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Interoperable, modular and Smart hybrid energy STORage systeM for stationarY applications

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Deliverable Report

D1.3 – Testing protocols overview

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Publishable summary

This document describes the test protocols which will be used for each component of the Hybrid Battery Energy Storage System (HBESS) developed in iSTORMY. This includes the test definition to meet the requirements of the different use cases, to be compatible with each other and to ensure safe operation in within the targeted operating window. Safety will be a crucial aspect of the testing protocols. These testing protocols will be defined for:

- The demonstrator system, including grid requirements, protections and safety, test sources and test loads.
- The power electronics interface, which will be first tested in a regular lab environment before being integrated in the demonstrator.
- The self-healing EMS platform, also considering the communication with other subsystems.
- The battery pack system which will be developed in WP2.

Contents

1 Introduction

This document describes the test protocols which will be used for each component of the Hybrid Battery Energy Storage System (HBESS) developed in iSTORMY. This includes the test definition to meet the requirements of the different use cases, to be compatible with each other and to ensure safe operation in within the targeted operating window. Safety will be a crucial aspect of the testing protocols. These testing protocols will be defined for:

- The demonstrator system, including grid requirements, protections and safety, test sources and test loads.
- The power electronics interface, which will be first tested in a regular lab environment before being integrated in the demonstrator.
- The self-healing EMS platform, also considering the communication with other subsystems.
- The battery pack system which will be developed in WP2.

2 Methods and Results (task 1.3)

2.1 Testing protocols for the demonstrator system

Once the components of the HBESS will be built in the different WPs, the complete system will be integrated in EDF Concept grid network for the demonstration carried out in WP 5. Prior to the use cases, the system must be commissioned properly to achieve the compliance with the requirements specified in D1.1. This section describes the commissioning and testing protocol which will be done once the system is built. The main objective is to go through all the main functionalities of the HBESS making sure that the behavior of the complete system complies with the specifications especially in terms of safety. Figure 1 shows a simplified one-line diagram of the solution.

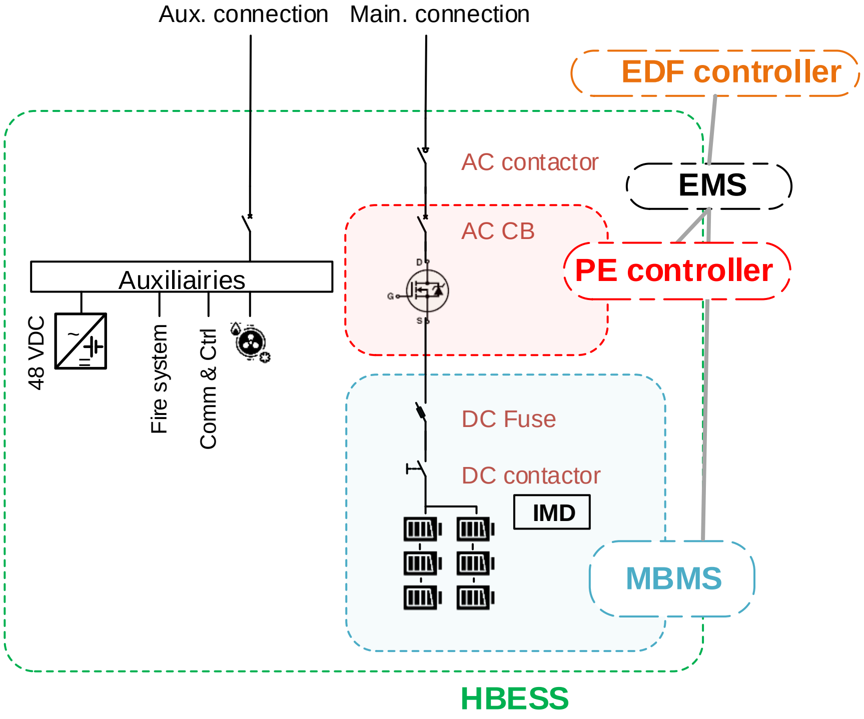

Figure 1 – Simplifed one-line diagram of the HBESS prototype

Once the commissioning is done, it means that the system can operate normally under all the different configurations and state of operations embedded in the EMS.

Figure 2 below states the organization of the commissioning to guaranty that safety is optimized during the whole process. It starts with power supply commissioning to ensure that monitoring and safety protocols are the first milestone to be achieved.

