REMOTE

Project n° 779541

"Remote area Energy supply with Multiple Options for integrated hydrogen-based Technologies"

Deliverable number 3.4

General indications concerning the engineering and permitting procedures of H2-based energy storage systems

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Abstract:

This document is the deliverable of Work Package 3. As such, this document contains general and common indications concerning the engineering and the regulatory framework of H2-based energy storage systems that will be installed by three different users in Southern EU. The document covers:

a) General description of the system and its auxiliaries

b) Standards and directive applied

c) Hazard identification

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Contents

1 List of Abbreviations

Reference	Description
EPS	Electro Power Systems
Hazid	Hazard Identification
H_2ESS	Hydrogen Energy Storage System
P2P	Power to Power
P2G	Power to gas
G2P	Gas to Power
PCS	Power Conversion System
MD	Machine Directive
LVD	Low Voltage Directive
PED	Pressure Equipment Directive
CHP	Combined Heat and Power
HVAC	Heating Ventilation and air condition
HMI	Human machine interface
AC/DC	Rectifier
DC/AC	Inverter
PEM	Polymer Electrolyte Membrane
HPP	Hybrid Power Plant
BES	Battery Energy Storage
EMS	Energy Management System
EMI	Electromagnetic Interference
HPP	Hybrid Power Plant
BOL	Beginning of Life
EOL	End of Life
RES	Renewable Energy Sourses
DG	Diesel Generator
PV	Photovoltaic plant

2 Introduction

2.1 Scope and context

This report presents results from the Task 3.3, whose main objective is to collect information about the design, engineering, and permitting process for DEMO 1, 2 and 3.

This document contains:

- System general description
- System concept design
- Regulations framework
- Hazard Identification
- Demos Description

The work has been led by EPS Elvi Energy Srl (EPS).

3 Plant Description

3.1 System Description

3.1.1 Equipment Description

Subject of the project is the supply of H2 energy storage system that will composed by the components and systems outlined below:

- Gas-To-Power module («**G2P**»): PEM fuel cell system used to produce electrical energy from hydrogen
- Power-To-Gas («**P2G**»): Alkaline electrolyzer used to produce hydrogen from electrical energy
- Pressure vessels: Steel tank to store produced gas (Hydrogen and Oxygen)
- Power conversion systems («**PCS**»): Power converters to allow the integration of each submodules according their requirements
- Batteries: Used to provide energy during the start-up of the system and to allow grid services (Voltage and frequency regulation)

The following schematic shows the general configuration of the main components of the plants.

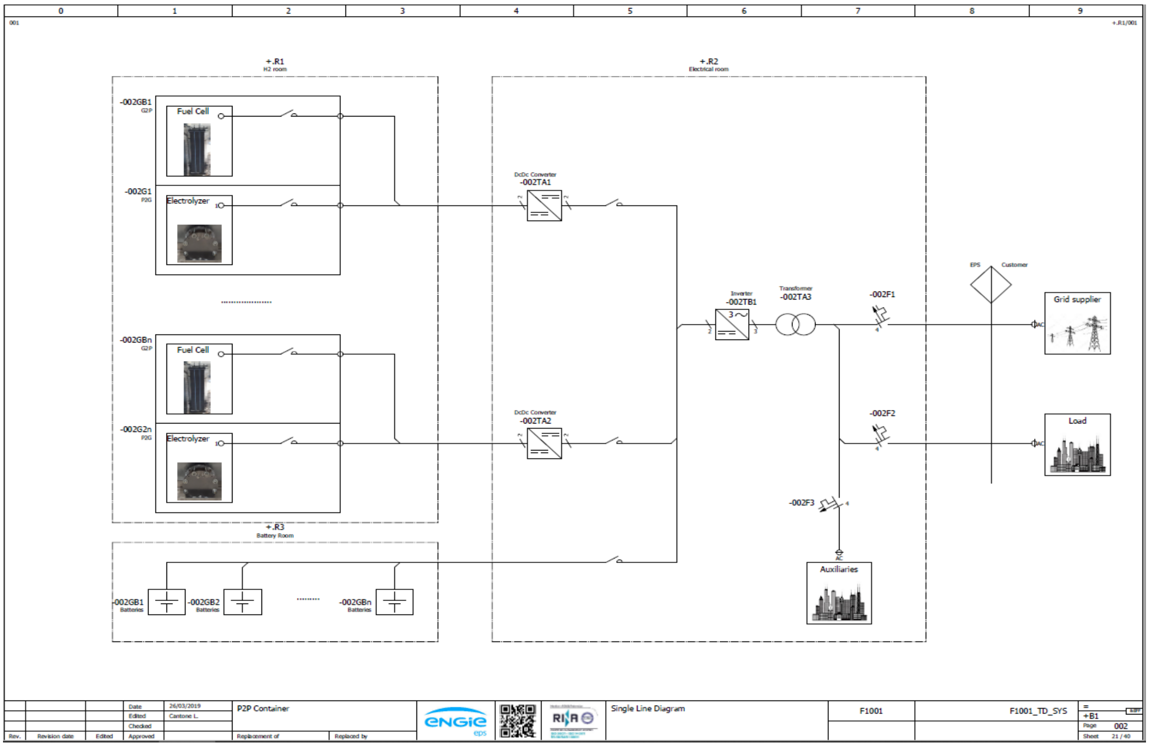


Figure 1: Single Line Diagram

3.1.2 Subsystem's description

P2P Module

The P2P module is conceptually identical to a battery: it stores energy that is produced by a renewable source or that comes from the grid (by the P2G), and supplies it upon load's demand, when the primary power source is not available or insufficient (by the G2P).

The P2G module consists in an advanced hydrogen generator (P2G – Power-to-Gas) that re-establishes the hydrogen reserve on site by using electricity and pure water.

