01-29 04:30:00;2018-01-29 03:30:00;2198;50;609;964;1186;1333;1476;1584;1682;1777;1849;1992;2101;2228;2287;2420;2555;2710;2940;3228;3732;5161
2018-01-29 05:00:00;2018-01-29 03:30:00;2009;84;378;669;881;1056;1162;1328;1432;1563;1653;1719;1832;2012;2143;2294;2458;2595;2792;3142;3633;5939
2018-01-29 05:30:00;2018-01-29 03:30:00;1752;46;231;369;563;717;849;967;1056;1188;1291;1392;1471;1592;1738;1917;2046;2159;2410;2839;3429;5161
…
```

With:

"date.prevue»: beginning of the 30 minutes interval to apply the forecast, the time is in UTC

"date.prevision»: date and time of computation of the forecast, the time is in UTC

"prevision": deterministic forecast of the wind farm generation in kW

"q0.01" to "q0.99": quantiles 1% to 99% of the forecast in kW

ANNEX II. DETAILED SUC OF THE DEMONSTRATION

Distributed Energy Resources Aggregator Operation

Based on IEC 62559-2 edition 1
Generated from UML Use Case Repository with Modsarus® (EDF R&D Tool)

1. DESCRIPTION OF THE USE CASE

1.1. NAME OF USE CASE

Use case identification		
ID	***Area(s)/Domain(s)/Zone(s)***	***Name of use case***
		Distributed Energy Resources Aggregator Operation

1.2. VERSION MANAGEMENT

1.3. SCOPE AND OBJECTIVES OF USE CASE

Scope and objectives of use case	
Scope	Participation of an aggregator in multiple flexibility services using an IEC-61850 based platform and hardware-agnostic solutions.
Objective(s)	- Evaluate the participation of the aggregator in different services: one of the main goals of this demonstration is to demonstrate the technical feasibility and benefits of the participation of an aggregator in several services normally provided by conventional power plants as well as new services that could be of good potential in the future power system but are not yet required in the current grid codes and new services required due to the new generation means and new consumption modes. The aggregator should coordinate the use of its resources in order to assure this participation. - Evaluate the quality of the forecast methods considering the use of real-measurements: the forecast tools should update all the forecast (wind and PV generation) based on the real measurements provided by the GEDs. - Evaluate the communication performance: evaluate the performance of the communication platform. - Evaluate the performance of the scheduler considering the considered uncertainties: the scheduler will perform the scheduling integrating stochastic constraints. The solution provided by the scheduler should be evaluated to determine if the solution is risky or robust. - Evaluate the performance of the short term performance evaluation module: the goal is to evaluate the capacity of the short term performance evaluation module to re-dispatch the services into the aggregated resources to assure the required services in case of almost-real-time unplanned events or emergency situations. - Evaluate the performances of services provided by wind farm and storage: the goal is to perform an evaluation of the participation of wind and storage in the scheduled services

1.4. NARRATIVE OF USE CASE

Narrative of use case
Short description
This system use case intends to describe the information exchange requirements to the French demonstration of EU-SysFlex European project. The main goal is to test the participation of an aggregator in multi flexible services at same time. Six scenario have been identified, namely: - Normal Operation - Manual services activation - Manual Operational Planning Definition - Autonomous Operation of GED - Operation under a system operation external order - Operation under alarm
Complete description
In the present use case, the information exchange requirements of a decentralized multi-resources aggregator containing wind and PV generation, a battery energy storage system (BESS) as well as controllable loads will be described. This demonstration is part of WP8 of the EU-SysFlex project. The main objectives of this demonstration are: - To demonstrate the technical feasibility of performing optimal management and coordinated control of the multi-resources aggregator to provide multi-services to the power system; - To assess the performances of different services and flexibility solutions that can be procured from the aggregator by considering the grid codes' requirement. It is therefore expected to increase the TRL of the concept and the operation of such a "multi-resources multi-services" aggregator through the demonstration works. Six scenario have been identified, namely: - Normal Operation - Any special event occurs and the aggregator can dispatch all the services according scheduling. - Manual services activation - The services activation of each resource (wind farm and/or storage system) are controlled manually (through the HMI). - Manual Operational Planning Definition - The services scheduling is defined manually. The short-term controller should follow the manual planning and not the planning determined by the scheduler.

- Autonomous Operation of GED - The EMS loses the communication with a GED (wind farm, storage system or PV unit). The EMS should re-schedule the services and the GED should operate in autonomous mode - Operation under a system operation external order - A resource (wind farm, storage system or PV unit) receives an external order from the SO. The EMS should re-schedule the services and the GED-W should follow the external order. - Operation under alarm - An alarm occurs for a resource (wind farm, storage system or PV unit). The EMS should re-schedule the services and the GED should operate under alarm.

1.5. KEY PERFORMANCE INDICATORS (KPI)

Key performance indicators			
ID	***Name***	***Description***	***Reference to mentioned use case objectives***
1	Services participation success rate	It is important to ensure the effective participation of the aggregator in different services as scheduled to guarantee the revenue income for the operator. This KPI allows to measure the global performance of all the solutions as well as control modules developed to operate the demonstration and can be assessed by the percentage of time during which the programmed services are delivered as expected with required performance. Formula: $$SPR[\%] = \frac{TPS}{TPS + TRS} \times 100\%$$ Where: $T_{redispatch\_suc}$ [min] is the time duration in which the aggregator provides correctly the scheduled services. $T_{redispatch\_act}$ [min] is the period of time during which the aggregator should have provided some services but fails to do so for different technical reasons.	- Evaluate the participation of the aggregator in different services - Evaluate the performance of the scheduler considering the considered uncertainties - Evaluate the performance of the short term performance evaluation module
2	Forecast accuracy evaluation	The performance of generation forecasting will be a key factor for the multi-resources aggregator's operation and will have significant impacts on the quality of the services provided by variable renewables as well as on the market integration possibility of those services. This KPI can be determined by different indexes such as	- Evaluate the quality of the forecast methods considering the use of real-measurements

		MAPE, RMSE, sMAPE, etc. The proposed approach is to use the RMSE (root-mean-square error) for performance evaluation. Formula: $FO[\%] = \frac{1}{P_{nom}} \sqrt{\frac{\sum_{t=1}^{T}(Forecast_t - Generation_t)^2}{T}} \times 100\%$ Where: $Forecast_t$ [kW] is the wind or PV generation forecast at each time step t. $Generation_t$ [kW] is the measured wind or PV generation produced at each time step t. T [min] is the considered total period. P_{nom} is the installed capacity of the wind or PV farm.	
3	Availability of the communication infrastructure	To ensure the interoperability and scalability of the WP8 demonstration, a new full IEC 61850 based and hardware-agnostic R&D software and communication platform is developed. The availability of this ICT (Information and Communication Technology) infrastructure and interface is essential to ensure the constant exchanges between the centralised control and all the assets, so as to guarantee a proper functioning of the aggregator and its full services delivery capacity. This availability can be measured in percentage of the time during which the communication infrastructure is working as expected. Formula: $AV[\%] = \frac{T_{com}}{T_{op}} \times 100\%$ Where: T_{com} [s] is the total duration in which all the communication platform is working correctly as defined in the demonstration specifications. T_{op} [s] is the total operational time of the aggregator during the tests carried out.	- Evaluate the communication performance:
4	Scheduling performance	The idea is to determine the obtained benefits with the scheduling provided by the scheduler based on uncertainties (determinist or stochastic) and the benefits that the aggregator could be obtained without uncertainties (forecast with zero error). This means that it is necessary to execute the scheduling after the real time operation considering the real operation values.	- Evaluate the performance of the scheduler considering the considered uncertainties
5	Increase in revenue	In a context of aggregation of various assets, the use of an optimizer	- Evaluate the

	of the multi-resources aggregator for multi- services provision	will help maximize the revenue of the aggregator when providing multi-services by taking account generation forecasts, market prices, service remunerations, etc. This will encourage new players to participate in ancillary service markets. Formula: $$IR[\%] = \frac{G_{EUSysFlex} - G_{BaU}}{G_{BaU}} \times 100\%$$ Where: $G_{EUSysFlex}$ [€] is the measured or simulated aggregator revenue when EU-SysFlex solutions are applied (while the WP8 demonstration is operated with the scheduler developed). G_{BaU} [€] is the simulated aggregator revenue in the BaU (Business as Usual) scenario (without optimal use and economic dispatch of the aggregator's assets).	performance of the scheduler considering the considered uncertainties
6	Services re-dispatch success rate	One of the functionalities of the short-term control is to re-dispatch the allocation of services during unexpected operational events (e.g. loss of one unit, unavailability of a variable resource, etc.) to make sure that the programmed services can be delivered constantly with limited impact on the expected performance of service provision. The proper functioning of the short-term control can be assessed using the re-dispatch success rate, which is determined by considering the percentage of time during which the services re-allocation is successful when it is needed and technically possible. Formula: $$SRR[\%] = \frac{T_{redispatch\_suc}}{T_{redispatch\_act}} \times 100\%$$ Where: [s] is the time duration in which the short-term control succeeds in re-allocating the capacities and services to available resources or units during unexpected operational events. [s] is the total operational time during which unexpected events occur and services re-dispatch is technically possible (i.e. the corresponding function of the short-term control is activated).	- Evaluate the performance of the short term performance evaluation module
7	Performance and reliability of existing services provision	The WP8 demonstration will provide multi-services to the power system. The idea is to analyse the performance and reliability of some of the services corresponding to the existing products in the current system, such as FCR, aFRR and voltage controls. The current and updated ENTSO-E grid codes, although initially defined for the qualification and performance control of the services provided by	- Evaluate the performances of services provided by wind farm and storage

		conventional generators, will be used as references for this KPI evaluation. Suggestions on methods adaption could be given to assess the performance of the corresponding services procured from renewables or storage according to the experimental results analyses and field tests feedback. Detailed description of the TSO requirement, performance measurement approaches as well as the performance control formula for the different existing services can be found in the ENSTO-E guidelines and in the French / German grid codes. These approaches will be applied firstly to assess this KPI.	
8	Performance and reliability of new services provision	The idea is to analyse the performance of some "new" services that could be provided by the multi-resources aggregator, such as FFR and flexibility products (ramp rate control or peak shaving). These services have not been required in the current continental markets. The performance measurement methods would be defined at a later stage through discussions with system operators and findings from WP4 of the project.	- Evaluate the performances of services provided by wind farm and storage

1.6. USE CASE CONDITIONS

	Use case conditions
	Assumptions
1	Markets simplifying assumptions: • All the offers provided by the aggregator will be accepted by the corresponding market. • For both spot energy market and services market, it is assumed that: - The volume of energy or reserves provided by WP8 aggregator will be marginal and have slight impacts on prices, i.e. historical prices could be used to analyse the economic gain. - All the markets are hourly-based markets with hourly prices. - Gate closure time of all the markets will be at 12h for all the D+1 offers at a first stage. - An intraday market exists also to allow the aggregator to adapt its offers on the hour of the day according to the updated forecasts and latest measurement.
2	The SO will not communicate the services to the aggregator but only to the resources: in some specific cases, the SO can activate some services directly to the resources through the SOSD and not to the aggregator control center.