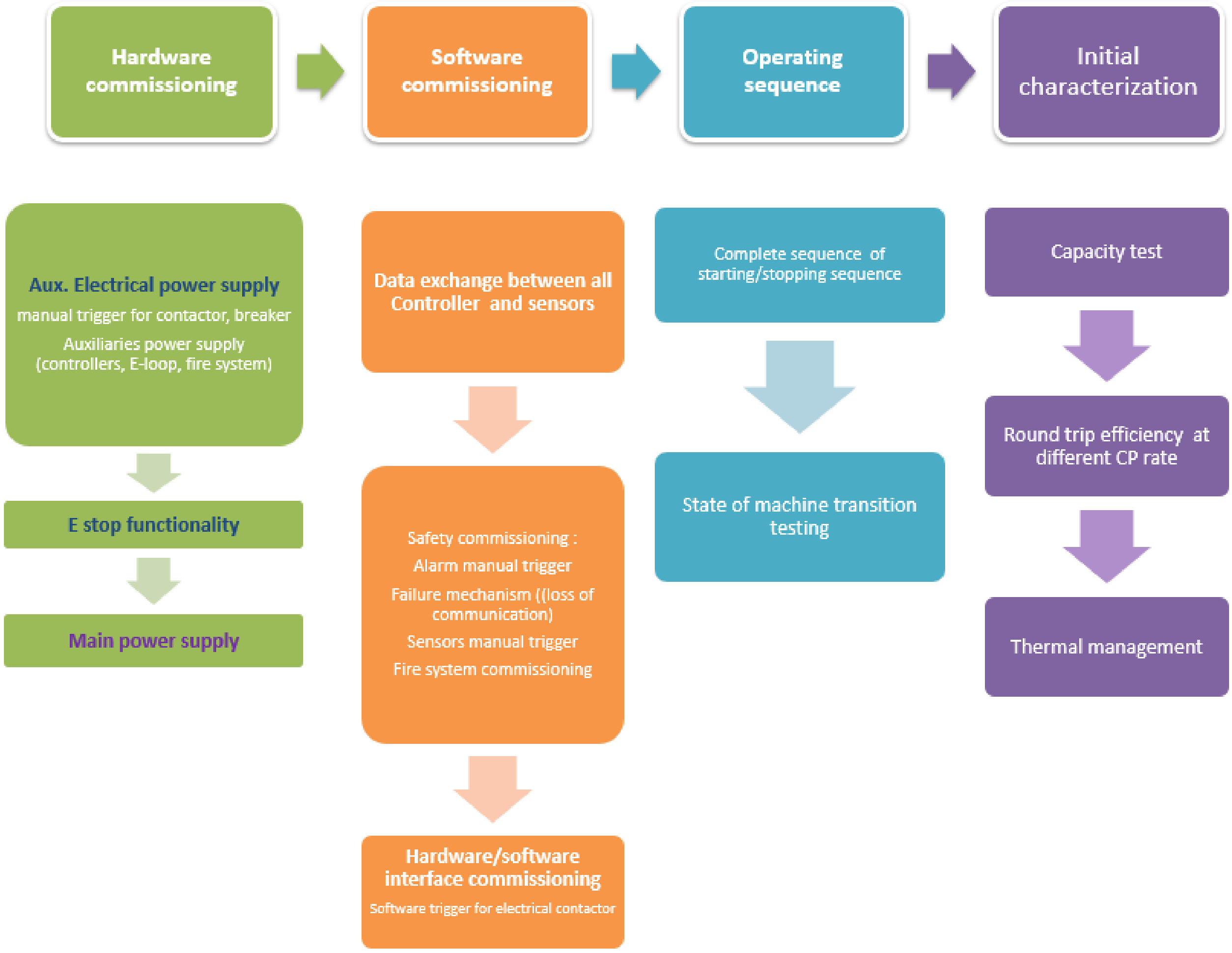

Figure 2 – Organigram of the commissioning

As a reminder, deliverable D1.1 stated that the emergency loop should work as normal when closed, which means that as long as the voltage is not equal to 48V DC, the loop triggers the opening of the main AC and DC contactors. As a result, the auxiliary power supply is the very beginning of the commissioning.

2.1.1 Preliminary test

The first step of the commissioning is to supply the auxiliary 400V AC power to the HBESS. As soon as the auxiliary power is supplied, the following components can be accessed:

- 48V DC power supply
- Fire system
- E stop functionality with the 48 DC power supply
- Thermal management system
- All controllers of the system

Once the auxiliaries are supplied, the main priority is to check the emergency loop, allowing to stop the system efficiently in any emergency case.

2.1.1.1 E stop loop

The emergency loop implementation is described in Figure 3. Once the 48DC power supply is working, the E loop can be tested. It means that each individual contact in series in the loop has to be tested. For this matter, the procedure should be:

- The main power supply is switched off (main Circuit Breaker (CB) in the substation is opened and locked)
- The 48V DC power supply is switched on
- All the E contacts are closed manually
- AC contactor and DC contactor are manually closed
- One at a time, the contact from each subsystem is opened, then leading normally to a trip of both AC and DC contactors

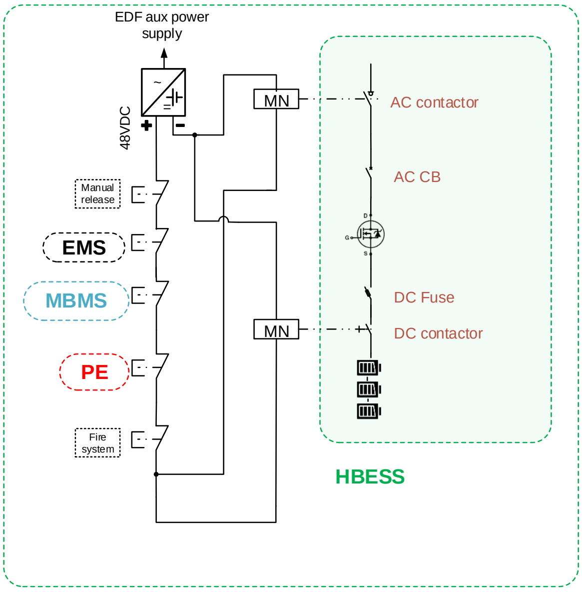

Figure 3 – Emergency loop implementation

Only after the validation of the E stop, the main CB in the substation can be closed.