The G2P module consists in a PEM Fuel Cell that will provide electrical energy to the load if requested. According the technology used, the G2P could be air or oxygen fed. While the oxygen technology allows to reach higher power density and efficiencies of the system, it requires an additional storage system and consequently extra costs.

The P2P module is specifically designed to provide an energy intensive storage solution for blackouts or off-grid applications, granting high reliability and low maintenance costs by eliminating fuel logistics.

It has 3 working modes:

- Hydrogen production: when the grid/renewable source is available, the P2G module generates and stores hydrogen and oxygen in pressurized vessels, converting the electricity from the grid or the renewable sources available and using the water generated during the power production mode;
- Power production: when it is requested, the G2P module generates power converting the stored hydrogen and oxygen and produces water;
- Stand-by: when the grid/renewable source is available and the storage is full, the equipment simply stands-by.

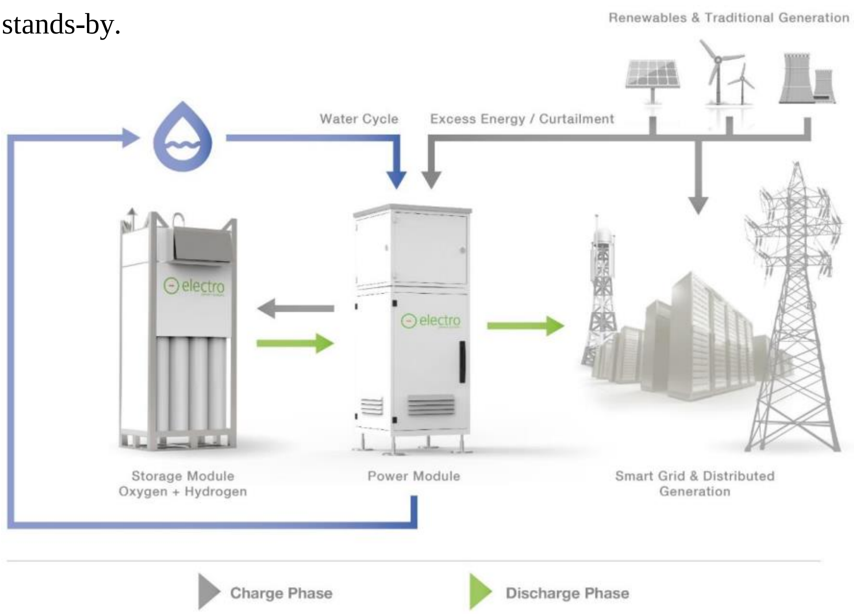


Figure 2: P2P Flow chart

C-HPP125

The C-HPP125 is a bidirectional inverter with an integrated chopper for the integration of photovoltaic plant. The converter as a part of the Hybrid Power Plant (HPP) system is capable to generate electricity from a renewable energy source and a conventional, fossil fuel fed generator, typically a diesel generating set. The HPP is usually equipped with a Battery Energy Storage (BES).

The HPP can operate parallel connected to the main grid (on-grid operation), stand-alone (off-grid operation) or connected to a micro grid, with other generators working in parallel (grid supporting mode, with droop control).

It is practical that the same HPP can function in these three different modes of operation and that the suitable control strategy is either automatically selected by an Energy Management System (EMS), or by the operator.

EPS inverter control allows to implement all these different modes of operation.

EPS HPP Conversion and Control cabinets are suitable for indoor operation, with forced air cooling.

The block diagram of C-HPP125 cabinet is shown in Figure 3.

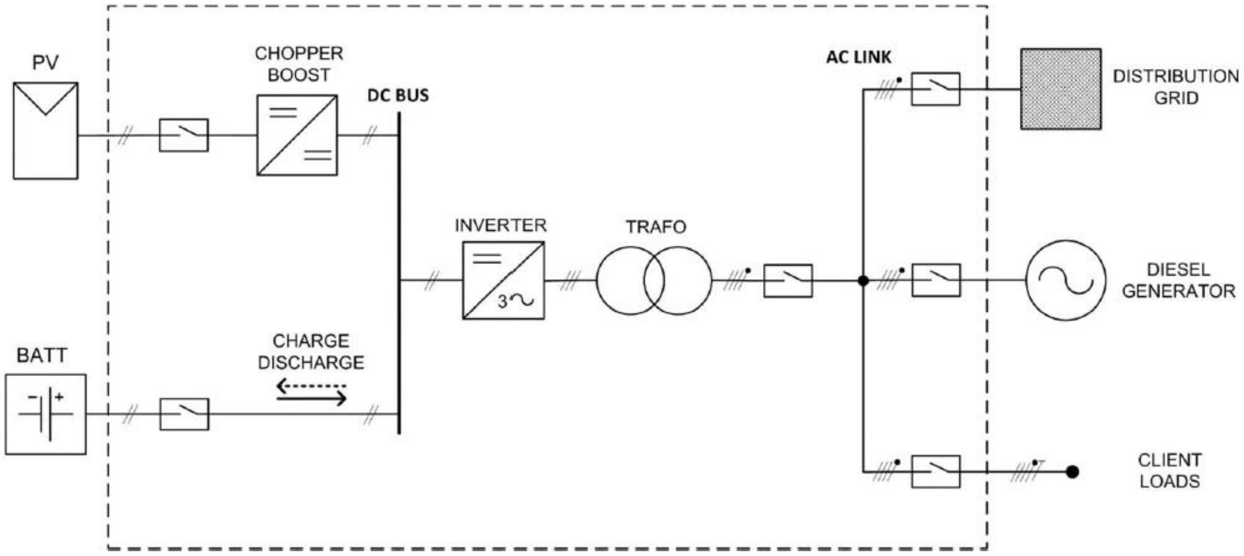


Figure 3: Block Diagram of C-HPP125

DcDc Converters

DC-to-DC converter is an electronic device that converts a source of direct current (DC) from one voltage level to another allowing the integration of the oxygen fed P2P (that operates in a voltage range of 50-100Vdc) with batteries (that operate in a voltage range of 630-850Vdc). Due to the high voltage ratio requested for the conversion, it is adopted a solution with an integrated transformer. The following figure shows an example of this kind of converter. The transformer has also the advantage to isolate electrically the P2P circuit with the battery ones avoiding straight currents that could reduce the lifetime of the electrochemical devices.