	Prerequisites

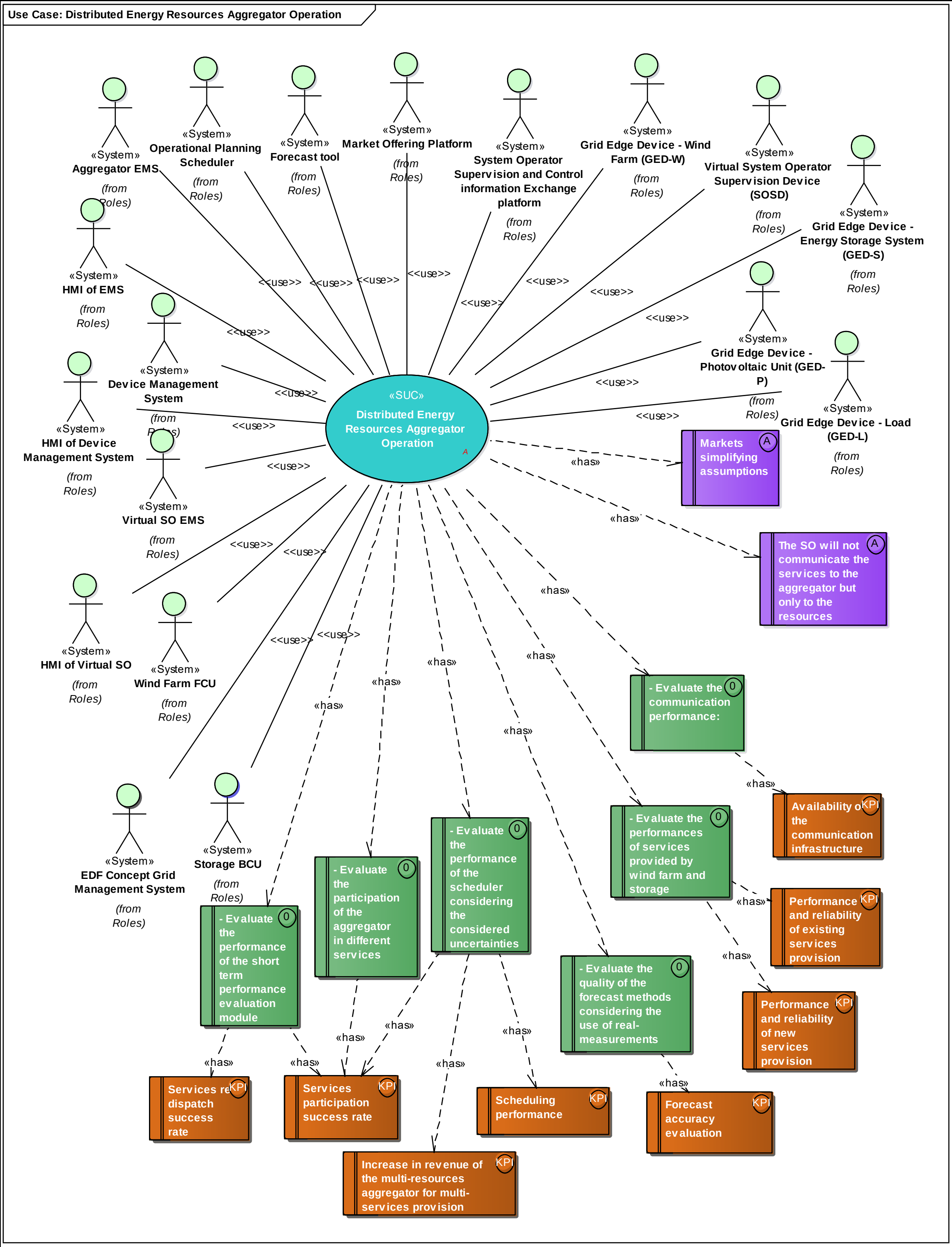
1.7. FURTHER INFORMATION TO THE USE CASE FOR CLASSIFICATION/MAPPING

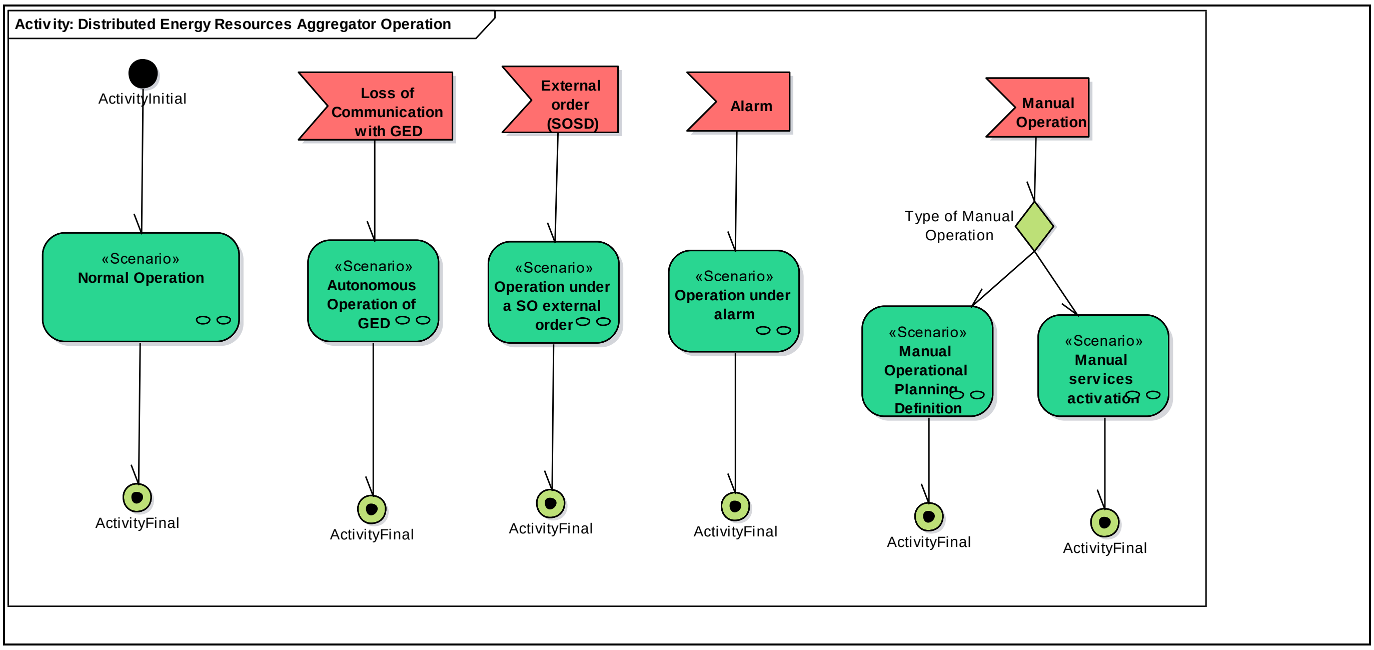
Classification information
Relation to other use cases
Level of depth
Prioritisation
High
Generic, regional or national relation
Specific use case to be implemented in EU-SysFlex French demonstration
Nature of the use case
SUC
Further keywords for classification
Aggregators, Distributed Energy Resources Control, Real-time Operation, Multi-services optimization

1.8. GENERAL REMARKS

2. DIAGRAMS OF USE CASE

Diagram(s) of use case





3.1. ACTORS

Actors			
Grouping (e.g. domains, zones)		***Group description***	
Actor name	***Actor type***	***Actor description***	***Further information specific to this use case***
Aggregator EMS	System	System responsible for managing all the information exchanges between the aggregator and control center and all the external devices and platforms. The system includes a data base and integrates all the real-time control algorithms. In the present demonstration the aggregator EMS should have the following applications: - Master coordination - EDF R&D solution for communication middleware - MySQL data base - System Operator Supervision and Control (to be included in a future version) - Scheduling Management (coordinated with Operational Planning Scheduler or defined manually)	

		- Short-Term Control including: --Performance Analysis and Control -- Emergency Operation Control -- Manual Services Activation	
Operational Planning Scheduler	System	System responsible for providing the operational planning scheduling of each service for the aggregated resources of aggregator (or the "scheduler"). In the present demonstration, the scheduler sends the reactive power (Q[kVAr]) or active power (P[kW]) for the next 48 hours in intervals of 15 minutes, every 15 minutes, for each aggregated resource (Wind farm*, Storage System, Load Curtailment). The information is organized as follows: - Scheduling(Time start [day, hour, minute], Time end [day, hour, minute], Resource, Service, Parameter) with the service specification. The number of parameters is dependent on the type of service. * In the present demonstration, the reactive setpoints will not be sent to the wind farm.	
Forecast tool	System	The forecast tool provides information of: - Wind generation forecast (every 15 minutes for the next 2 days) - PV generation forecast (every 15 minutes for the next 2 days) Each forecast includes the mean and 6 quantiles of the forecasted active power (expressed as a percentage of the maximum power) by a resource	
Market Offering Platform	System	System responsible for defining the market offers and communicating the procured services to the EMS. As the study of the market strategies is not the main goal of this demonstration, a simple simulation will be used. In the present demonstration it is assumed that all the proposed offers are accepted in the market. The market prices will be uploaded in the EMS through a file. This file should also include the penalties for each service. In the present demonstration, the information required is:	

		- Market prices (Period [day, hour, minutes], Price, Service) - Market penalties (Period [day, hour, minutes], Price, Service)	
System Operator Supervision and Control information Exchange platform	System	To participate in some services, the aggregator should send information in real-time to the system operator (TSO and/or DSO). The SO can also activate some services through this information exchange platform. In the present demonstration, no services will be activated by the SO and any information will be send to the SO. In a future version of the demonstration the interactions with the SO can be considered.	
Grid Edge Device - Wind Farm (GED-W)	System	Device connected to the wind farm, assuring the communication between the aggregator EMS and the Wind Farm FCU (device provided by Enercon). In the present Demonstration, the GED-W should communicate with the aggregator EMS and with a FCU (device provided by Enercon). The list of values exchanged is defined in the SUC. The measurement should be sent to the aggregator EMS every second. In case of alarm, the information should be pre-processed and sent to EMS. The GED should be capable of storing at least one day of information. The GED should have an algorithm to manage the wind farm in case of autonomous operation (loss of communication). The GED should consider the information provided by the SOSD (simulated DSO device) first and foremost. In case of real action of Enedis, sent through DEIE device, the aggregator operation should be stopped and an information of P_available=0 should be sent to the GED-W. This action is managed by Enercon (FCU device).	
Grid Edge Device -	System	Device connected to the storage system, assuring the	

Energy Storage System (GED-S)		communication between the EMS and the storage system SCADA. In the present demonstration, the GED-S should communicate with the aggregator EMS and with a BCU storage controller (device provided by Enercon). The list of values exchanged is defined in the SUC. The measurement should be sent to the aggregator EMS every second. In case of alarm, the information should be pre-processed and sent to aggregator EMS. The GED should be capable of storing at least one day of information. The GED should have an algorithm to manage the storage system in case of autonomous operation (loss of communication).	
Grid Edge Device - Photovoltaic Unit (GED-P)	System	Device connected to the PV unit, assuring the communication between the aggregator EMS and the PV system. In the present demonstration, the PVs will not be controlled. The GED-P will only communicate with a mobile measurement unit which can measure the production of one PV unit, several PV units (aggregated measure) or a simulated unit though power amplifiers units available in EDF Concept Grid. In case of alarm (information provided by the EDF Concept Grid EMS), the information should be pre-processed and sent to aggregator EMS. The GED should be capable of storing at least one day of information.	
HMI of EMS	System	The HMI specification will be defined in future documents but should provide at least the following information: - Overall generation and load consumption -- Wind farm: P(t), Q(t), Pavailable(t), Pmax -- PV: P(t), Q(t), Pmax* -- Storage: P(t), Q(t), SOC(t), Pmax, T(t) -- Load: P(t), Pmax	

		The HMI specification will be defined in future documents but should provide at least the following information: -Generation and Consumption -- Wind farm: P(t), Q(t), P_available(t) -- PV: P(t), Q(t), P_available(t)* -- Storage: P(t), Q(t), SOC(t), P_available(t), T(t) -- Load: P(t), P_available(t) - Weather Forecast -- Wind generation (forecast with the 6 quantiles and measured) -- PV generation (forecast with the 6 quantiles and measured) Manual Operation definition: - Manual scheduling program - Manual services activation/deactivation *The Pmax of PV will be a theoretical value because it is not possible to verify the state of the inverters.	
Device Management System	System	The Device Management System is used to remote update of firmware and configuration of GED devices. The system should do a versioning of the uploaded versions in each device.	
HMI of Device Management System	System	Allows the interactions between the user and the Device Management System.	
Virtual SO EMS	System	The Virtual SO EMS intends to simulate the actions of a System Operator during the demonstration. The system will be operated manually and will not include any "intelligence". This Virtual SO will send the orders to the resources (wind farm) through the SOSD.	
HMI of Virtual SO	System	This HMI will allows the definition of the orders to be sent to the wind farm. These orders intend to simulate the ones made by real System Operators.	
Virtual System Operator Supervision Device (SOSD)	System	This device represents a device used by a (virtual) system operator to monitor and send orders (services activation) to the resources. In the present Demonstration, it will be used in the coordination with the wind farm.	
Wind Farm FCU	System	The ENERCON SCADA Farm Control Unit (FCU) can be used to	

		implement fast and constant central closed-loop control in the wind farm. The reference point for this closed-loop control a project-specific reference point. The reference point is usually the same as the wind farm's point of connection with the high or medium voltage grid. The ENERCON SCADA FCU will deliver the measurements from the point of connection of the wind farm as well as additional data points, e.g. available active power. For different system service demonstrations, the FCU will perform various wind farm controls.	
Storage BCU	System	The ENERCON SCADA Battery Control Unit (BCU) can be used to implement fast and constant central closed-loop control in the batteries energy storage system. The ENERCON SCADA BCU will deliver the measurements from the point of connection of the BESS as well as additional data points. For different system service demonstrations, the BCU will perform various BESS controls.	
Grid Edge Device - Load (GED-L)	System	Device that should an external load. The orders should be done through the EDF Concept Grid 'simulator'. The GED-L will also communicate with a mobile measurement unit which can measure the active and reactive power consumption. The GED should be capable of storing at least one day of information.	
EDF Concept Grid Management System	System	System responsible for the EDF Concept Grid Operation. In the present demonstration will have two roles: - Load curtailment system - Operator that can stop the storage system avoiding problems in EDF Concept Grid laboratory. This order have priority related to the aggregator orders.	

4. STEP BY STEP ANALYSIS OF USE CASE

4.1. OVERVIEW OF SCENARIOS

Scenario conditions						
No.	***Scenario name***	***Scenario description***	***Primary actor***	***Triggering event***	***Pre-condition***	***Post-condition***
1	Normal Operation	Normal operation of the system. Any special event occurs and the aggregator can dispatch all the services according scheduling.			- No alarms: no alarms sent by the GEDs. - No limitations imposed by SO: the system operator does not impose any limitation. - Manual Operation mode deactivated. - Communication with GED without problems.	