2.1.1.2 Software commissioning

The second step after the main security protection (E stop) is to commission the complete monitoring of the system, which is taken care of by the software architecture in Figure 4. The goal is to make sure that all communication connections are operational in the first place and then to validate the communication protocol and data exchange table for all the network.

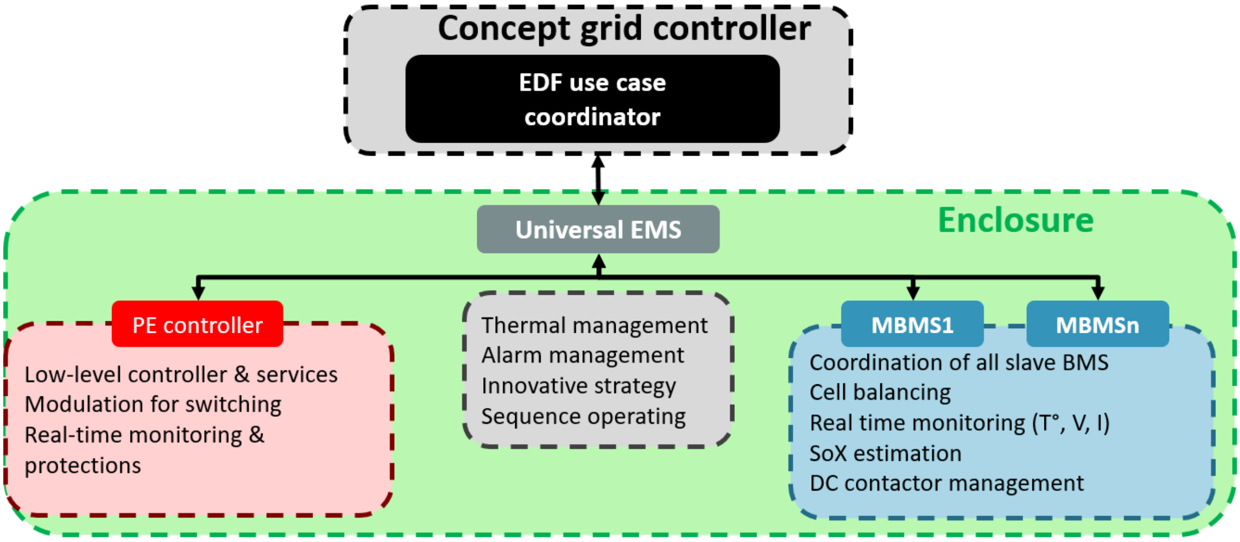

Figure 4 – Sowftare implementation

Communication and data exchange

For each connection the commissioning of the monitoring is described in the sequence below:

- Test of the connection between the EMS and other controller
- Data exchange (write and read) accordingly to the signals described in D1.1
- Loss of communication supervision (watchdog functionalities)
- Self-protection from absurd PPC commands

For this matter, all registers will be checked especially regarding the kind of units used by the different controllers.

Monitoring of the alarms and failure

The second milestone for the commissioning of the monitoring is to check all the alarms, warnings feedback coming from the battery, and power electronics, sensors inside the enclosure used by the EMS for the overall safety management. For this part, the consequences are not already tested, only the information collected is verified.

2.1.2 Commissioning and characterization of the HBESS

In the first part, the basic functionalities were tested individually, without making the complete system work. Once the elementary blocks are operational, a standard sequence of operation can be tested. As described in Figure 5 the EMS can operate within several modes of operation called state machines.

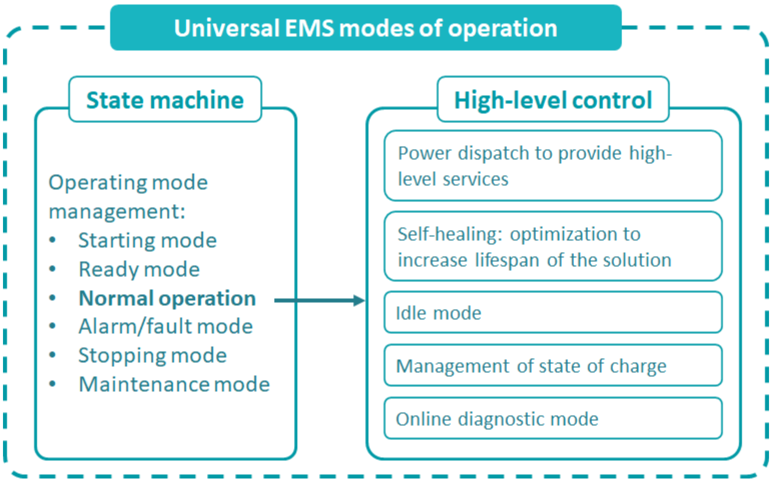

Figure 5 – State machine of the EMS

Over the process of a standard sequence, the EMS will coordinate the action and information coming from all the components to switch from one state machine to another.