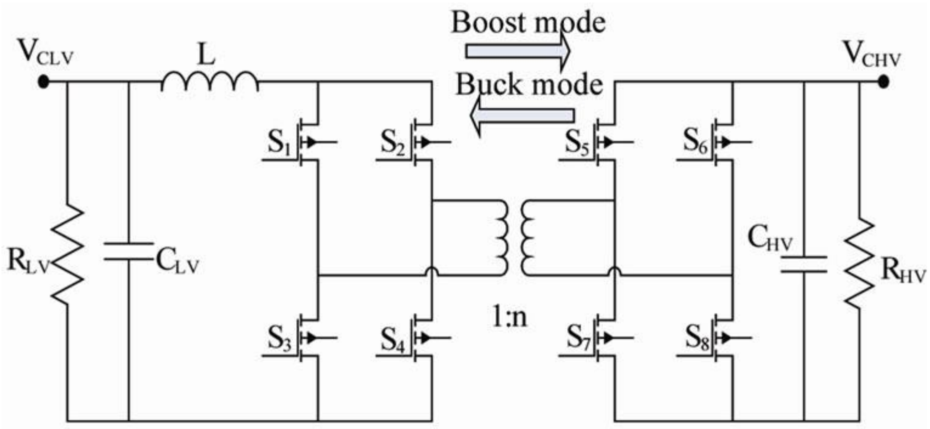


Figure 4: DcDc converter topology (Example)

For the air fed technology, the fuel stack used will operate form 280 to 420Vdc. As a consequence, the converter described above won't be suitable for the integration of the fuel cell with the batteries. However, the voltage ratio is low enough to allow the connection of the fuel cell directly to the chopper of the C-HPP125 instead of the photovoltaic plant.

Storage Tanks

The storage tanks are used to store hydrogen and oxygen produced by the P2G module and used by the G2P module. The maximum storage pressure is 30 bar. The tank is equipped with overpressure safety valve, manometer and certificate of conformity, according to the PED directive.

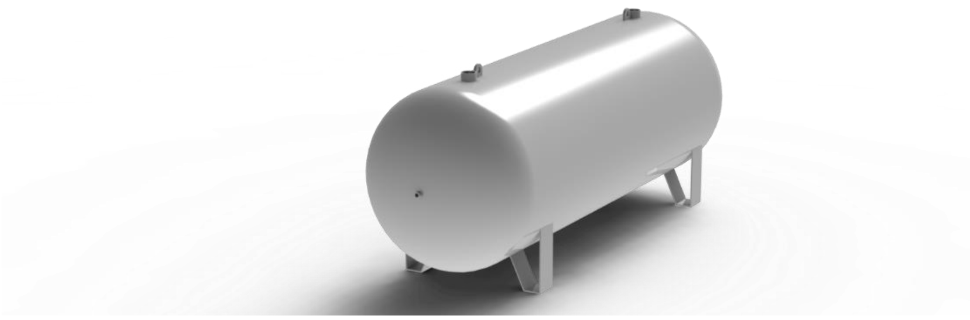


Figure 5: Example of storage tank

Batteries

The Batteries used in this project refer to Li-ion technology and they are used to stabilize the common DC-Bus in which the P2P systems are connected. They also allow the system rapid change of power absorbed/generated in order to properly manage the voltage and frequency regulation in case of off-grid application.

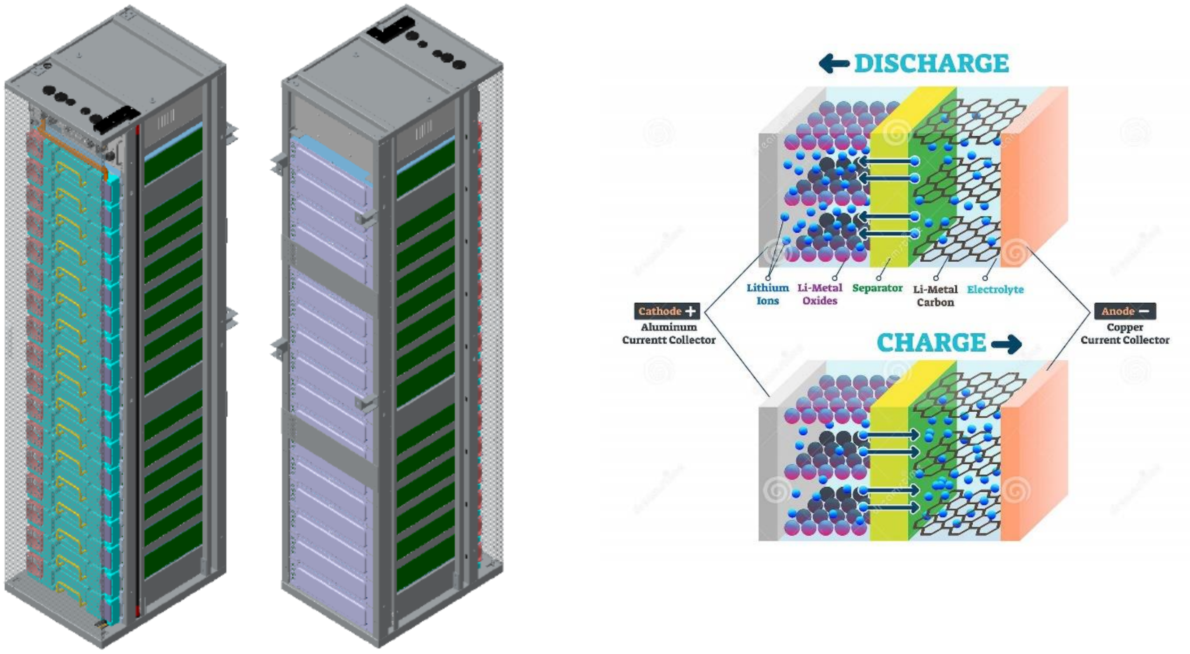


Figure 6: Li Ion Batteries

3.2 Auxiliaries systems

For the proper operation of the plant, some auxiliaries are needed in order to satisfy the requirements of the subsystem. In particular, the following subsystems are required:

1. HT Cooling System: To provide cooling flow to P2P modules and to control their temperature through the dissipation of the generated thermal power
2. LT Cooling System: For the dehumidification of the gas produced
3. HVAC and Heater: To manage the ambient temperature of the rooms where the systems are installed
4. Demi Plant: To provide water to the electrolyzer at the required purity
5. Pressure reducers: To provide hydrogen and oxygen at a stable and limited pressure
6. Safety Systems

3.2.1 HT Cooling System

The HT Cooling System dissipate the heat generated by the P2P system due to its inefficiencies in order to manage and control its temperature. This system consists in a liquid/air heat exchanger properly sized for the purpose.

Figure 7: Dry Cooler

3.2.2 LT Cooling System

The LT cooling system consists in a chiller that provides cold water (about 5°C) used to cool down the outlet gas temperature in order to reduce the water content of the produced gas.

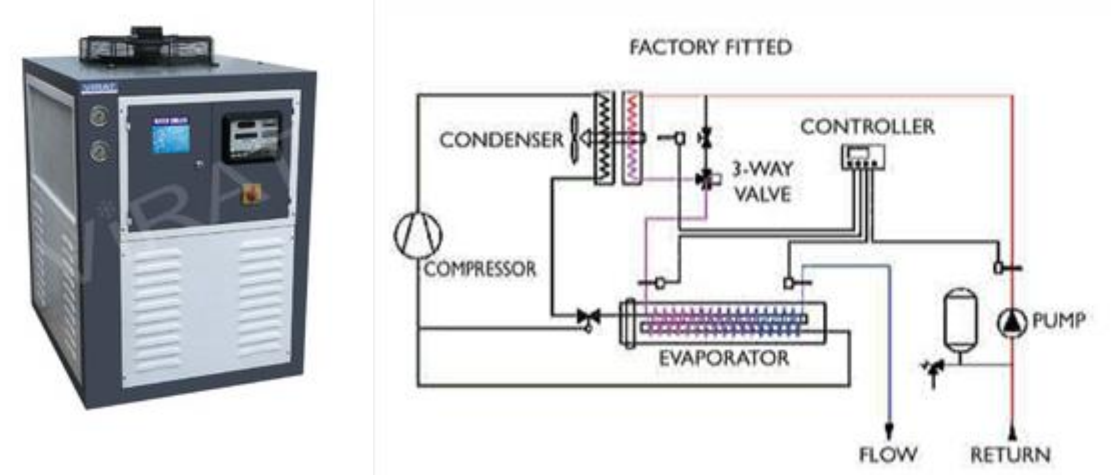


Figure 8: Example of Chiller

3.2.3 HVAC and Heater

These systems are sized in order to guarantee, for all the components installed in the plant, a proper operation according their requirements, avoiding problems generated by freezing and/or overtemperatures.

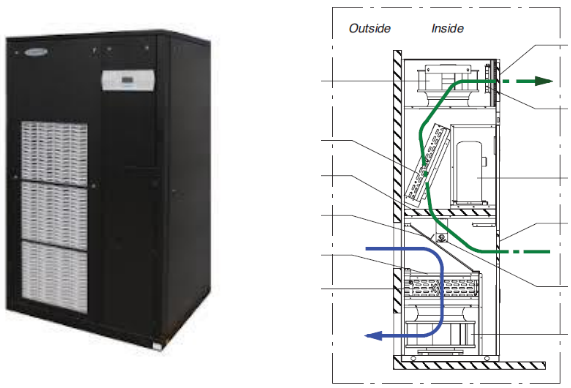


Figure 9: HVAC example

3.2.4 Demineralizing Water System

The Demineralizing water system removes mineral salts from tap water in order to be compatible with the electrolytic process of the P2G module. The system provides the water required by the process and will automatically refill the demineralized water tank inside the H2 room. It consists in an Ion-exchange resins column. This technology is the chosen one as it allows to reduce the water consumption as low as possible.

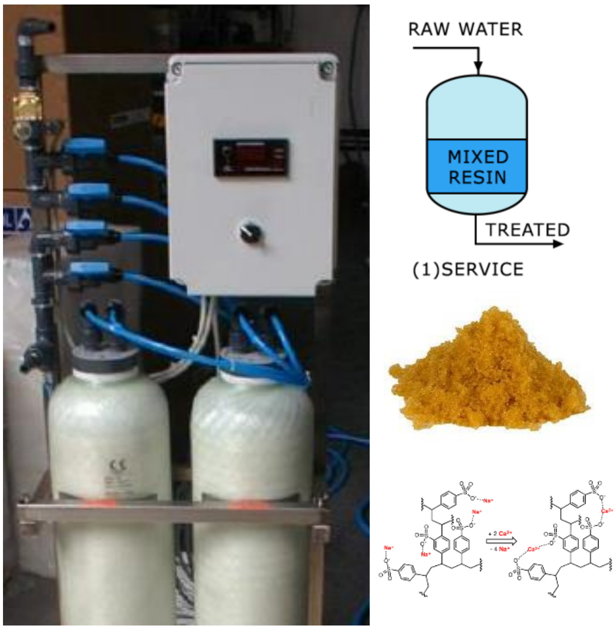


Figure 10: Example of demineralising water system

3.3 Input, Output and Waste

3.3.1 Inputs of the system

Water: the system is fed with tap water which has to be filtered with a filter of about 100 µm. Nominal consumption is 1 L/Nm^3 of H_2 produced.
Electricity: the P2G module is the main component in term of consumption and it is connected to the AC grid through one or more power conversion system according the plant topology defined for each installation (400VAC; +10% / -15%).