2	Manual services activation	The services activation of each resource (wind farm and/or storage system) are controlled manually (through the HMI).			- Communication with GED without problems. - No Alarms: no alarms sent by the GEDs. - No limits imposed by the SO: the system operator does not impose any limitation. - Manual Operation mode activated.	
3	Manual Operational Planning Definition	The services activation of each resource (wind farm and/or storage system) are controlled manually (through the HMI).			- Communication with GED without problems - No alarms. - No limitations imposed by SO. - Manual Operation mode Activated.	
4	Autonomous Operation of GED	The EMS loses the communication with a GED (wind farm, storage system or PV unit). The EMS should re-schedule the services and the GED should operate in autonomous mode.		Loss of Communication with GED	- Communication with GED with problems (Loss of communication). - No alarms: no alarms sent by the GEDs. - No limitations imposed by SO: the system operator does not impose any limitation. - Manual Operation mode deactivated.	
5	Operation under a SO external order	A resource (wind farm, storage system or PV unit) receives an external order from the SO. The EMS		External order (SOSD)	- No alarms: no alarms sent by the GEDs. - Limitations imposed by SO: the system operator	

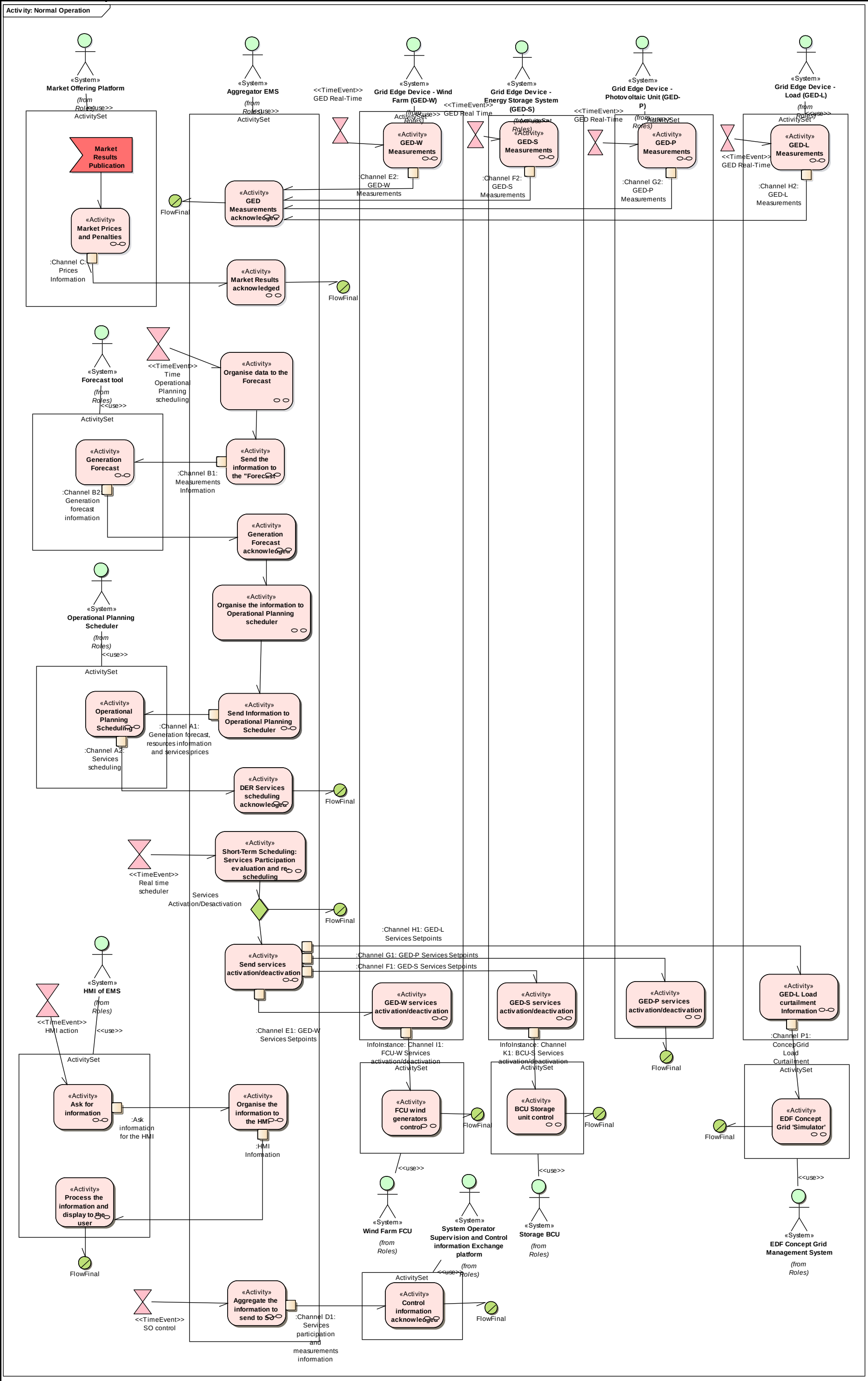
		should re-schedule the services and the GED-W should follow the external order.			imposes some limitation in the aggregator or directly in the aggregated resources operation. - Communication with GED without problems. - Manual Operation mode deactivated.	
6	Operation under alarm	An alarm occurs for a resource (wind farm, storage system or PV unit). The EMS should re-schedule the services and the GED should operate under alarm.		Alarm	- Manual Operation mode deactivated. One or more GEDs return alarm information - No limitations imposed by SO: the system operator does not impose any limitation. - Communication with GED without problems.	

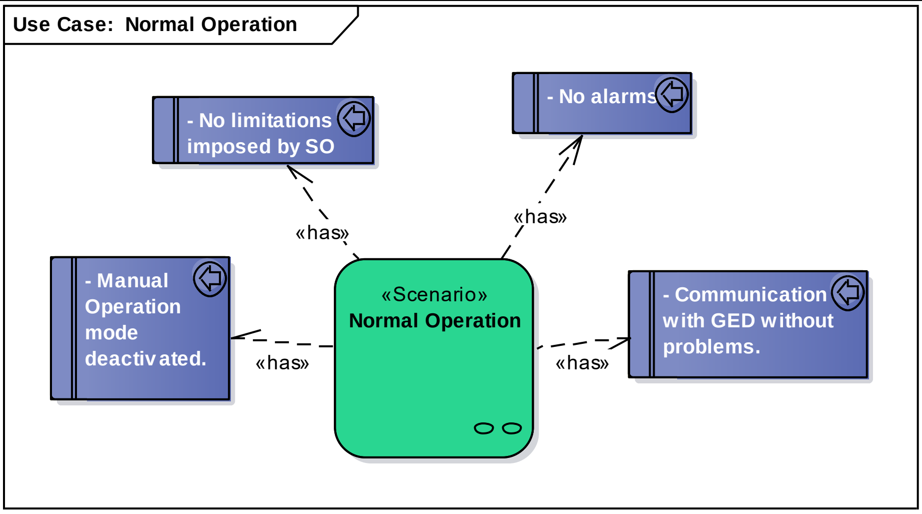
4.2. STEPS - SCENARIOS

4.2.1. NORMAL OPERATION

Scenario step by step analysis

Scenario	
Scenario name	Normal Operation





Step No	*Event*	*Name of process/activity*	*Description of process/activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
1.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by the FCU of the wind farm using IEC 60870-5-104.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info1-Channel E2: GED-W Measurements	
1.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-S.		Grid Edge Device - Energy Storage System (GED-S)	Aggregator EMS	Info2-Channel F2: GED-S Measurements	

			The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.					
1.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements	
1.4		GED-L Measurements	The GED-L should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L. The measurements will be provided by a measurements bank.		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info4-Channel H2: GED-L Measurements	
1.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
1.6		Market Prices and Penalties	Every day, the Market Offering Platform should send the necessary market information for the next 72 hours.		Market Offering Platform	Aggregator EMS	Info5-Channel C: Prices Information	

			NB: the services that will be tested are: Provide Frequency support services - Fast Frequency Response (FFR) - Frequency Containment Reserve (FCR) - Frequency Restoration Reserve (FRR) Flexibility solutions Ramp-rate control (RRC) Peak shaving (PS) Reactive power services Local voltage support* Dynamic reactive response* * For these services the prices are not required					
1.7		Market Results acknowledged	Receive the information of the market prices and penalties and save in the data base.		Aggregator EMS			
1.8		Organise data to the Forecast	The Operational Planning Algorithm should: - Ask the data base (or use the information in the memory) the measurement of wind and PV units generation in the last 15 minutes and the available		Aggregator EMS			

			P_available. - Compute the average generation by resource in (%) of Pmax.					
1.9		Send the information to the "Forecast"	The information should be sent to the generation forecast tool using REST (Representational State Transfer) or BDD (Behaviour-Driven Development).		Aggregator EMS	Forecast tool	Info6-Channel B1: Measurements Information	
1.10		Generation Forecast	Determine the generation forecast (Active Power) for wind and PV units considering the real measurements and the meteorology information. The output of the Forecast should include the most probable value (mean value) and the values of different confidence levels, 6 quantiles will be used. Send the forecast to the aggregator EMS.		Forecast tool	Aggregator EMS	Info7-Channel B2: Generation forecast information	
1.11		Generation Forecast acknowledged	Receive the information of generation forecast and save in the data base. The information that a new forecast is available should be transmitted to operational planning function.		Aggregator EMS			
1.1		Organise the	Organize the		Aggregator			

2		information to Operational Planning scheduler	information of generation forecast and of the market prices to send to the operational planning scheduler.		EMS			
1.1 3		Send Information to Operational Planning Scheduler	For each wind and PV unit: - the forecast generation, including the confidence levels (7 values) in 15-minute intervals for the next 48 hours (192 periods). - the prices and penalties (2 values) for each service (10 values) and period (192 values)		Aggregator EMS	Operational Planning Scheduler	Info8-Channel A1: Generation forecast, resources information and services prices	
1.1 4		Operational Planning Scheduling	Schedule the services provided by the resources, based on the market prices, the generation forecasts, the last SoC measure and the user parameters. Provide a merit order of the services.		Operational Planning Scheduler	Aggregator EMS	Info9-Channel A2: Services scheduling	
1.1 5		DER Services scheduling acknowledged	Receive the DER services scheduling information and the merit order list and save in the data base.		Aggregator EMS			
1.1 6		Short-Term Scheduling: Services Participation evaluation and	Evaluate the participation of each DER in the services taking into account the scheduled services		Aggregator EMS			

		re-scheduling	determined by the OP-scheduler and the real measurements provided by the GEDs. If necessary, the ST-scheduler can re-dispatch the services between the aggregated resources (Wind farm, storage or load curtailment). The ST-scheduler will send the information concerning the services activation/deactivation to each GED and save the activation orders in the data-base.					
1.17		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Wind Farm (GED-W)	Info10-Channel E1: GED-W Services Setpoints	
1.18		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	
1.19		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each		Aggregator EMS	Grid Edge Device - Load (GED-L)	Info12-Channel H1: GED-L Services Setpoints	

			service.					