State machine and alarm management

Acting as the coordinator of the HBESS, the EMS has a specific role to play in terms of safety. It is responsible for the management of the different levels of alarms described in D1.1. The main goal of this control is to make sure that the EMS monitors correctly all the alarms coming from the sub systems and sensors and can react according to the level of alarms (warning, alarm, critical alarm, and E stop).

All the individual mechanisms have already been tested separately. The point of this is to check that the system state machine goes as designed. Especially, unexpected restarts will be considered since it is expected from the HBESS to wait for a specific order to restart after an issue.

According to this, the flow chart in Figure 6 summarizes the sequence of tests done in the commissioning phase.

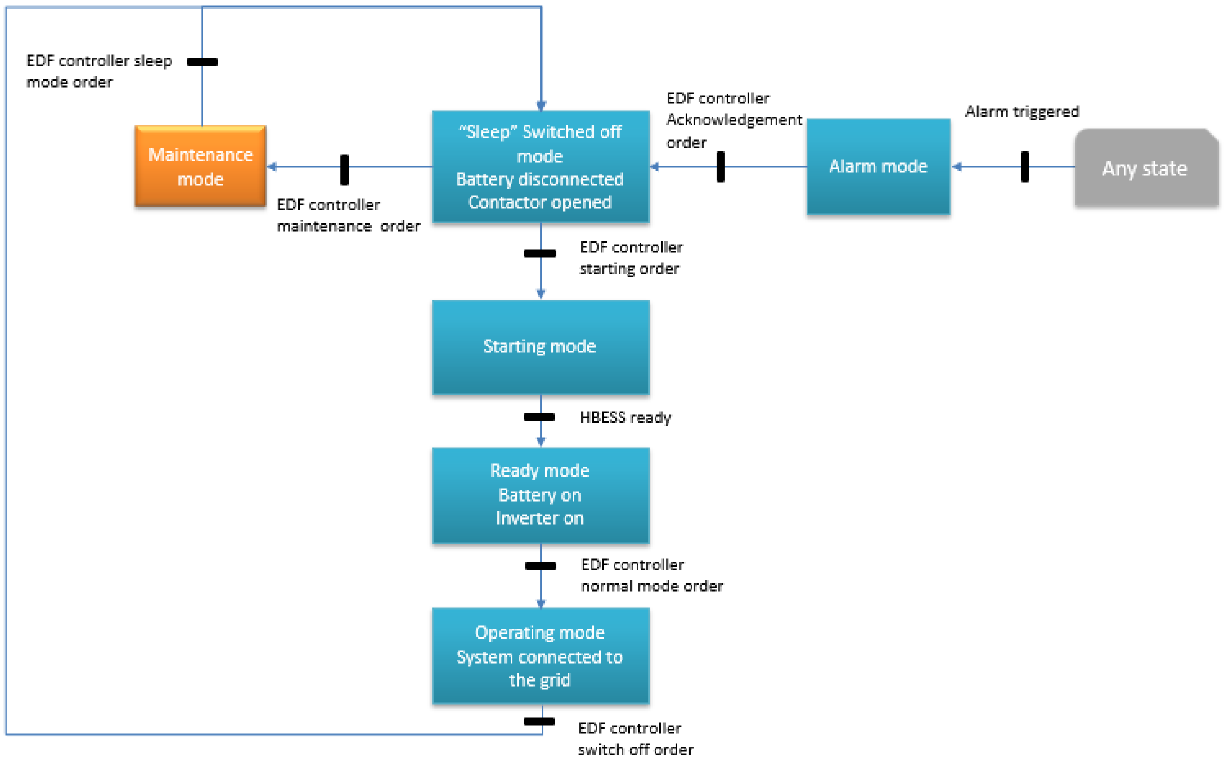

Figure 6 – State machine and alarm management

During this phase, the different levels of alarms will be tested, and the actions taken by the EMS should comply with the requirements defined earlier in the project.

Initial characterization of the complete system

The last part of the commissioning purpose is to fully characterize the behavior of the HBESS in terms of total capacity, round-trip efficiency, dynamic behavior, and thermal management under operation. The ageing analysis will be considered as well. Several cycles of full charge/discharge will be done at different C rate providing a detailed picture of the behavior of the HBESS at the beginning of the project. This procedure will be repeated at the very end of the project. Due to the limited time of demonstration and limited number of cycles, the ageing and lifetime will be analysed mainly in simulation with the support of these experimental data.