3.3.2 Outputs of the system

Heat: the main source is represented by the heat generated due to the inefficiencies of G2P modules (each application realized in the project is defined to reach an electrical output of 50kW from the G2P). As a consequence, the heat produced is around 80kWth at maximum power at EOL. Heat is removed with a water and glycol circuit and an external cooling system. Part of the heat generated will be used to heat the H2 room during cold seasons.
Gas: H2 and O2 produced by the P2G module are stored in two storage tanks. Gases are then used to feed the G2P modules to produce electrical energy. Note that for air application the oxygen will be vented directly to atmosphere
Electricity: The system output can be connected to the grid or to the AC load by the C-HPP inverter (400VAC; +10% / -15%), which manages the DC bus (battery and P2P modules) and the AC connection.

3.3.3 Waste of the system

Purges: both G2P and P2G purge H2 gas and O2 gas during normal operation modes. Purges should be vented outside the container to a safe area according to the Hazardous area evaluation which will be carried out by EPS (usually 1 m above the roof of the P2P container).
Used KOH solution (maintenance): the P2G module is filled with a KOH solution (30%), the solution must be replaced every year during ordinary maintenance. The module is provided with a tub to avoid KOH leakage in case of damages or ruptures.
Resins (maintenance): The Demineralizing water system is provided with a cartridge of strong anionic and cationic resins in mixed bed. The cartridge should be changed when exhaust, depending on input water hardness. It could be regenerated.

The equipment will be connected to the external systems as indicated in the following Tables.

Connection	Description
Grid Connection	125 kW 3P+N+PE (400VAC @50Hz)
Load Connection	50 kW 3P+N+PE (400VAC @50Hz)
Clean Contacts	4x1 cable (EN 60332-1-2, CEI 20-22 II): -External Emergency -System Fault
Remote System Monitoring	Ethernet cable RJ45

Connection	Materials (suggested)	Maximum pressure	Diameter
Water Inlet	Depending on available water connection	5barg	8mm

4 Regulatory framework

The main applicable European legislative/administrative process are:

Directive/legislation	Short description
ATEX Directive 2014/34/EU	Covering equipment and protective systems intended for use in potentially explosive atmospheres. Not specific to hydrogen but it is referred to any fuel that is capable of generating a flammable atmosphere.
Pressure Equipment Directive (97/23/EC)	For the manufacture and conformity assessment of pressure equipment that is subjected to an internal pressure greater than 0.5 bar above atmospheric pressure.
Machinery Directive (Supply of Machinery Safety Regulations)	Applies to machinery and safety components. This would not apply to the fuel cell installation itself but may apply to associated equipment required for operating the installation.
LVD (Low Voltage Directive)	For the manufacture and conformity assessment of electrical equipments.

4.1 Standards applied to the PCSs

Standard	Description
IEC 61000-6-2:2011	Electromagnetic Compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
IEC 61000-6-3:2016	Electromagnetic Compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and ligth-industrial environments
IEC 60076:2015	Power Transformers
IEC 61439-1:2011	Low-voltage switchgear and controlgear assemblies (Low-voltage enclosures) Part 1: General rules
IEC 61439-2:2011	Low-voltage switchgear and controlgear assemblies (Low-voltage enclosures) Part 2: Power switchgear and controlgear assemblies
EN 50178:1998	Electronic equipment for use in power installations
IEC 61378:2011	Converter transformers
IEC 62477-1:2012	Safety requirements for power electronic converter systems and equipment - Part 1: General

4.2 Standards applied to G2P

Standard	Description
IEC 60204-1:2016 “	Safety of machinery – Electrical equipment of machines. Part 1: General requirements”
IEC 61000-6-2:2011	Electromagnetic Compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
IEC 61000-6-3:2016	Electromagnetic Compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and ligth-industrial environments
IEC TS 62282	Fuel cell technologies
ISO/TR 15916	Basic Consideration for safety of hydrogen system

4.3 Standards applied to P2G

Standard	Description
IEC 60204-1:2016 “	Safety of machinery – Electrical equipment of machines. Part 1: General requirements”
IEC 61000-6-2:2011	Electromagnetic Compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
IEC 61000-6-3:2016	Electromagnetic Compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and ligth-industrial environments
ISO 22734-1:2008	Hydrogen generators using water electrolysis process – Part 1: Industrial and commercial applications
UNI EN ISO 13445-3	Unfired pressure vessels - Part 3: Design
EN ISO 4126-1	Safety Devices for protection against excessive pressure – Part 1: Safety valves
ISO/TR 15916	Basic Consideration for safety of hydrogen system

4.4 Standards applied to Storage

Standard	Description
UNI EN ISO 13445-3	Unfired pressure vessels - Part 3: Design
EN ISO 4126-1	Safety Devices for protection against excessive pressure – Part 1: Safety valves
ISO/TR 15916	Basic Consideration for safety of hydrogen system

4.5 Standards applied to the electrical plant

Standard	Description
CEI EN 62477-1	Safety requirements for power electronic converter systems and equipment. Part 1: General requirements
CEI EN 61439	Low-voltage switchgear and controlgear assemblies (Low-voltage enclosures)
CEI EN 60076	Power transformers
CEI EN 61378-1	Converter transformers Part 1: Transformers for industrial applications
CEI EN 61000-3-11	Electromagnetic compatibility (EMC) – Part 3-11: Limits: Limit of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subjected to conditional connection
CEI EN 61000-3-12	Electromagnetic compatibility (EMC) – Part 3-12: Limits: Limit for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase
CEI EN 50178	Electronic equipment for use in power installations
CEI EN 60529	Degrees of protection provided by enclosures (IP code)
CEI EN 60721-3-3	Classification of environmental conditions Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weather protected locations
CEI EN 50160	Voltage characteristics of electricity supplied by public distribution systems
IEC 60364	Low Voltage Electrical Installations

4.6 Standards applied to plant and documentation

The design of the plant is structured in accordance to the Standard ISO/IEC 81346. The standard, published jointly by IEC and ISO, establishes general principles for the structuring of systems including structuring of the information about systems.