1.20		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Photovoltaic Unit (GED-P)	Info13-Channel G1: GED-P Services Setpoints	
1.21		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
1.22		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	
1.23		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the PV system cannot be controlled. However, an emulation algorithm will be integrated in the GED-P.		Grid Edge Device - Photovoltaic Unit (GED-P)			
1.24		GED-L Load curtailment	The GED-L will sent the load curtailment		Grid Edge Device - Load	EDF Concept Grid	Info16-Channel P1: ConcepGrid	

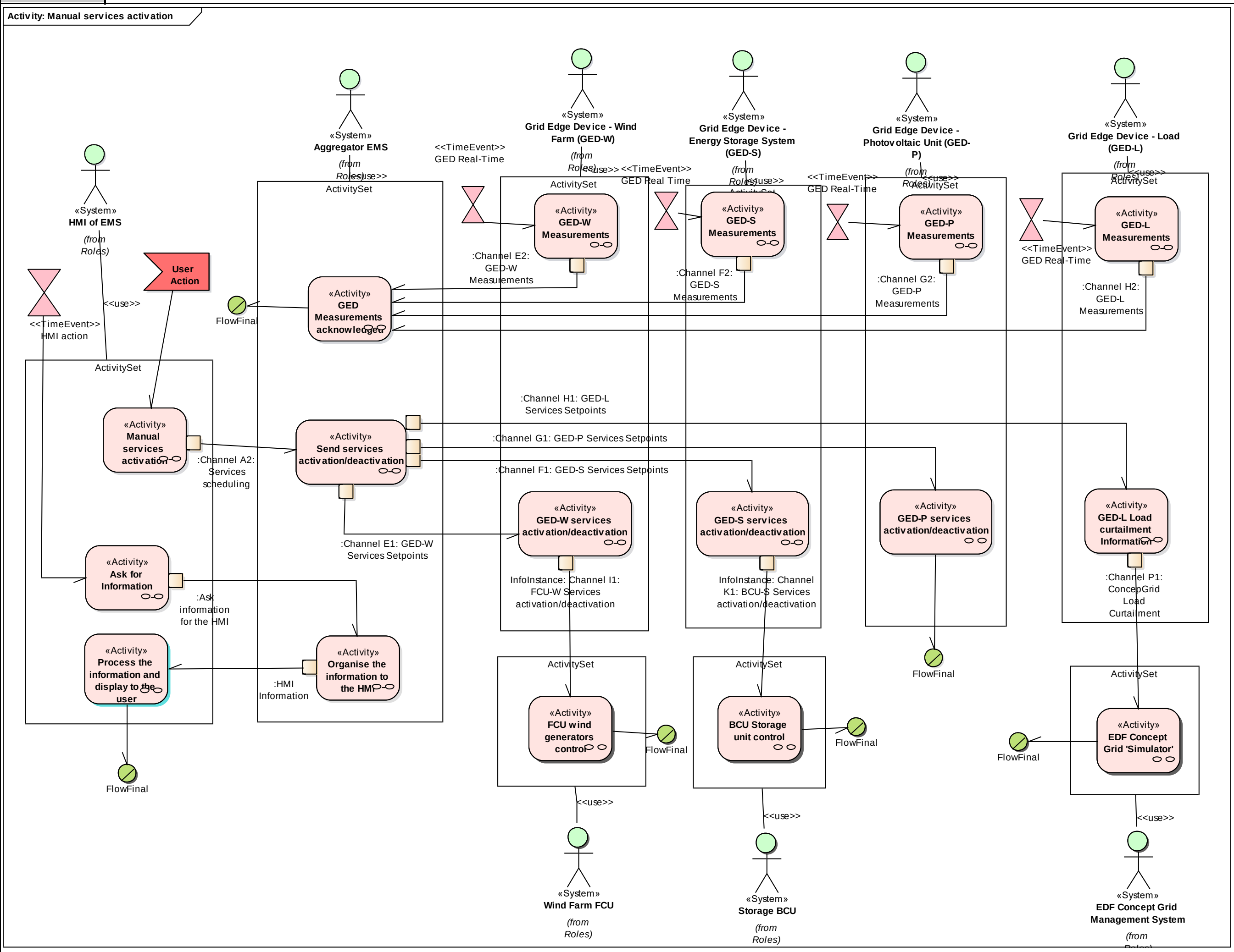
		Information	information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during a period of 1 day.		(GED-L)	Management System	Load Curtailment	
1.25		FCU wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
1.26		BCU Storage unit control	The BCU storage controller should receive the information concerning the activation/deactivation of the services. The BCU can assure the services using internal measurements of active and reactive power, state of charge, voltage and frequency.		Storage BCU			
1.27		EDF Concept Grid 'Simulator'	System in EDF Concept Grid responsible for load curtailment.		EDF Concept Grid Management System			
1.2		Ask for	HMI should ask the		HMI of EMS	Aggregator	Info17-Ask	

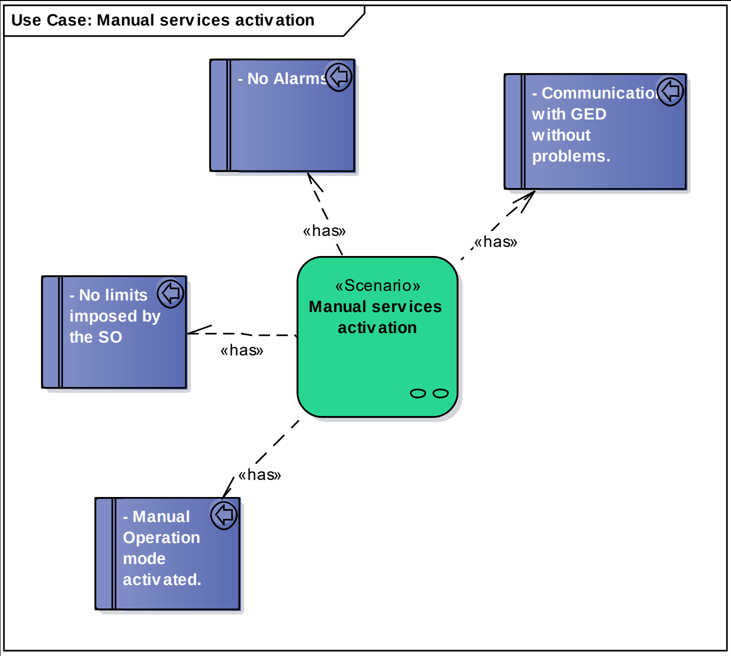
8		information	information to the EMS as a 'client' every second.			EMS	information for the HMI	
1.2 9		Organise the information to the HMI	The HMI specification will be defined in future documents but should provide at least the following information: - Overall generation and load consumption -- Wind farm: P(t), Q(t), Pavailable(t), Pmax -- PV: P(t), Q(t), Pmax* -- Storage: P(t), Q(t), SOC(t), Pmax, T(t) -- Load: P(t), Pmax - Weather Forecast -- Wind generation (forecast with the 6 quantiles and measured) -- PV generation (forecast with the 6 quantiles and measured) Manual Operation definition: - Manual scheduling program - Manual services activation/deactivation *The Pmax of PV will be a theoretical value because it is not possible to verify the state of the inverters.		Aggregator EMS	HMI of EMS	Info18-HMI Information	

1.30		Process the information and display to the user			HMI of EMS			
1.31		Aggregate the information to send to SO			Aggregator EMS	System Operator Supervision and Control information Exchange platform	Info19-Channel D1: Services participation and measurements information	
1.32		Control information acknowledged			System Operator Supervision and Control information Exchange platform			

4.2.2. MANUAL SERVICES ACTIVATION

Scenario step by step analysis

<table>
<tr><th colspan="2">Scenario</th></tr>
<tr><td>Scenario name</td><td>Manual services activation</td></tr>
<tr><td colspan="2">
</td></tr>
</table>



Step No	*Event*	*Name of process/activity*	*Description of process/activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
2.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by the FCU of the wind farm using IEC 60870-5-104.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info1-Channel E2: GED-W Measurements	
2.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator		Grid Edge Device - Energy Storage	Aggregator EMS	Info2-Channel F2: GED-S Measurements	

			EMS. The information should also be saved in an internal data-base of the GED-S. The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.		System (GED-S)			
2.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements	
2.4		GED-L Measurements	The GED-L should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L.		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info4-Channel H2: GED-L Measurements	

			The measurements will be provided by a measurements bank.					
2.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
2.6		Manual services activation	The user can activate/deactivate the services in a specific resources. A GUI (Graphical User Interface) should be developed for this propose.		HMI of EMS	Aggregator EMS	Info9-Channel A2: Services scheduling	
2.7		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Photovoltaic Unit (GED-P)	Info13-Channel G1: GED-P Services Setpoints	
2.8		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Wind Farm (GED-W)	Info10-Channel E1: GED-W Services Setpoints	
2.9		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	

			service.					
2.10		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Load (GED-L)	Info12-Channel H1: GED-L Services Setpoints	
2.11		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
2.12		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	
2.13		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the PV system cannot be controlled. However, an		Grid Edge Device - Photovoltaic Unit (GED-P)			

			emulation algorithm will be integrated in the GED-P.					
2.14		GED-L Load curtailment Information	The GED-L will sent the load curtailment information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during a period of 1 day.		Grid Edge Device - Load (GED-L)	EDF Concept Grid Management System	Info16-Channel P1: ConcepGrid Load Curtailment	
2.15		FCU wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
2.16		BCU Storage unit control	The BCU should receive the information concerning the activation/deactivation of the services.		Storage BCU			

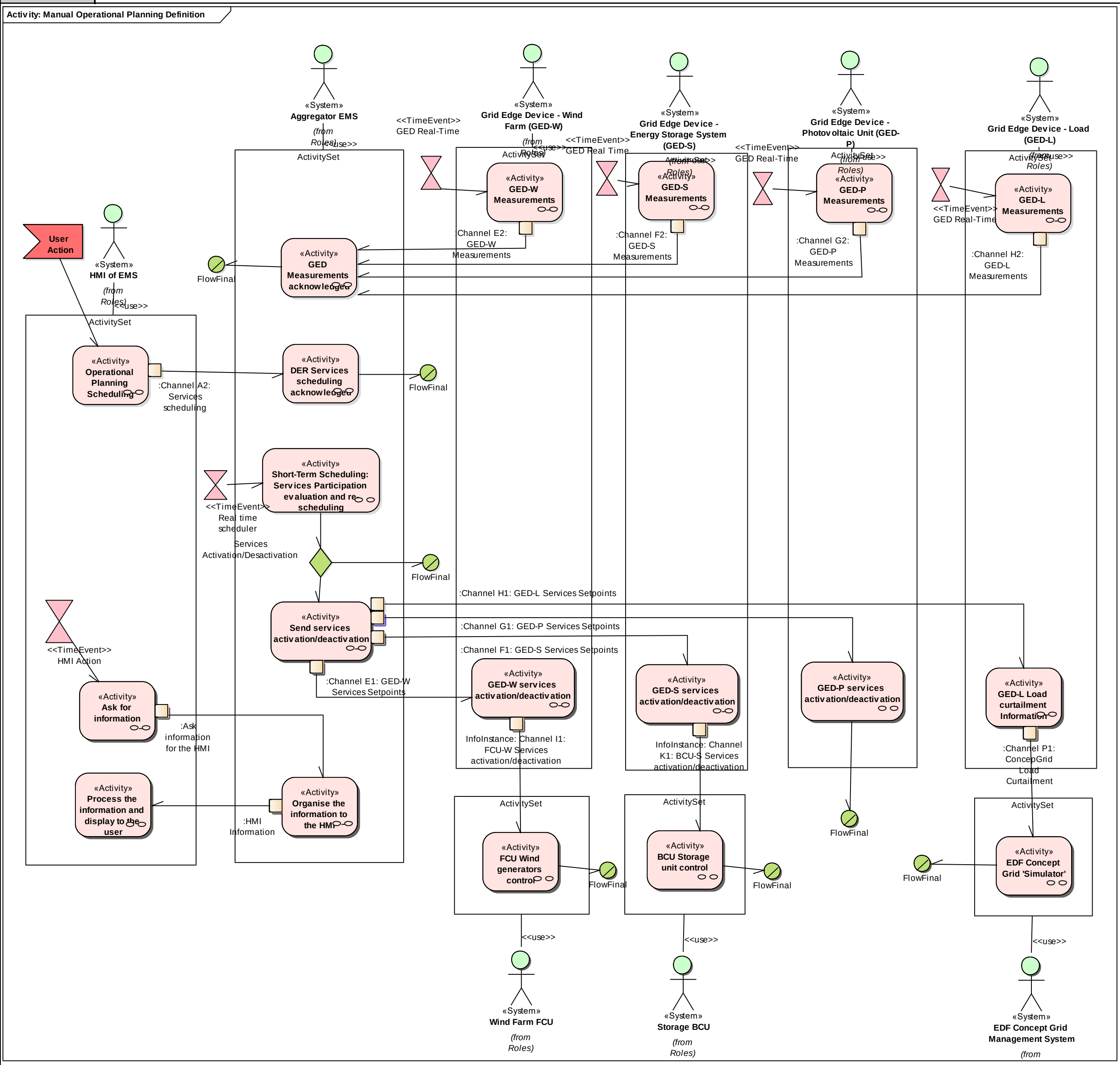
			The BCU can assure the services using internal measurements of active and reactive power, state of charge, voltage and frequency.					
2.17		EDF Concept Grid 'Simulator'	System in EDF Concept Grid responsible for load curtailment.		EDF Concept Grid Management System			
2.18		Ask for Information	HMI should ask the information to the EMS as a 'client' every second.		HMI of EMS	Aggregator EMS	Info17-Ask information for the HMI	
2.19		Organise the information to the HMI	The HMI specification will be defined in future documents but should provide at least the following information: - Overall generation and load consumption -- Wind farm: P(t), Q(t), Pavailable(t), Pmax -- PV: P(t), Q(t), Pmax* -- Storage: P(t), Q(t), SOC(t), Pmax, T(t) -- Load: P(t), Pmax		Aggregator EMS	HMI of EMS	Info18-HMI Information	

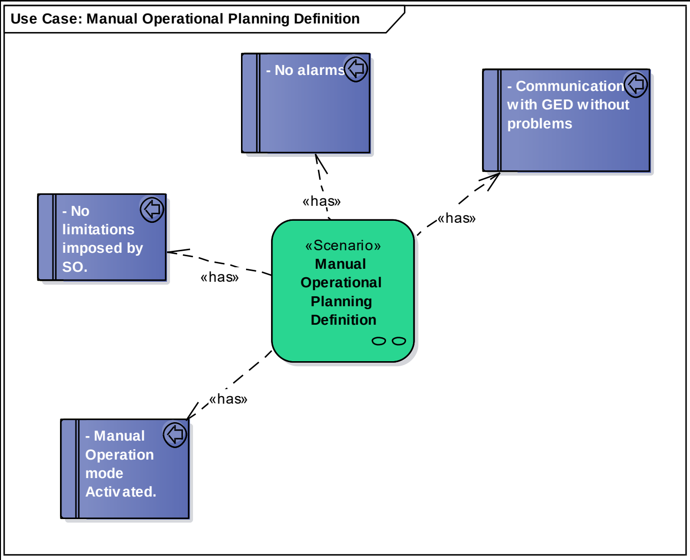
			- Weather Forecast -- Wind generation (forecast with the 6 quantiles and measured) -- PV generation (forecast with the 6 quantiles and measured) Manual Operation definition: - Manual scheduling program - Manual services activation/deactivation *The Pmax of PV will be a theoretical value because it is not possible to verify the state of the inverters.						