2.2 Testing protocols for the Power Electronics interface

A general Power Electronics (PE) interface will be developed to define the interfacing with the rest of the hybrid energy storage system. The interface will be developed in WP3 based on the specifications and requirements defined in WP1. The testing protocols overview in this section is defined to guarantee that the performance and communication requirements are met, based on available standards and methods.

2.2.1 Committees and regulatory organizations for standard PE testing protocols

Committees and regulatory organizations responsible for preparing standard power electronics testing protocols are listed below, as depicted in Table 1.

Table 1 Name of the committees and regulatory organizations according to their location.

Name of the organization	EU region	Worldwide
European Centre for Power Electronics	✓	
European Committee of Manufacturers of Electrical Machines and Power Electronics	✓	
European Committee of Electrotechnical Standardization	✓	
European Power Electronics and Drives Association	✓	
Institute of Electrical and Electronics Engineers		✓
International Electrotechnical Commission		✓
Electronics Standards - ASTM International		✓
JEDEC Solid State Technology Association	USA only	

2.2.2 Summary of requirements

iSTORMY aims to develop a wide-band-gap-based (e.g., SiC) modular PE interface to connect the different battery modules for offering a higher battery redundant operation (e.g., replacement or maintenance of battery modules).

The general architecture of PE interface is shown in Figure 7 together with the communication signals between the PE interface and the universal EMS. These signals are further detailed in D1.1.

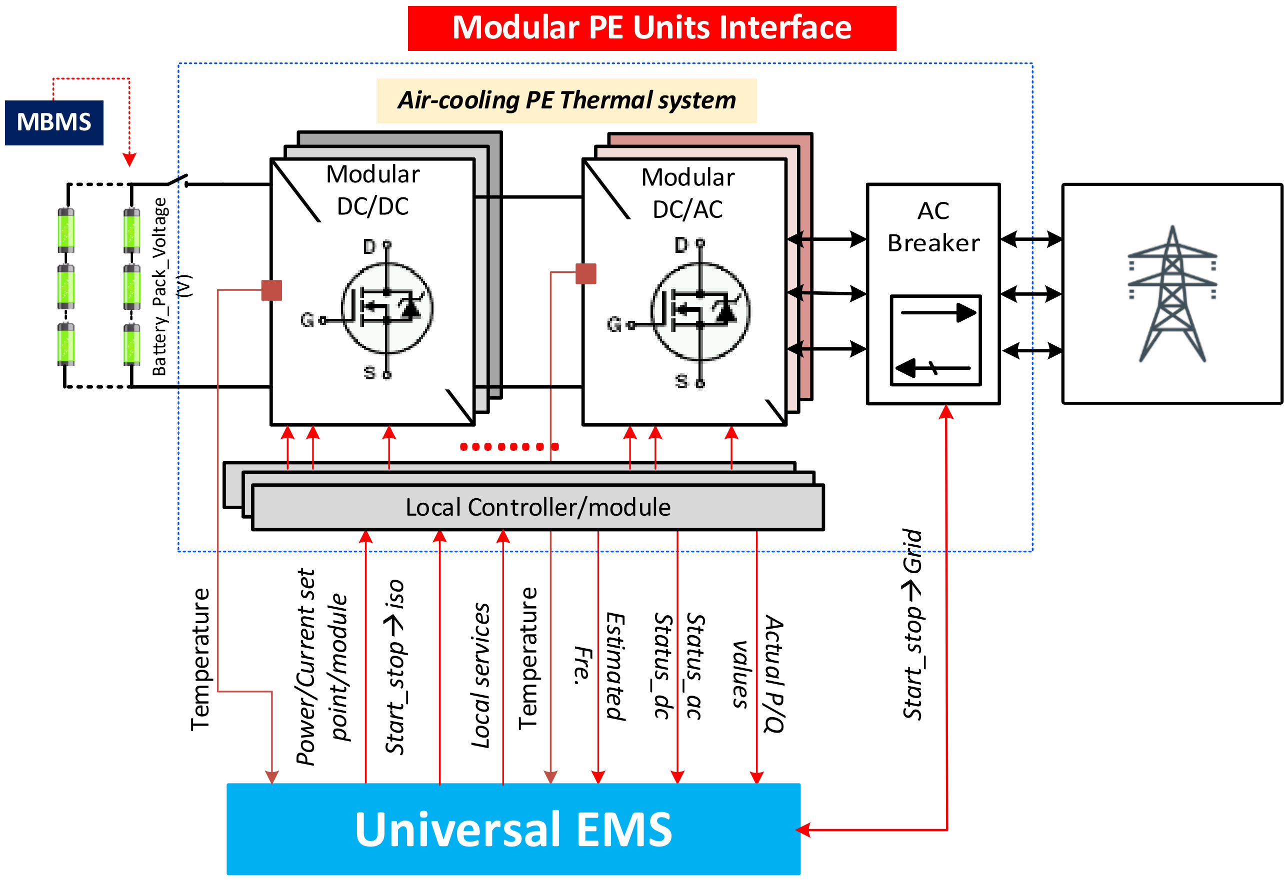

Figure 7 – Overall system architecture of the Modular PE interface with both logical (red) and physical (black) interface connectivity