Based on these principles, rules and guidance are given for the formulation of unambiguous reference designations for objects in any system.

The reference designation identifies objects for the purpose of creation and retrieval of information about an object, and where realized about its corresponding component.

Each object installed in the plant is defined according three aspects defined in the following way:

- The Location aspect: +

  Where the object can be found

- The function aspect: =

  What the object does or is intended to do

- The product aspect: -

  How the object is constructed

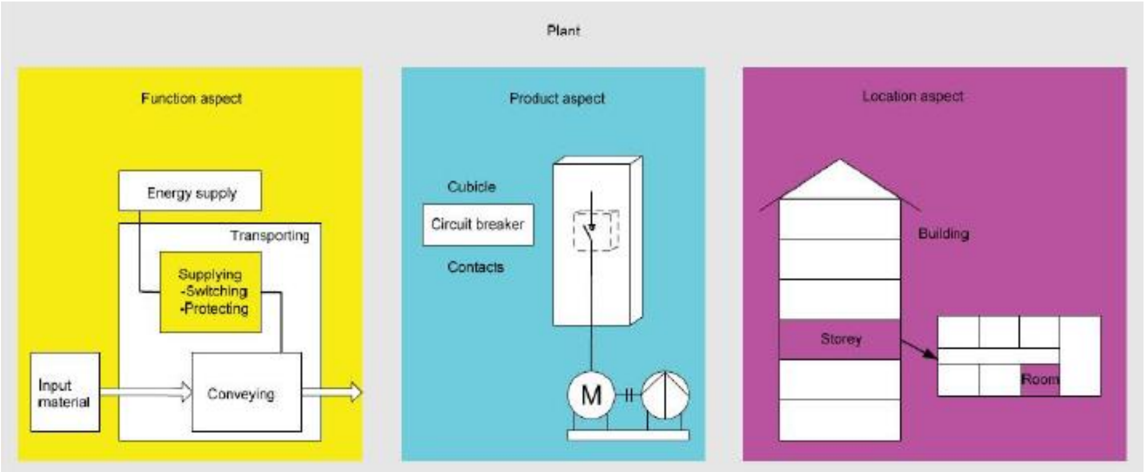
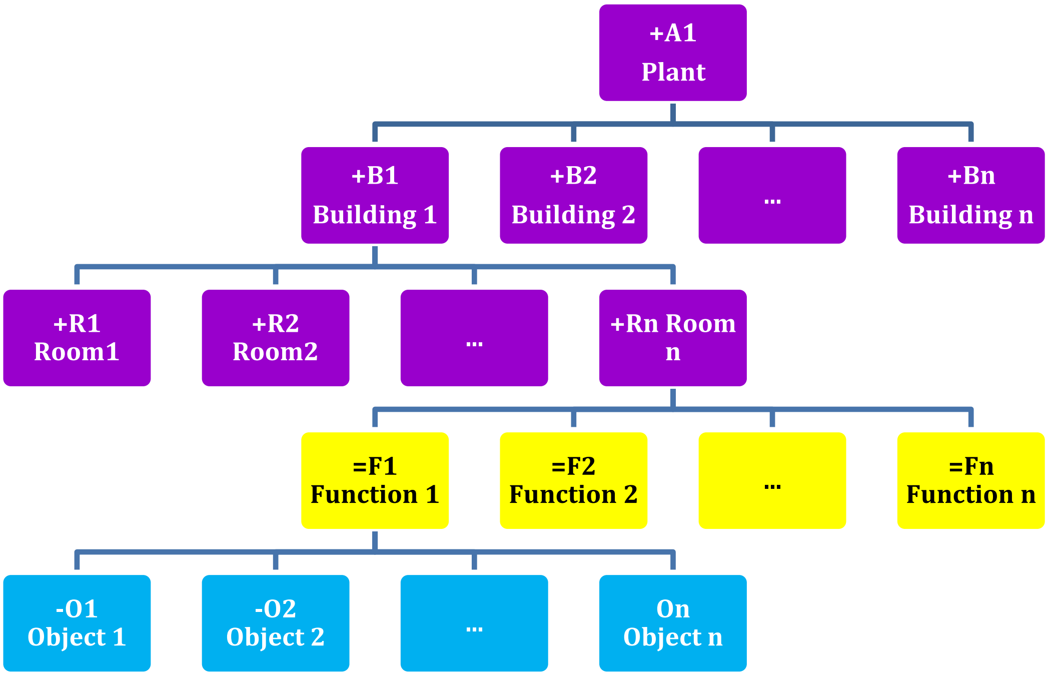


Figure 11: 81346 Aspects

According to these rules, the plant is structured in the following way:



In this way, every component of the plant is identified uniquely with the following structure:

+A1.B1.R1=F1-O1

Standard	Description
IEC/ISO 81346	Industrial systems, installations and equipment and industrial products –structuring principles and reference designations
CEI EN 60617	Graphical Symbols for Diagrams
EN ISO 10628	Diagrams for the chemical and petrochemical industry specifies the classification, content, and representation of flow diagrams

5 Hazid (Hazard Identification)

In this chapter, the hazards related to the installation, operation and maintenance of the Hydrogen Energy Storage System (H_2ESS) are identified and listed. A hazard, by definition, is an agent which has the potential to cause harm to a vulnerable target (humans, property, environment).