2.20		Process the information and display to the user			HMI of EMS				

4.2.3. MANUAL OPERATIONAL PLANNING DEFINITION

Scenario step by step analysis

Scenario	
Scenario name	Manual Operational Planning Definition





Step No	*Event*	*Name of process/activity*	*Description of process/activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
3.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by the FCU of the wind farm using IEC 60870-5-104.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info1-Channel E2: GED-W Measurements	
3.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator EMS.		Grid Edge Device - Energy Storage System (GED-S)	Aggregator EMS	Info2-Channel F2: GED-S Measurements	

			The information should also be saved in an internal data-base of the GED-S. The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.					
3.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements	
3.4		GED-L Measurements	The GED-L should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L. The measurements		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info4-Channel H2: GED-L Measurements	

			will be provided by a measurements bank.					
3.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
3.6		Operational Planning Scheduling	The operational planning scheduling for each service and for each resource should be defined by the user through a specific GUI or using a CVS file.		HMI of EMS	Aggregator EMS	Info9-Channel A2: Services scheduling	
3.7		DER Services scheduling acknowledged	Receive the DER services scheduling information and the merit order list and save in the data base.		Aggregator EMS			
3.8		Short-Term Scheduling: Services Participation evaluation and re-scheduling	Evaluate the participation of each DER in the services taking into account the scheduled services determined by the OP-scheduler and the real measurements provided by the GEDs. If necessary, the ST-scheduler can re-dispatch the services between the aggregated resources (Wind		Aggregator EMS			

			farm, storage or load curtailment). The ST-scheduler will send the information concerning the services activation/deactivation to each GED and save the activation orders in the data-base.					
3.9		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	
3.10		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Photovoltaic Unit (GED-P)	Info13-Channel G1: GED-P Services Setpoints	
3.11		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Wind Farm (GED-W)	Info10-Channel E1: GED-W Services Setpoints	
3.12		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be		Aggregator EMS	Grid Edge Device - Load (GED-L)	Info12-Channel H1: GED-L Services Setpoints	

			different for each service.					
3.13		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
3.14		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	
3.15		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the PV system cannot be controlled. However, an emulation algorithm will be integrated in the GED-P.		Grid Edge Device - Photovoltaic Unit (GED-P)			
3.16		GED-L Load curtailment	The GED-L will sent the load		Grid Edge Device -	EDF Concept	Info16-Channel P1: EDF Concept Grid	

		Information	curtailment information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during a period of 1 day.		Load (GED-L)	Grid Management System	Load Curtailment	
3.17		FCU Wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
3.18		BCU Storage unit control	The BCU should receive the information concerning the activation/deactivation of the services. The BCU can assure the services using internal measurements of active and reactive power, state of		Storage BCU			

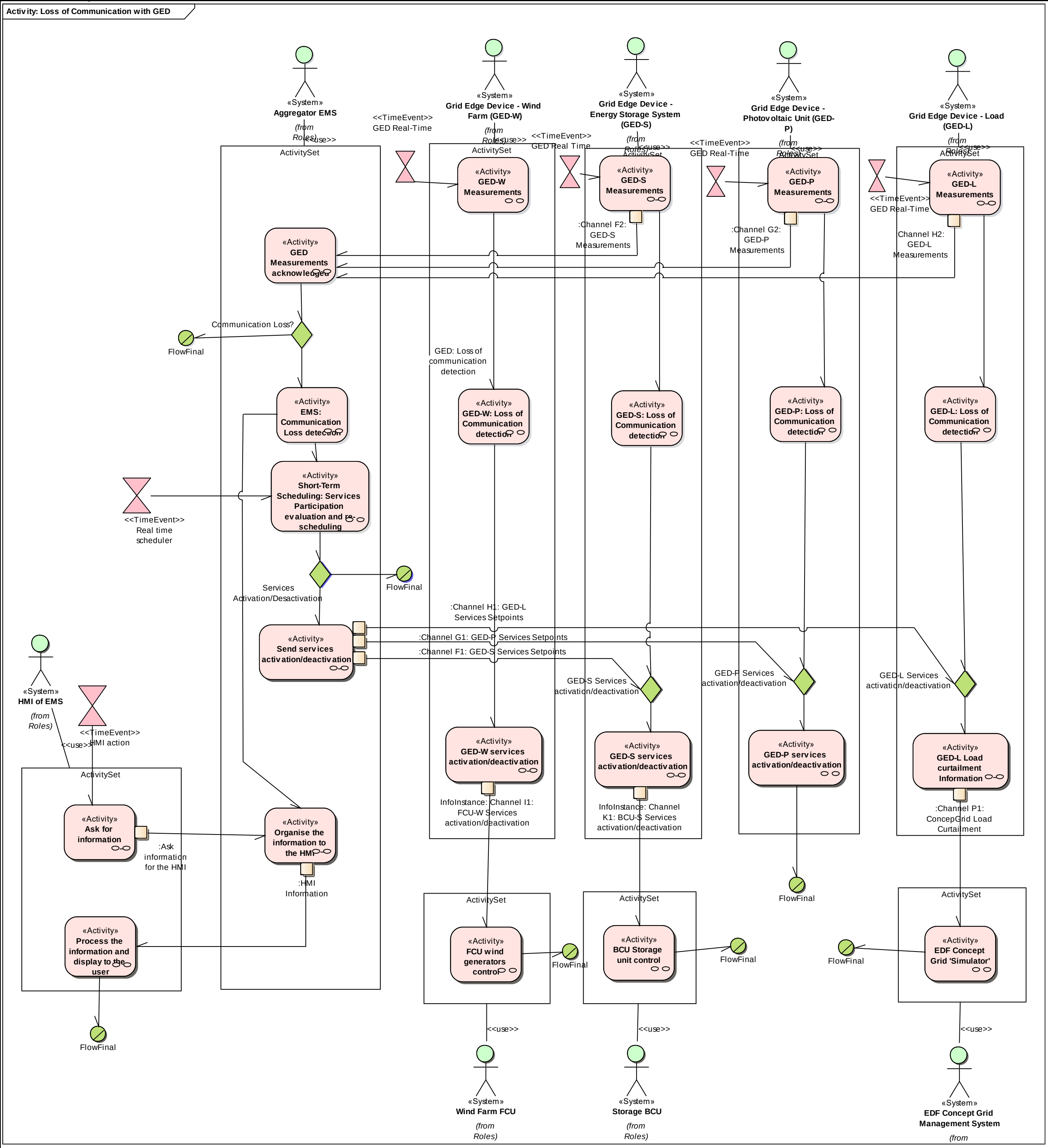
			charge, voltage and frequency.					
3.19		EDF Concept Grid 'Simulator'	System in EDF Concept Grid responsible for load curtailment.		EDF Concept Grid Management System			
3.20		Ask for information	HMI should ask the information to the EMS as a 'client' every second.		HMI of EMS	Aggregator EMS	Info17-Ask information for the HMI	
3.21		Organise the information to the HMI	The HMI specification will be defined in future documents but should provide at least the following information: - Overall generation and load consumption -- Wind farm: P(t), Q(t), Pavailable(t), Pmax -- PV: P(t), Q(t), Pmax* -- Storage: P(t), Q(t), SOC(t), Pmax, T(t) -- Load: P(t), Pmax - Weather Forecast -- Wind generation (forecast with the 6 quantiles and measured) -- PV generation		Aggregator EMS	HMI of EMS	Info18-HMI Information	

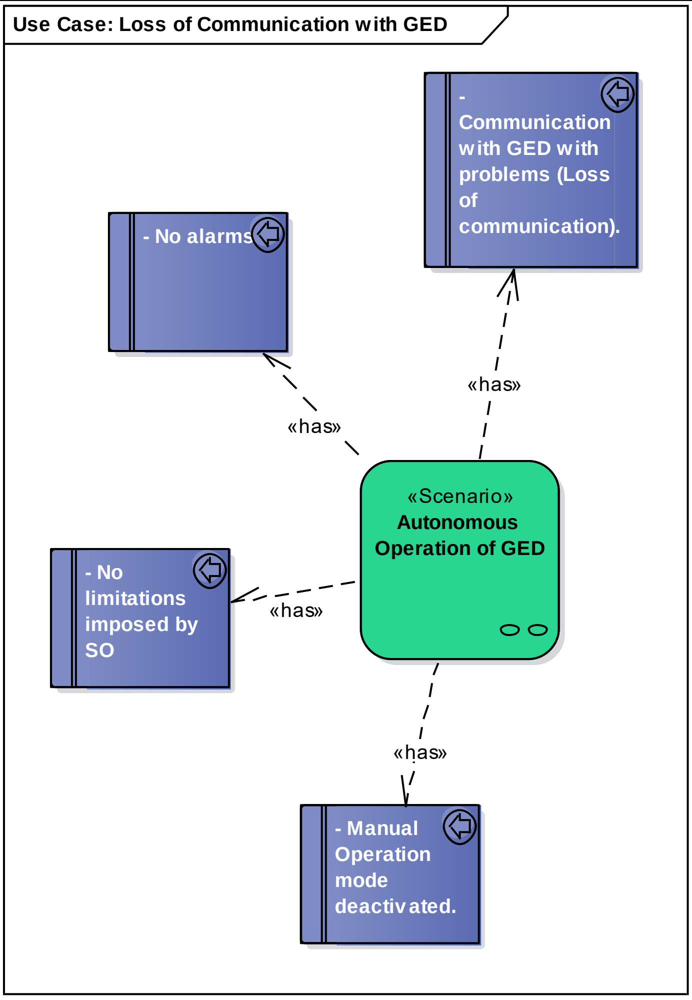
			(forecast with the 6 quantiles and measured) Manual Operation definition: - Manual scheduling program - Manual services activation/deactivation *The Pmax of PV will be a theoretical value because it is not possible to verify the state of the inverters.						
3.22		Process the information and display to the user			HMI of EMS				

4.2.4. AUTONOMOUS OPERATION OF GED

Scenario step by step analysis

Scenario	
Scenario name	Autonomous Operation of GED





Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
4.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by		Grid Edge Device - Wind Farm (GED-W)			

			the FCU of the wind farm using IEC 60870-5-104.					
4.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-S. The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.		Grid Edge Device - Energy Storage System (GED-S)	Aggregator EMS	Info2-Channel F2: GED-S Measurements	
4.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements	
4.4		GED-L Measurements	The GED-L should provide the information every		Grid Edge Device - Load (GED-	Aggregator EMS	Info4-Channel H2: GED-L Measurements	

			1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L. The measurements will be provided by a measurements bank.		L)			
4.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
4.6		EMS: Communication Loss detection	The EMS should integrate and algorithm to detect the loss of communication withe the GEDs. In case of communication loss detection, the event should be saved in a data base and the convenient values concerning the production limits, curtailment availability, and storage systems charge and discharge limits should be also updated in the data-base to be		Aggregator EMS			

			used by the scheduling process. The information of communication loss, of a respective GED, should be transmitted to the short-term scheduling and to the operator through the HMI.					
4.7		Short-Term Scheduling: Services Participation evaluation and re-scheduling	Evaluate the participation of each DER in the services taking into account the scheduled services determined by the OP-scheduler and the real measurements provided by the GEDs. If necessary, the ST-scheduler can re-dispatch the services between the aggregated resources (Wind farm, storage or load curtailment). The ST-scheduler will send the information concerning the services activation/deactivation to each GED and save the		Aggregator EMS			

			activation orders in the data-base.					
4.8		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S), Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	
4.9		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS		Info10-Channel E1: GED-W Services Setpoints, Info12-Channel H1: GED-L Services Setpoints, Info13-Channel G1: GED-P Services Setpoints	
4.10		GED-W: Loss of Communication detection	An algorithm to detect the loss of communication between the GED and the EMS should be integrated in the GED. In case of communication loss detection, the GED should deactivate all the activate services in the wind-farm.		Grid Edge Device - Wind Farm (GED-W)			
4.1		GED-S: Loss of	An algorithm to		Grid Edge			

1		Communication detection	detect the loss of communication between the GED and the EMS should be integrated in the GED. In case of communication loss detection, the GED should deactivate all the activate services in the storage system.		Device - Energy Storage System (GED-S)			
4.12		GED-P: Loss of Communication detection	An algorithm to detect the loss of communication between the GED and the EMS should be integrated in the GED. In case of communication loss detection, the GED should deactivate all the activate services in the PV system. In some test scenarios the PV system will not the controlled meaning that no services can be activated.		Grid Edge Device - Photovoltaic Unit (GED-P)			
4.13		GED-L: Loss of Communication detection	An algorithm to detect the loss of communication between the GED and the EMS should		Grid Edge Device - Load (GED-L)			

			be integrated in the GED. In case of communication loss detection, the GED should maintain all the curtailment services already activated during a predefined period of time.					