The main system specifications and constraints to be verified with the testing protocols are specified below:

- Total Power rating: 100kW
- AC side: 3-phase without neutral, 400V ±10%, 50Hz ±3Hz
- Battery stack voltage range: 200 V – 400 V
- Ambient temperature range : -10°C to 40°C
- Industrial grid requirements: Total Harmonic Distortion < 5%, *EMC following IEC and EN standards*
- Power electronics interface efficiency (input to output, half to full power) ≥ 98%*98% (dc/dc and dc/ac stage)
- Local controller response time: Faster than 1 sec

The developed PE interface will be modular, based on 2 system configurations:

1. Integrated DC to AC modules developed by PT with galvanic isolation.
2. Separate DC/DC and DC/AC modules developed by ZIG with a DC link voltage between 700 V – 800 V.

As a summary, the requirements of the PE interface are shown in Figure 8.

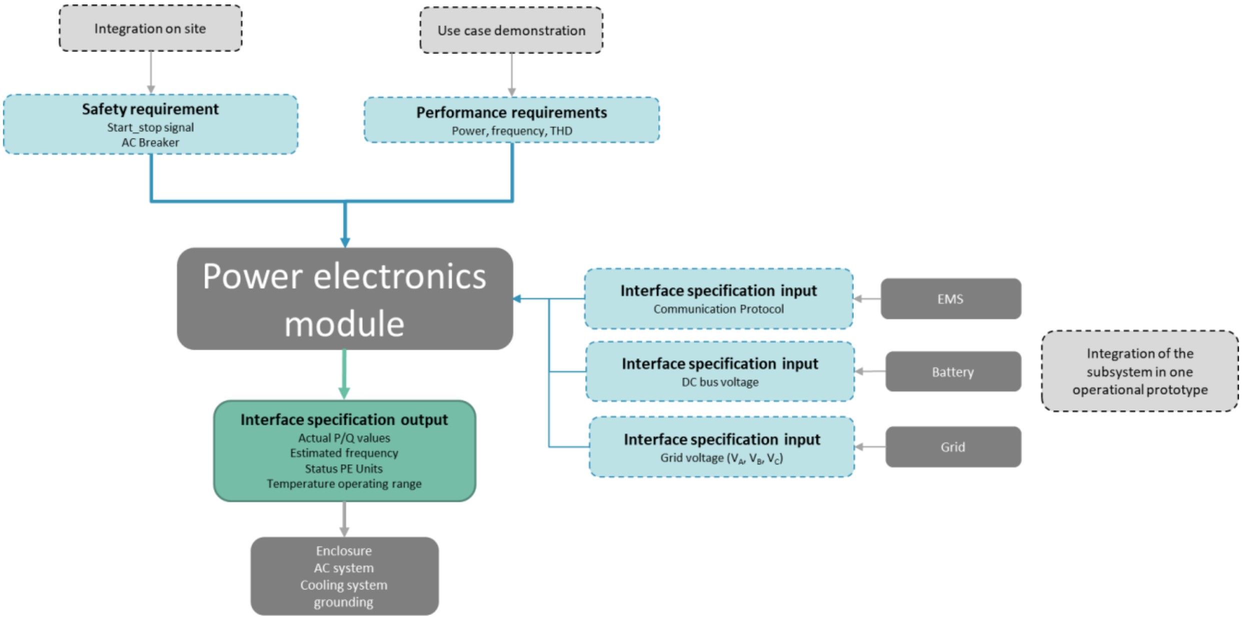

Figure 8 – Power-electronics input/output specification

2.2.3 Description of testing protocols

The following protocols will be used to ensure the PE interface requirements are met in terms of performance, communication with other subsystems and safety. The table below shows the standard reference for the test, the objective of the test, the technique used, the test conditions and the scenario - simulation and hardware-in-the-loop (SH), test bench (TB) or real test (RT)-conditions. These will be considered both for PT and ZIG prototype testing, following the indications in Table 2 below.

Table 2 Testing protocols for the PE interface

Power Electronics interface – PT and ZIG					**Test scenario**		
#	**Standard Ref**	**Requirement / Goal**	**Technique**	**Test Condition**	**SH**	**TB**	**RT**
1	NA	Hardware LV sub-circuit electrical qualification	Apply Low voltage supplies and check performance against design requirements	PT labs, lab table / ZIG lab		x	
2	NA	Debug Communication interface	Connect a debug tool and check the debug communication features	PT labs, lab table / ZIG lab		x	
3	NA	Galvanic isolation test	Apply the required HV test voltage between the HV circuits and the SELV circuits and check for leakage currents	PT labs, safety room / ZIG lab		x	
4	NA	Hardware HV sub-circuit electrical qualification	Apply Low voltage supplies and apply the required HV voltages or currents and check performance against design requirements	PT labs, safety room / ZIG lab		x	
5	NA	Hardware protection circuits	Apply Low voltage supplies and force all protection circuits to trip and check the trip levels against design requirements	PT labs, safety room / ZIG lab		x	