The main hazards connected to the plant are related with the materials and the components involved in the process. The main risks can be classified in the following list:

1. Risks related to the production, storage and use of Hydrogen
2. Risks related to the production of Oxygen
3. Risks related to the storage and use of Potassium Hydroxide
4. Risks related to high Pressure
5. Risks related to Electrical energy
6. Risks related to Heat and Temperature
7. Residual Risks

Each of the Hazard reported above will be detailed in the following paragraph and it all the prevention and mitigation measures taken in account in the system will be reported.

5.1 Hydrogen

Hydrogen is a flammable, colourless, odourless, compressed gas packaged in cylinders at high pressure (up to 30 barg). It forms the smallest, lightest molecule of any gas. The principal hazard presented by hydrogen is the uncontrolled combustion of accidental release. It poses an immediate fire and explosive hazard when concentrations exceed 4%. The radiation of a fire generated by the combustion of hydrogen is practically invisible and can cause something like sunburn. The heat released by an uncontrolled hydrogen fire can be very destructive to its surroundings. In a sealed region, the fire can produce an increase of pressure causing explosions.

Preventive:

- When possible welded or compression fittings are used in the hydrogen piping to reduce as low as possible any possible gas leakages. All sealing materials are chosen to be compatible with the gas.

- The H2 room is properly ventilated to ensure that its concentration is always lower than LEL (Low explosive Limit).

- An area classification will be made according the Atex directive to identify all the dangerous area. All the electric device will be compliant with the directive if they are positioned in a dangerous area

Mitigation:

- A gas detection system will automatically detect H2 presence and shut-down safely the system

- A fire fighting system will automatically fill the room with Inert gas in case of fire detection

5.2 Oxygen

Gaseous oxygen is colourless and odourless. Oxygen does not burn, but readily supports combustion of other substances. It is capable of reacting with most metals and organic materials. The rate of reaction varies with the material and other conditions. The reaction may be slow (as in the rusting of steel) or rapid (as in combustion and explosion). Air contains 21% oxygen, but if the amount of oxygen is increased, there is an increased risk of fire. Therefore, personnel must not be exposed to atmospheres that contain oxygen concentrations more than approximately 2% higher than air. Clothing, and even body hair and oils, are subject to flash fires if ignited in an oxygen-rich atmosphere. Therefore, matches and lighters must never be carried on the person where there is a risk of oxygen enrichment. Compared with a fire in air, a fire in an enriched oxygen atmosphere is more intense, with higher temperatures and has a greater heat output rate. Under most circumstances, an oxygen fire cannot be extinguished until any source of oxygen feeding the fire has been isolated.

Preventive:

- All the components used in the oxygen line will be cleaned as stated in ASTM G93 Level C for proper operation with oxygen.

- The oxygen will be purged in a safe area, away from any combustible source.

5.3 Potassium Hydroxide

Potassium hydroxide is used as electrolyte in the P2G unit, in order to allow the electrochemical reactions inside the stack. Potassium hydroxide is a colourless solid and a prototypical strong base. Due to this last property, it can be very hazardous in case of skin contact (corrosive, irritant), of eye contact (irritant), of ingestion, of inhalation. Liquid or spray mist may produce tissue damage particularly on mucous membranes of eyes, mouth and respiratory tract. Skin contact may produce burns. Inhalation of the spray mist may produce severe irritation of respiratory tract, characterized by coughing, choking, or shortness of breath. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Preventive:

- All the sealing has been properly chosen to be compatible with this solution to avoid any possible leakage

- Proper sensor will automatically detect any KOH leakage and will shut-down automatically the system.

Mitigation:

- The P2G system is provided by a proper tank able to collect all the KOH solution used in the system.

- For all the maintenance activities, the operator will use all the defined PPE (Personal protective equipment)

5.4 Pressure

The gas produced by the electrolyzer are stored at high pressure. The pressure energy in accidental events can be released generating a blast wave. Besides, in case of rupture of cylinders, the gas flow can throw heavy fragments of the vessels, providing them with high mechanical energy, that can damage people and/or buildings.

Preventive:

- All the pressure vessels are provided by a pressure transmitter that will automatically shut-down the system and a pressure safety valve to avoid any pressure increase.

5.5 Electrical

Exposure to electrical current may cause injury or death. The voltage is not so important as the amount of current. It doesn't take much current to kill. There are four principle categories of electrical hazards:

- Shock. Electrical shock is a sudden and accidental stimulation of the body's nervous system by an electrical current. Look for bare conductors, insulation failures, build-up of static electricity, and faulty electrical equipment.
- Ignition of combustible (or explosive) material. Ignition is usually caused by a spark, arc, or corona effect (ionized gas allows a current between conductors).
- Overheating. High current creates high heat that can result in fires, equipment burnout and burns to employees.
- Electrical explosions. Rapid overheating of circuit breakers, transformers, and other equipment may result in an explosion.

Preventive:

- All the electrical panel are closed and designed to be compliant with the LVD. This will take in account all the possible electrical hazard.

5.6 Heat and Temperature

Overexposure to heat and temperature extremes may result in a range of injuries from burns to frostbite. Temperature indicates the level of heat present. The second law of thermodynamics states that heat will flow from an area of higher temperature to one of lower temperature.