4.14		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
4.15		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day.		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	
4.16		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the		Grid Edge Device - Photovoltaic Unit (GED-P)			

			PV system cannot be controlled. However, an emulation algorithm will be integrated in the GED-P.					
4.17		GED-L Load curtailment Information	The GED-L will sent the load curtailment information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during a period of 1 day.		Grid Edge Device - Load (GED-L)	EDF Concept Grid Management System	Info16-Channel P1: ConcepGrid Load Curtailment	
4.18		FCU wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
4.19		BCU Storage unit control	The BCU should receive the information		Storage BCU			

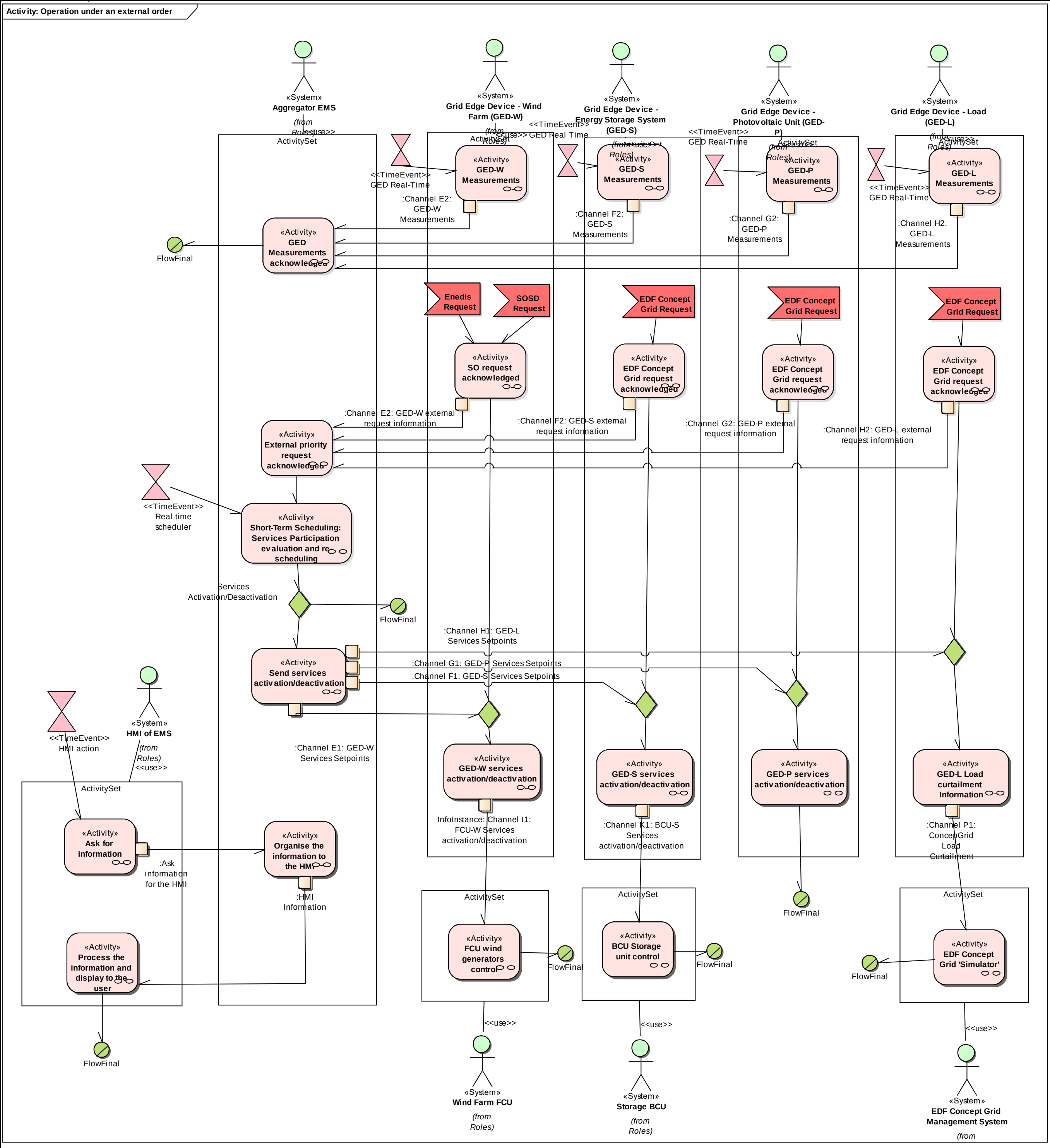
			concerning the activation/deactivation of the services. The BCU can assure the services using internal measurements of active and reactive power, state of charge, voltage and frequency.					
4.20		EDF Concept Grid 'Simulator'	System in EDF Concept Grid responsible for load curtailment.		EDF Concept Grid Management System			
4.21		Ask for information	HMI should ask the information to the EMS as a 'client' every second.		HMI of EMS	Aggregator EMS	Info17-Ask information for the HMI	
4.22		Organise the information to the HMI	The HMI specification will be defined in future documents but should provide at least the following information: - Overall generation and load consumption -- Wind farm: P(t), Q(t), Pavailable(t), Pmax -- PV: P(t), Q(t), Pmax* -- Storage: P(t), Q(t), SOC(t), Pmax,		Aggregator EMS	HMI of EMS	Info18-HMI Information	

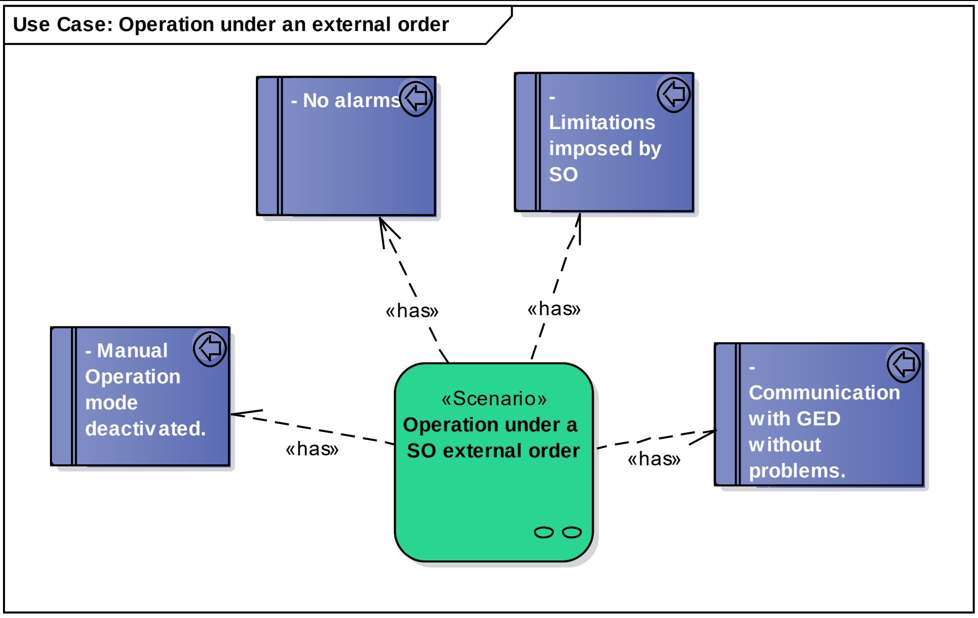
			T(t) -- Load: P(t), Pmax - Weather Forecast -- Wind generation (forecast with the 6 quantiles and measured) -- PV generation (forecast with the 6 quantiles and measured) Manual Operation definition: - Manual scheduling program - Manual services activation/deactivation *The Pmax of PV will be a theoretical value because it is not possible to verify the state of the inverters.					
4.23		Process the information and display to the user			HMI of EMS			

4.2.5. OPERATION UNDER A SO EXTERNAL ORDER

Scenario step by step analysis

Scenario	
Scenario name	Operation under a SO external order





Step No	*Event*	*Name of process/activity*	*Description of process/activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
5.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by the FCU of the wind farm using IEC 60870-5-104.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info1-Channel E2: GED-W Measurements	
5.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator EMS.		Grid Edge Device - Energy Storage System	Aggregator EMS	Info2-Channel F2: GED-S Measurements	

			The information should also be saved in an internal data-base of the GED-S. The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.		(GED-S)			
5.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements	
5.4		GED-L Measurements	The GED-L should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L.		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info4-Channel H2: GED-L Measurements	

			The measurements will be provided by a measurements bank.					
5.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
5.6		External priority request acknowledged	The information concerning the external request should be saved in the data base and a notification should be sent to the short-term scheduling.		Aggregator EMS			
5.7		Short-Term Scheduling: Services Participation evaluation and re-scheduling	Evaluate the participation of each DER in the services taking into account the scheduled services determined by the OP-scheduler and the real measurements provided by the GEDs. If necessary, the ST-scheduler can re-dispatch the services between the aggregated resources (Wind farm, storage or load curtailment). The ST-scheduler will send the		Aggregator EMS			

			information concerning the services activation/deactivation to each GED and save the activation orders in the data-base.					
5.8		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S), Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	
5.9		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Wind Farm (GED-W), Grid Edge Device - Wind Farm (GED-W)	Info10-Channel E1: GED-W Services Setpoints	
5.10		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Load (GED-L), Grid Edge Device - Load (GED-L)	Info12-Channel H1: GED-L Services Setpoints	
5.11		Send services activation/deactivat	Send the required information to the		Aggregator EMS	Grid Edge Device -	Info13-Channel G1: GED-P Services	

		ion	services activation or deactivation. The parameters will be different for each service.			Photovoltaic Unit (GED-P), Grid Edge Device - Photovoltaic Unit (GED-P)	Setpoints	
5.12		SO request acknowledged	When the SO sends a request, the GED should send the information to the EMS and give priority to the SO request instead of the services activated by the EMS.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info20-Channel E2: GED-W external request information	
5.13		EDF Concept Grid request acknowledged	When the EDF Concept Grid sends a request, the GED should send the information to the EMS and give priority to the request instead of the services activated by the EMS.		Grid Edge Device - Energy Storage System (GED-S)	Aggregator EMS	Info21-Channel F2: GED-S external request information	
5.14		EDF Concept Grid request acknowledged	When the EDF Concept Grid sends a request, the GED should send the information to the EMS and give priority to the request instead of the services		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info22-Channel G2: GED-P external request information	

			activated by the EMS.					
5.15		EDF Concept Grid request acknowledged	When the EDF Concept Grid sends a request, the GED should send the information to the EMS and give priority to the request instead of the services activated by the EMS.		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info23-Channel H2: GED-L external request information	
5.16		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day. In case of an external request, the priority should be done to this request.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
5.17		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day. In case of an external request,		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	

			the priority should be done to this request.					