6	NA	Control software at low voltage	Connect the PE between a bidirectional DC power supply and an AC source, both at low voltage (SELV) and verify the correct functioning of the control software	PT labs, lab table / ZIG lab		x	
7	NA	Control software at nominal voltage	Connect the PE between a bidirectional DC power supply (200-400V/25kW) and an AC source (400V/25kVA), and verify the correct functioning of the control software	PT labs, safety room / ZIG lab		x	
8	NA	Grid current THD	Connect the PE between a bidirectional DC power supply (200-400V/25kW) and an AC source (400V/25kVA), and verify the THD with a spectrum analyser.	PT labs, safety room / ZIG lab		x	
9	NA	Input to output Efficiency	Connect the PE between a bidirectional DC power supply (200-400V/25kW) and an AC source (400V/25kVA), and measure the input and output power with a power analyser.	PT labs, safety room / ZIG lab		x	
10	NA	Local controller response time	Connect the PE between a bidirectional DC power supply (200-400V/25kW) and an AC source (400V/25kVA), and measure the response time of the local controller under different battery and grid conditions.	PT labs, safety room / ZIG lab		x	
11	NA	Parallel operation	Connect two PE modules in parallel (back-back) between a bidirectional DC power supply (200-400V/3kW) and an AC source (400V/3kVA), and let the energy flow between the two modules.	PT labs / ZIG lab		x	
12	NA	HESS operation	Integrate the PE interface in the HESS system and let the EMS operate the PE in different operating points	EDF Concept Grid			x
13	EN 62116	Islanding prevention measures	While inverter is injecting/consuming power, disconnect mains. Islanded grid load to be adjusted to be higher or lower than PE injecting power. Verify islanding prevention mechanism.	ZIG lab		x	
14	2016/631	LVRT	Low Voltage Ride Through reactive current injection verification	ZIG lab		x	
15	2016/631 IEC 62933-2-1	Rated voltage and frequency range test	Verification the stable operation of PE in all voltage and frequency range.	ZIG lab		x	
16	IEC 62477-1	Thermal test	Verification of thermal performance of critical devices (semiconductors, magnetic components and capacitors)	ZIG lab		x	
17	TBD	Communications with EMS	Emulate EMS and verify PE ←→ EMS communication protocol.	ZIG lab		x	

2.3 Testing protocols for the self-healing EMS platform

The self-healing EMS platform can be seen as the brain of the HBESS as it controls the different components and hosts the main functionalities that will lead to increased reliability and lifetime for the system together with lower cost. The requirements and functionalities of the software and hardware EMS in order to optimize the operation of the system are extensively defined in D1.1. It is crucial for the EMS platform to meet the performance targets and ensure proper communication and exchange of information with the PE interface, the battery system through a Master BMS, the cloud for computing the data and the Concept Grid platform.

As shown in Figure 9, 3 communication protocols are used:
1) Modbus TCP – Concept grid and EMS
2) CAN – MBMS and EMS / PE Controller and EMS
3) REST API – EMS and cloud

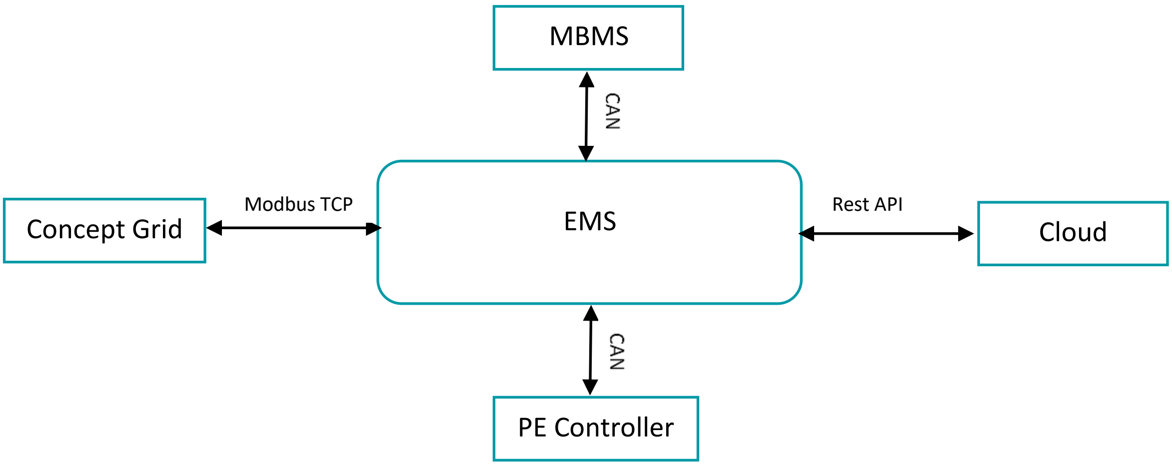

Figure 9 – Communication protocols used between the EMS and the other system components

2.3.1 Testing of communication protocols

The communication protocols will be tested following the test descriptions in Table 3.