Preventive:

- All the Hot/Cold surfaces are protected by a proper cabinet to avoid any incidental contact

5.7 Residual risks

Residual risks are all the risks that are not highlighted in the previous paragraphs. In this category there are reported all risk that are expected to have low magnitude and low probability to happen due to design of the system. They include:

- Fall of components and heavy object in case of rupture of mechanical support
- Fall from height that can be possible during the commissioning and the decommissioning of the plant
- Noise

- Asphyxia caused by accidental release of Nitrogen and/or Novec 1230

6 Demo Description and configuration

The demos described below are the ones included in the WP3 of the remote project:

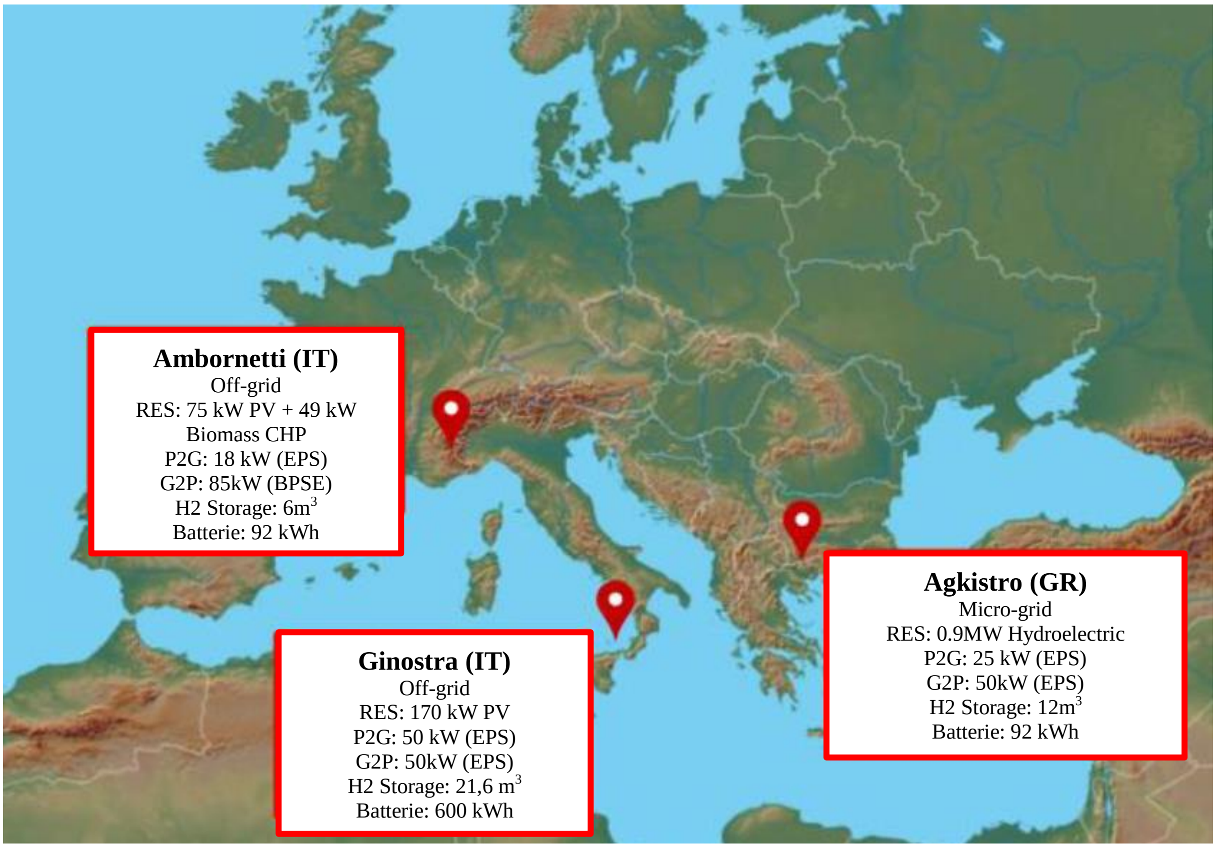


Figure 12: DEMOs Installation Map

1) Ginostra:

   Ginostra is a small village on the Island of Stromboli. Due to geographic limitation, it is not connected to the Italian distribution and transmission grid. The load of the island is covered by diesel generators. In order to reduce the diesel consumption, an energy storage system coupled with a photovoltaic plant will be installed.

2) Agkistro:

   Agkistro is a small village in Serres region (Greece). In this application the load consists in the consumption of the processing unit of an agri-food. It will be covered by the energy produced by a hydroelectric power plant. However due to its unreliability an energy storage system is needed to provide back-up solution in case of grid shortage.

3) Ambornetti:

Ambornetti is a small village in Piedmont not connected to the main grid. In this application the goal is to cover the load of the village with neutral impact to the environment. To do so, a biomass CHPP generator and a photovoltaic plant will be installed. In this application the energy storage will provide stability to the microgrid.

	Technology \Demo	Ginostra	Agkistro	Ambornetti
GENERATION PLANTS	PV	170 kW	-	75 kW
	Biomass	-	-	49 kW
	Hydroelectric Plant	-	900 kW	-
	Diesel Generator	2x48kW	-	-
BATTERIES	Rated Energy	600kWh	92kWh	92kWh
P2P	H2 stored (Gross)	2 MWh	1 MWh	0.5 MWh
	G2P Power	50 kW	50 kW	85 kW
	P2G Power	50 kW	25 kW	18 kW

Furthermore, each demo presents different characteristics that have an important impact on the design of the plant. In particular, the aspects analyzed are:

- Logistic
    1. From this point of view, Ginostra is the most complicated installation. In fact, all the components need to travel with helicopter, which means that the system must be designed including the constraint on the weight of each component that has to be lower than 1 ton. This excludes the possibilities to define containerized solutions.
    2. From this point of view, Agkistro is easier and well connected to the main roads. This allows to define a containerized solution that will reduce the on-site installation activities simplifying the commissioning of the plant.
    3. Although Ambornetti is connected well enough to consider a containerized solution, this was not acceptable from the final user point of view due to the limitations on the landscape impact, thus all the components of the system need to be integrated within its architectural and natural mountain landscape
- Environmental condition: the different environmental temperatures have a major impact on the sizing of the thermal conditioning of the systems. Besides, in the Demo 1 a saline atmosphere is present, and it must be considered in the design by selecting proper materials or paintings to avoid an early corrosion of components.

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