5.18		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the PV system cannot be controlled. However, an emulation algorithm will be integrated in the GED-P. In case of an external request, the priority should be done to this request.		Grid Edge Device - Photovoltaic Unit (GED-P)			
5.19		GED-L Load curtailment Information	The GED-L will sent the load curtailment information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during		Grid Edge Device - Load (GED-L)	EDF Concept Grid Management System	Info16-Channel P1: ConcepGrid Load Curtailment	

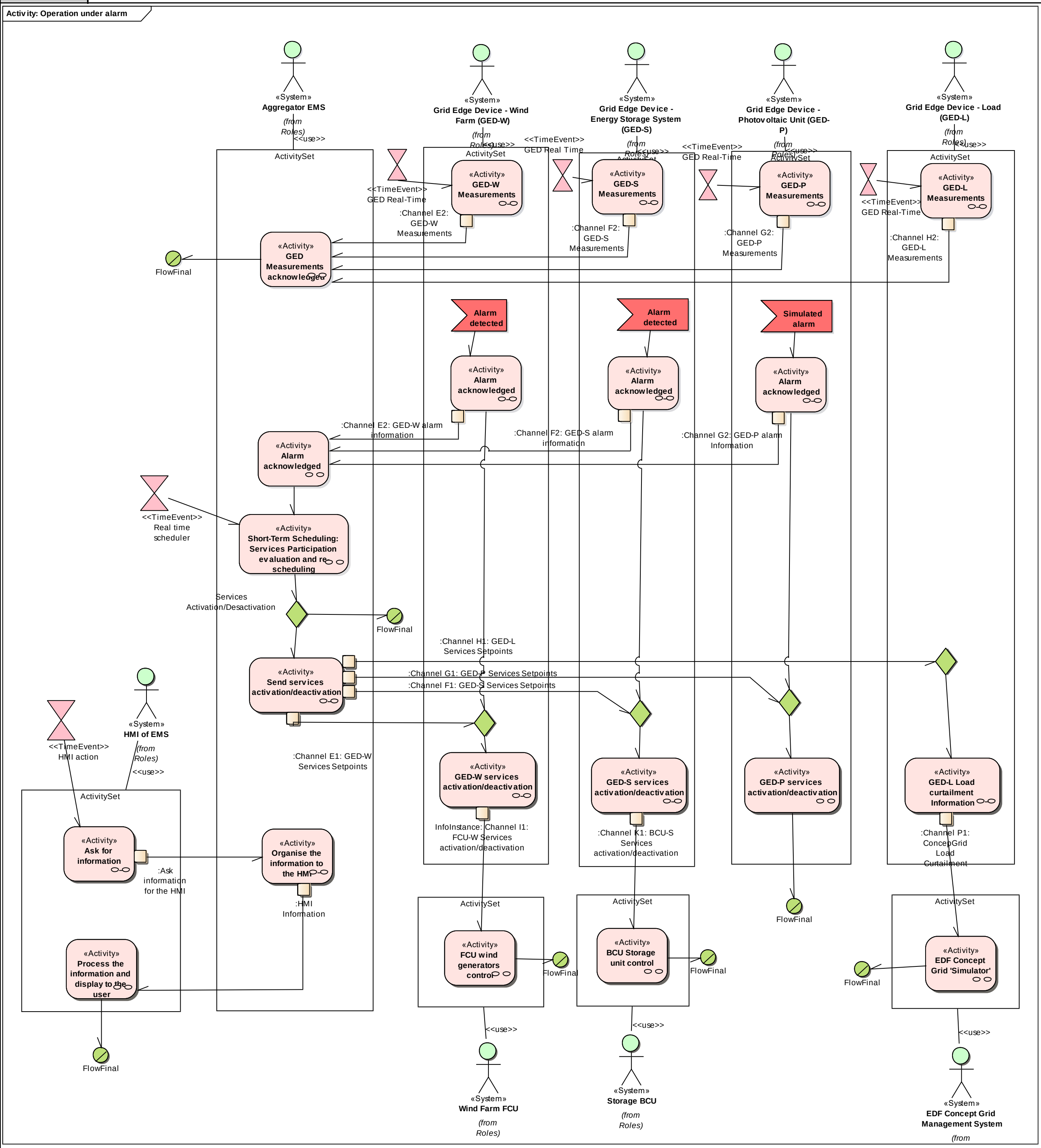
			a period of 1 day. In case of an external request, the priority should be done to this request.					
5.20		FCU wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
5.21		BCU Storage unit control	The BCU should receive the information concerning the activation/deactivation of the services. The BCU can assure the services using internal measurements of active and reactive power, state of charge, voltage and frequency.		Storage BCU			
5.2		EDF Concept Grid	System in EDF		EDF			

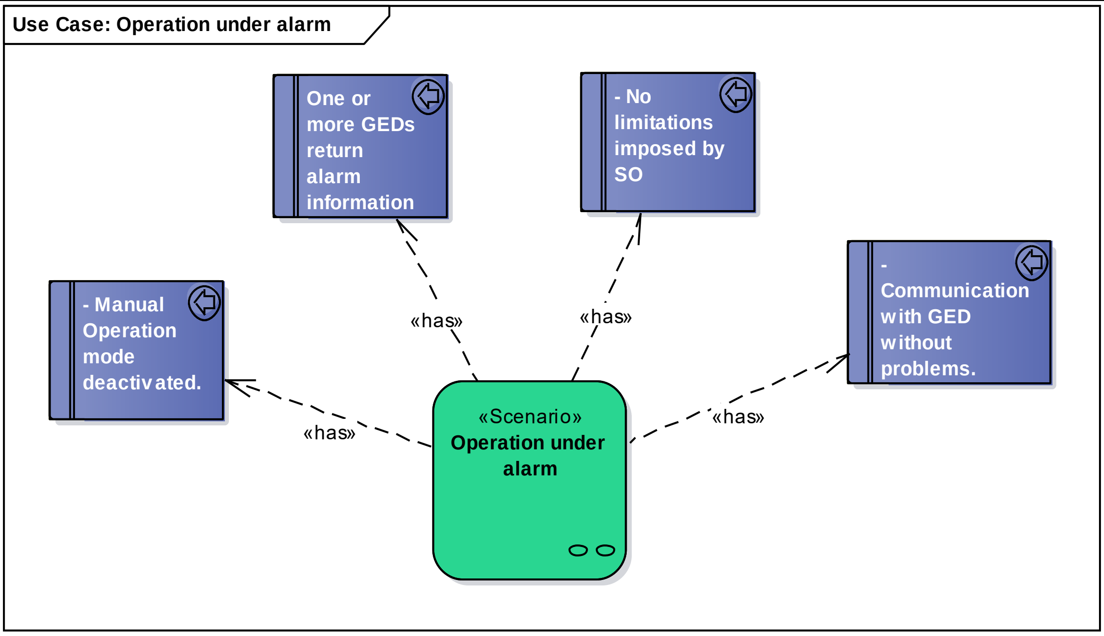
2		'Simulator'	Concept Grid responsible for load curtailment.		Concept Grid Management System			
5.23		Ask for information	HMI should ask the information to the EMS as a 'client' every second.		HMI of EMS	Aggregator EMS	Info17-Ask information for the HMI	
5.24		Organise the information to the HMI	The HMI specification will be defined in future documents. Beyond the normal information, the SO request information should be transmitted to the users.		Aggregator EMS	HMI of EMS	Info18-HMI Information	
5.25		Process the information and display to the user			HMI of EMS			

4.2.6. OPERATION UNDER ALARM

Scenario step by step analysis

Scenario	
Scenario name	Operation under alarm





Step No	*Event*	*Name of process/activity*	*Description of process/activity*	*Service*	*Information producer (actor)*	*Information receiver (actor)*	*Information exchanged (IDs)*	*Requirement, R-IDs*
6.1		GED-W Measurements	The GED-W should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of the GED-W. The measurements will be provided by the FCU of the wind farm using IEC 60870-5-104.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info1-Channel E2: GED-W Measurements	
6.2		GED-S Measurements	The GED-S should provide the information every 1s to the aggregator		Grid Edge Device - Energy Storage	Aggregator EMS	Info2-Channel F2: GED-S Measurements	

			EMS. The information should also be saved in an internal data-base of the GED-S. The measurements will be provided by the BCU of the storage unit using IEC 60870-5-104.		System (GED-S)				
6.3		GED-P Measurements	The GED-P should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-P. The measurements will be provided by a measurements bank.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info3-Channel G2: GED-P Measurements		
6.4		GED-L Measurements	The GED-L should provide the information every 1s to the aggregator EMS. The information should also be saved in an internal data-base of GED-L.		Grid Edge Device - Load (GED-L)	Aggregator EMS	Info4-Channel H2: GED-L Measurements		

			The measurements will be provided by a measurements bank.					
6.5		GED Measurements acknowledged	Receive the information and save in the Data Base.		Aggregator EMS			
6.6		Alarm acknowledged	The information concerning the alarm should be saved in the data base and a notification should be sent to the short-term scheduling.		Aggregator EMS			
6.7		Short-Term Scheduling: Services Participation evaluation and re-scheduling	Evaluate the participation of each DER in the services taking into account the scheduled services determined by the OP-scheduler and the real measurements provided by the GEDs, and the alarms. Depending of the type of the alarm, the services should be stopped in the concerned GED and re-dispatched between the other		Aggregator EMS			

			aggregated resources. The ST-scheduler will send the information concerning the services activation/deactivation to each GED and save the activation orders in the data-base.					
6.8		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Wind Farm (GED-W), Grid Edge Device - Wind Farm (GED-W)	Info10-Channel E1: GED-W Services Setpoints	
6.9		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Energy Storage System (GED-S), Grid Edge Device - Energy Storage System (GED-S)	Info11-Channel F1: GED-S Services Setpoints	
6.10		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each		Aggregator EMS	Grid Edge Device - Load (GED-L)	Info12-Channel H1: GED-L Services Setpoints	

			service.					
6.11		Send services activation/deactivation	Send the required information to the services activation or deactivation. The parameters will be different for each service.		Aggregator EMS	Grid Edge Device - Photovoltaic Unit (GED-P), Grid Edge Device - Photovoltaic Unit (GED-P)	Info13-Channel G1: GED-P Services Setpoints	
6.12		Alarm acknowledged	The FCU can communicate an alarm in the wind farm. The GED can also integrate some algorithms to detect abnormal situations. Depending of the alarm type, the GED can cancel the services automatically.		Grid Edge Device - Wind Farm (GED-W)	Aggregator EMS	Info24-Channel E2: GED-W alarm information	
6.13		Alarm acknowledged	The BCU can communicate an alarm in the wind farm. The GED can also integrate some algorithms to detect abnormal situations. Depending of the alarm type, the GED can cancel the services		Grid Edge Device - Energy Storage System (GED-S)	Aggregator EMS	Info25-Channel F2: GED-S alarm information	

			automatically.					
6.14		Alarm acknowledged	Some alarms events can be simulated to test the global architecture performance. The 'virtual' alarms messages can also be created in the GED.		Grid Edge Device - Photovoltaic Unit (GED-P)	Aggregator EMS	Info26-Channel G2: GED-P alarm Information	
6.15		GED-W services activation/deactivation	Treatment of information and services activation. The GED-W should save all the services activation in a data-base during a period of 1 day. Depending of the alarm type, the GED can cancel the services automatically.		Grid Edge Device - Wind Farm (GED-W)	Wind Farm FCU	Info14-Channel I1: FCU-W Services activation/deactivation	
6.16		GED-S services activation/deactivation	Treatment of information and services activation. The GED-S should save all the services activation in a data-base during a period of 1 day. Depending of the alarm type, the GED can cancel the services automatically.		Grid Edge Device - Energy Storage System (GED-S)	Storage BCU	Info15-Channel K1: BCU-S Services activation/deactivation	

6.17		GED-P services activation/deactivation	Treatment of information and services activation. The GED-P should save all the services activation in a data-base during a period of 1 day. In the demonstration the PV system cannot be controlled. However, an emulation algorithm will be integrated in the GED-P. In case of an external request, the priority should be done to this request.		Grid Edge Device - Photovoltaic Unit (GED-P)			
6.18		GED-L Load curtailment Information	The GED-L will sent the load curtailment information to the EDF Concept Grid 'Simulator'. The GED-L should save all the load curtailment order in a data-base during a period of 1 day. In case of an		Grid Edge Device - Load (GED-L)	EDF Concept Grid Management System	Info16-Channel P1: ConcepGrid Load Curtailment	

			external request, the priority should be done to this request.					
6.19		FCU wind generators control	The FCU should receive the information concerning the activation/deactivation of the services and coordinate their application in each wind turbine. The FCU can assure the services using internal measurements of active and reactive power, voltage and frequency.		Wind Farm FCU			
6.20		BCU Storage unit control	The BCU should receive the information concerning the activation/deactivation of the services. The BCU can assure the services using internal measurements of active and reactive power, state of charge, voltage and frequency.		Storage BCU			
6.21		EDF Concept Grid 'Simulator'	System in EDF Concept Grid responsible for load curtailment.		EDF Concept Grid Manageme			

					nt System			
6.22		Ask for information	HMI should ask the information to the EMS as a 'client' every second.		HMI of EMS	Aggregator EMS	Info17-Ask information for the HMI	
6.23		Organise the information to the HMI	The HMI specification will be defined in future documents. Beyond the normal information, the alarm information should be transmitted to the users.		Aggregator EMS	HMI of EMS	Info18-HMI Information	
6.24		Process the information and display to the user			HMI of EMS			

Information exchanged			
Information exchanged, ID	***Name of information***	***Description of information exchanged***	***Requirement, R-IDs***
Info1	Channel E2: GED-W Measurements	The GED-W should provide the following information every 1s and all the information needs to be time-stamped: - Wind farm active power available - P_available (kW) - Wind farm active power setpoint - Pset (kW) - Wind farm reactive power setpoint - Qset (kVAr) [positive means power injection/negative means power absorption] - wind farm active power measured P (kW) - wind farm reactive power measured Q (kVAr) [positive means power injection/negative means power absorption] - Grid frequency (Hz) - Voltage amplitude (kV) (average of the 3 phases) at the connecting point of the wind farm - Wind Speeds of each turbine inside the farm (m/s) [6] - Wind Directions of each turbine inside the farm (°) [6] - Maximum available power of each turbine of the wind farm P_available (kW) [6] - active power measured of each turbine (kW) [6] - Pitch (°) by wind turbine [6] - Number of available wind turbines or maximum available power of the wind farm (kW or %) - Service activation flags - Other information 1 - Other information 2 - Other information 3	
Info2	Channel F2: GED-S Measurements	The GED-S should provide the following information every 1s: - Active power charge available - Pmax_c (kW) - Active power discharge available - Pmax_d (kW) - Active power setpoint - Pset (kW) [positive means discharge/negative means charge] - Reactive power setpoint - Qset (kW) [positive means power injection/negative means power absorption] - Active power measured P (kW) [positive means discharge/negative means charge]	

		- Reactive power measured Q (kVAr) [positive means power injection/negative means power absorption] - State of Charge SoC (%) - State of Health SoH (%) - Storage Temperature (º) - Frequency (Hz) - Voltage amplitude (kV) (average of the 3 phases) - Number of available power modules (%) - Service activation flags - Other information 1 - Other information 2 - Other information 3	
Info3	Channel G2: GED-P Measurements	The GED-P+L should provide the following information every 1s: <u>Concerning the PV system</u> - Active power available - P_available (kW*) (Theoretical value defined on GED-P+L) - Active power setpoint - Pset (kW) - Can be defined only if the controlled inverters are used - Reactive power setpoint - Qset (kVAr) [positive means power injection/negative means power absorption] (Can be defined only if the controlled inverters are used) - Active power measurements P (kW) - Reactive power measurements Q (kVAr) [positive means power injection/negative means power absorption] - Temperature (ºC) (To be confirmed) - Radiation (kW/m^2) (To be confirmed) - Frequency (Hz) - Voltage (kV) - Service activation flags - Other information 1 - Other information 2 - Other information 3 All the values are in kW or kVAr because a coefficient M should be applied to all the power measurements. This M value should be part of the GED P configuration	
Info4	Channel H2: GED-L Measurements	The GED-L should provide the following information every 1s: - Active power setpoint - Pset (kW) - Active power measurements P (kW) - Frequency (Hz) - Voltage (kV) - Service activation flags	

		- Other information 1 - Other information 2 - Other information 3 All the values are in kW or kVAr because a coefficient M should be applied to all the power measurements. This M value should be part of the GED- L configuration.	