Table 3 Test description for the EMS communication protocols

PROTOCOL	TEST CASES	TEST DESCRIPTION
CAN	Correctness by type	To send the data to the module and to check if acknowledgement is received
	Correctness by value	To send a dummy data to the module and check at the module if same data is received.
	Bandwidth	To check the no of data sent per second

	Latency	To check the time taken by dummy data to transit the system
MODBUS	Correctness by type	To send the data to the module and to check if acknowledgement is received
	Correctness by value	To send a dummy data to the module and check at the module if same data is received.
	Bandwidth	To check the no of data sent per second
	Latency	To check the time taken by dummy data to transit the system
REST	Correctness	To check if the EMS send value to cloud after receiving some input from module
	Idle	To check whether the EMS sends any data to cloud in case it is not receiving any data from modules.
	Functionality	To check if an event is triggered when EMS receives data from other modules or from cloud
		To check when EMS forwards a data to cloud, the data on the cloud is updated

2.3.2 Characterization of EMS functionalities and performances

The characteristics of the EMS incl. functionalities and performances (speed, scalability, etc.) will be tested following the tests described in Table 4.

Table 4 Test description for characterizing the EMS

TEST CATEGORIES	TEST CASE	TEST DESCRIPTION
Functional Testing	Simulation model validation	To simulate the EMS algorithm on a hardware simulator
	Software Simulation by Python	To simulate the EMS algorithm on python simulator
	Verification using dummy data	To check the functional behaviour of EMS (hardware and software) after providing dummy data
	Verification using actual data	To check the behaviour of the system by connecting it to all modules
	Error handling	To check whether the system identifies the error correctly and then take actions accordingly
	System Restart	To check the behaviour of the system in case of restart
	communication failure	To check the how the system responds when the communication between EMS and module is failed

Components Testing	Device hardware	To check if all the devices are connected properly
	Cloud Infrastructure	To check If the cloud server is up and running.
Performance Testing	Data transmission rate	To check if the data transmission rate is less than or equal to 1 sec.
	Multiple request handling	To check if data is sent/received to/from modules to EMS simultaneously
Communication Testing	Stress testing	To check the behaviour of the EMS when maximum data is sent to EMS from different modules.
	Interoperability	To check protocol communication between EMS and different modules.

2.4 Testing protocols for the battery pack system.

A battery pack system will be developed with new and used battery cells as part of the hybrid energy storage system. The battery pack system will be developed in WP2 based on the specifications and requirements defined in WP1. The testing protocols overview in this section is defined to qualify the functionality and performance of the battery pack system. The testing protocols are split into two parts: the performance checking procedures and the specific measurement and validation plan

2.4.1 Performance checking procedures

The procedure for checking the performance of the battery system is the following:

- Checking of capacity.
- Checking of correct discharge current from installation.
- Checking of discharge current with installation charges.
- Checking of SoC during one cycle of charge and discharge.
- Checking of the error in the measurement of current as well as bus voltage.
- Calculating of the charge and discharge efficiency.
- In particular, for the BMS the procedures are defined in Table 5

Table 5 Test description for advanced BMS software

Test Categories	Test Case	Test Description
Functional Testing Active Battery Diagnostics	MBMS-EMS communication	Activate the battery diagnostic algorithm and check if the messages sent between the MBMS and EMS are being sent and replied to correctly.
	Periodic diagnostic cycles	Activate the battery diagnostic algorithm and allow a diagnostic cycle to finish. Check if the algorithm runs autonomously and whether the information is correctly processed and sent to the passport.
	Non-nominal operation	As far as is safely possible, test the response of the diagnostic algorithm to interrupted signals, communications breakdown and emergency shutdown signals.

Performance Testing Active Battery Diagnostics	Measurement robustness	Run repeated diagnostics cycles back-to-back to measure accuracy and precision
	Post processing results	Run a diagnostic cycle and compare the accuracy/fidelity of the raw measurement data with the post processed data sent to the passport.
Functional Testing Battery Electronic Passport	Data storage	Run a diagnostic cycle and check whether the data is being stored correctly in the passport. Measure the size of the memory required.
	Accessibility	Can the data in the battery passport be retrieved/accessed from outside the system?
Performance testing Remaining Useful Life Algorithm	Accuracy	Access the data in the battery passport and run the RUL algorithm offline to assess its accuracy.

2.4.2 Specific measurement and validation plan

The validation plan for the battery system is the following:

- Capacity vs. cycles evolution.
- Temperature and capacity analysis vs. total harmonic distortion of DC signal.
- Thermal analysis of the modules vs. current.
- Analysis of the evolution of imbalance between cells.

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Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	PWD	POWERDALE
3	CEG	CEGASA ENERGIA S.L.U.
4	CEA	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
5	MGEP	MONDRAGON GOI ESKOLA POLITEKNIKOA JOSE MARIA ARIZMENDIARRIETA S COOP
6	ZIG	ZIGOR RESEARCH & DEVELOPMENT AIE
7	EDF	ELECTRICITE DE FRANCE
8	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
9	PT	PRODRIVE TECHNOLOGIES BV
10	GW	GREENWAY INFRASTRUCTURE SRO
11	AIT	AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH
12	UNR	UNIRESEARCH BV

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