Info5	Channel C: Prices Information	Prices and penalties.	
Info6	Channel B1: Measurements Information	Wind Unit ID Average wind load factor over the last 15 minutes (% of the rating power of the wind farm). PV Unit ID Average PV load factor over the last 15 minutes (% of the rating power of the PV unit).	
Info7	Channel B2: Generation forecast information	For each wind and PV unit the forecast generation in 15-minute intervals for the next 48 hours (192 periods). The forecast should provide the most probable value and different confidence levels (7 values). Wind: Unit ID Active Power in (%) [7;192] PV: Unit ID Active Power in (%) [7;192]	
Info8	Channel A1: Generation forecast, resources information and services prices	All the information should be sent for the next 48 hours Wind Farm: Unit ID Pmax in kW [240] Pforecast in kW (mean + 6 quantiles) [7,192] PV: Unit ID Pmax in kW [192] Pforecast in kW (mean + 6 quantiles) [7,192] Storage: Unit ID SoC (%) SoH (%) [192]	

		Market information; Hourly price for each service [10,192] Hourly penalty for each service [10,192]	
Info9	Channel A2: Services scheduling	Wind Unit ID Service 1 scheduling [x, 192] Service 2 scheduling [x, 192] Service 3 scheduling [x, 192] Service 4 scheduling [x, 192] Service 5 scheduling [x, 192] Service 6 scheduling [x, 192] Service 7 scheduling [x, 192] Service 8 scheduling [x, 192] Service 9 scheduling [x, 192] Service 10 scheduling [x, 192] PV Unit ID Service 1 scheduling [x, 192] Service 2 scheduling [x, 192] Service 3 scheduling [x, 192] Service 4 scheduling [x, 192] Service 5 scheduling [x, 192] Service 6 scheduling [x, 192] Service 7 scheduling [x, 192] Service 8 scheduling [x, 192] Service 9 scheduling [x, 192] Service 10 scheduling [x, 192] Storage Service 1 scheduling [x, 192] Service 2 scheduling [x, 192] Service 3 scheduling [x, 192] Service 4 scheduling [x, 192] Service 5 scheduling [x, 192] Service 6 scheduling [x, 192] Service 7 scheduling [x, 192] Service 8 scheduling [x, 192] Service 9 scheduling [x, 192] Service 10 scheduling [x, 192] PV Service 1 scheduling [x, 192] Service 2 scheduling [x, 192] Service 3 scheduling [x, 192] Service 4 scheduling [x, 192] Service 5 scheduling [x, 192] Service 6 scheduling [x, 192] Service 7 scheduling [x, 192] Service 8 scheduling [x, 192]	

		Service 9 scheduling [x, 192] Service 10 scheduling [x, 192] <u>Load</u> Service 1 scheduling [x, 192] Service 2 scheduling [x, 192] Service 3 scheduling [x, 192] Service 4 scheduling [x, 192] Service 5 scheduling [x, 192] Service 6 scheduling [x, 192] Service 7 scheduling [x, 192] Service 8 scheduling [x, 192] Service 9 scheduling [x, 192] Service 10 scheduling [x, 192] Services Priority (Merit Order List) by DER unit, by service and by period [4,10, 192]	
Info10	Channel E1: GED-W Services Setpoints	Information to activate the wind farm services: <u>Frequency emulation</u> Fake_frq Range: 0-150% Minimum step: 0,02% Refresh rate: 1s Comments: Each frequency controller (FFR, FCR, FRR) should be able to react either on the actual frequency, either on a fake frequency <u>Inertia Emulation</u> Act_IE Range: 0-1 Minimum step: 0;1 Refresh rate: Due to using OPC interface, each WEC gets the ON/OFF command individually. Each WEC can take 5-10seconds to give feedback that IE is enabled Comments: 0: Deactivation / 1: Activation of IE F_A_Freq_IE Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: If F_A_Freq_IE=0 then IE must react on Fake frequency, if not, react on actual frequency. <u>Service FFR - Primary reserve for frequency control</u> Act_FFR	

		Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: Deactivation / 1: Activation of FFR Pos_FFR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FFR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Negative Reserve relative to Available Power F_A_Freq_FFR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FFR=0 then FFR must react on Fake frequency, if not, react on acutal frequency <u>Service FCR - Primary reserve for frequency control</u> Act_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: Deactivation / 1: Activation of FCR Pos_FCR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FCR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Negative Reserve relative to	

		Available Power F_A_Freq_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FCR=0 then FCR must react on Fake frequency, if not, react on actual frequency <u>Service FRR - Primary reserve for frequency control</u> Act_FRR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: Deactivation / 1: Activation of FRR Pos_FRR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FRR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Negative Reserve relative to Available Power F_A_Freq_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FRR=0 then FRR must react on Fake frequency, if not, react on actual frequency <u>Service Inertia 'Ireland'</u> In discussion	
Info11	Channel F1: GED-S Services Setpoints	To be defined	
Info12	Channel H1: GED-L Services Setpoints	Load shedding: Power consumption (Pmax).	
Info13	Channel G1: GED-P Services Setpoints	In the initial stage, No services will be activated in the PV systems.	

Info14	Channel I1: FCU-W Services activation/deactivation	Information to activate the wind farm services: Frequency emulation Fake_frq Range: 0-150% Minimum step: 0,02% Refresh rate: 1s Comments: Each frequency controller (FFR, FCR, FRR) should be able to react either on the actual frequency, either on a fake frequency Inertia Emulation Act_IE Range: 0-1 Minimum step: 0;1 Refresh rate: Due to using OPC interface, each WEC gets the ON/OFF command individually. Each WEC can take 5-10seconds to give feedback that IE is enabled Comments: 0: Deactivation / 1: Activation of IE F_A_Freq_IE Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: If F_A_Freq_IE=0 then IE must react on Fake frequency, if not, react on actual frequency. Service FFR - Primary reserve for frequency control Act_FFR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: Deactivation / 1: Activation of FFR Pos_FFR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FFR Range: 0-100% Minimum step: 1% Refresh rate: 1s	

		Comments: % of Negative Reserve relative to Available Power F_A_Freq_FFR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FFR=0 then FFR must react on Fake frequency, if not, react on acutal frequency <u>Service FCR - Primary reserve for frequency control</u> Act_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: 0: Deactivation / 1: Activation of FCR Pos_FCR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FCR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Negative Reserve relative to Available Power F_A_Freq_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FCR=0 then FCR must react on Fake frequency, if not, react on actual frequency <u>Service FRR - Primary reserve for frequency control</u> Act_FRR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s	

		Comments: 0: Deactivation / 1: Activation of FRR Pos_FRR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Positive Reserve relative to Available Power Neg_FRR Range: 0-100% Minimum step: 1% Refresh rate: 1s Comments: % of Negative Reserve relative to Available Power F_A_Freq_FCR Range: 0-1 Minimum step: 0;1 Refresh rate: 1s Comments: If F_A_Freq_FRR=0 then FRR must react on Fake frequency, if not, react on actual frequency Service Inertia 'Ireland' In discussion	
Info15	Channel K1: BCU-S Services activation/deactivation	Information to activate the wind farm services: General: Start/Stop [0/1] Operation Mode [1, 2, 3] (used to change from RRC to FCR or other operation modes.) T shut down (s) [1:1800] (timer to shut down the Storage in case of communication loss) FCR fref [1...100] (Defined to 50 Hz) P set reg offset (setpoint balancing power (for maintaining battery SoC, superposed to FCR) fu[1] [-100...0] Hz P(fu1) [0...100] kW fu[0] [-100...0] Hz P(fu[0]) [0...100] kW fo[0] [0...100] Hz	

		P(fo[0]) [-100...0] kW fo[1] [0...100] Hz P(fo[1]) [-100...0] kW Max P for SoC control (kW) [0...2300] kW frequency measurement from 104 Simuated frequency (ON/OFF) [0/1] communication f grid (Simulated frequency input for FCR) [1...100] Hz P response dead time [0...10000] miliseconds P response dP/dt (in development) RRC Ramping setpoint (kW/s) [0...10000] kW/s Enable battery energy control [0/1] Battery day energy setpoint [0...X] kWh X-value in definition allowed gradient limit for Energy control [0...10000] kW/s SoC setpoint [0...100] % SoC tolerance band [0...50] % Max SoC [50...100] % Min SoC [0...50] % Max P for SoC control (can be used the same as for FCR (recomended around 10% of Pmax)) [0...2300] kW Enable frequency support [0/1] overlaps the frequency curve and depending on the current grid situation enables the production of power due to frequency deviations when running on RRC mode. (tested as described in the documentation) Manual Operation: Active power set point (P) [Min active power BCS...Max active power BCS] Reactive power set point (Q) [Min reactive power BCS...Max reactive power BCS]	
Info16	Channel P1: EDF Concept Grid Load Curtailment	Load shedding: Power consumption (Pmax).	

Info17	Ask information for the HMI	The HMI acts as a client to the EMS updating the information every second. The information needs should be defined in future deliverable.	
Info18	HMI Information	All relevant information (to be defined)	
Info19	Channel D1: Services participation and measurements information	Information to activate the wind farm services: General: Start/Stop [0/1] Operation Mode [1, 2, 3] (used to change from RRC to FCR or other operation modes.) T shut down (s) [1:1800] (timer to shut down the Storage in case of communication loss) FCR fref [1...100] (Defined to 50 Hz) P set reg offset (setpoint balancing power (for maintaining battery SoC, superposed to FCR) fu[1] [-100...0] Hz P(fu1) [0...100] kW fu[0] [-100...0] Hz P(fu[0]) [0...100] kW fo[0] [0...100] Hz P(fo[0]) [-100...0] kW fo[1] [0...100] Hz P(fo[1]) [-100...0] kW Max P for SoC control (kW) [0...2300] kW frequency measurement from 104 Simuated frequency (ON/OFF) [0/1] communication f grid (Simulated frequency input for FCR) [1...100] Hz P response dead time [0...10000] miliseconds P response dP/dt (in development) RRC Ramping setpoint (kW/s) [0...10000] kW/s Enable battery energy control [0/1] Battery day energy setpoint [0...X] kWh X-value in definition	

		allowed gradient limit for Energy control [0...10000] kW/s SoC setpoint [0...100] % SoC tolerance band [0...50] % Max SoC [50...100] % Min SoC [0...50] % Max P for SoC control (can be used the same as for FCR (recomended around 10% of Pmax)) [0...2300] kW Enable frequency support [0/1] overlaps the frequency curve and depending on the current grid situation enables the production of power due to frequency deviations when running on RRC mode. (tested as described in the documentation) Manual Operation: Active power set point (P) [Min active power BCS...Max active power BCS] Reactive power set point (Q) [Min reactive power BCS...Max reactive power BCS]	
Info20	Channel E2: GED-W external request information	External request information: P_available	
Info21	Channel F2: GED-S external request information	External request information: SOC Pcharge_max Pdischarge_max	
Info22	Channel G2: GED-P external request information	External request information: P_available	
Info23	Channel H2: GED-L external request information	External request information: P_consumption	
Info24	Channel E2: GED-W alarm information	Alarm information: P_available	
Info25	Channel F2: GED-S alarm information	Alarm information: SOC Pcharge_max Pdischarge_max	
Info26	Channel G2: GED-P alarm Information	Alarm information: P_available	