INGRID project

High-capacity hydrogen-based green-energy storage solutions for grid balancing

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The INGRID R&D European project is researching and demonstrating how and to what extent the combination of solid-state high-density hydrogen energy storage and advanced ICT technologies for real time monitoring and control of smart distribution grids will be able to balance highly variable power supply and demand, in a scenario of large penetration of intermittent distributed renewable energy sources.

1. THE INGRID IDEA

INGRID is a European R&D project co-funded by the 7^{th}FP for R&I aiming at investigating and demonstrating how and to what extent solid state hydrogen storage, combined with advanced ICT technologies for real time monitoring and control of smart distribution grids, will be able to balance power supply and demand. This is a particularly important issue if we consider that the production of renewable energy sources is often intermittent.

The partnership developing the project consists of organizations expressing scientific, industrial and administrative skills. Engineering Ingegneria Informatica, the largest private Italian ICT technology provider, coordinates the project. ARTI, the Apulian Regional Agency for Technology and Innovation (Italy), is the operational arm of Puglia Region in the field of innovation and technology transfer. Enel Distribuzione is Italy's largest electricity distribution company. Hydrogenics (Belgium) is the leading provider of hydrogen generators, while McPhy Energy is leader in innovative technologies for solid and safe hydrogen storage. The scientific partners are Ricerca sul Sistema Energetico (Italy), leader in research projects in the field of power generation, transmission and distribution, and TECNALIA Research and Innovation, the first research technology organization in Spain. Studio Tecnico BFP is a company involved in engineering activities necessary for the development of the INGRID project.

INGRID is being implemented through the design, deployment and operation of **a 39 MWh energy storage demonstrator**. The plant will use McPhy solid state hydrogen storage and Hydrogenics electrolysis technology and fuel cell power systems, and will be located in Puglia, the Italian region with the largest RES portfolio, where over 3.500 MW of solar, wind and biomass are already installed.

Such facility will include an hydrogen energy storage installation with more than one ton of safely stored hydrogen and a novel fast responding 1.2 MW water electrolyzer; it will provide effective and smart balancing support for the local distribution power grid managed by Enel Distribuzione. The plant also includes an energy delivery subsystem consisting of a fuel cell able to supply electric cars chargers or to provide Low Voltage regulation services to power distributors (Closed Loop Operation – CL). If not converted again in electricity, hydrogen is made available to the value chain either injected into gas distribution networks (Open Loop Operation – OL). The plant will be fully monitored and controlled by an Energy Management System allowing the optimal allocation of hydrogen surplus through the Closed and/or Open Loop modalities, depending from technical constraints or economic opportunity.

2. INGRID TECHNOLOGIES: HYDROGEN STORAGE

2.1 Hydrogen: an excellent energy carrier but difficult to store

Hydrogen is the simplest atom form (1 electron, 1 proton). It is the lightest and most abundant element in the universe (combined with oxygen in water and with carbon in hydrocarbons) and has the highest energy density per kilogram in comparison with other fuels, like natural gas.

Although hydrogen has a very high mass energy density, its lightness makes its storage and transportation real challenges. The aim of solid hydrogen storage technologies is thus to reduce the volume that hydrogen naturally occupies in its thermodynamically stable state under ambient conditions.

2.2 Magnesium hydride: a step forward new hydrogen storage generation that allows storing large quantity of energy

A very promising option to store hydrogen is in the form of metal hydrides which have been under intense scrutiny for many years, offering safe, reversible hydrogen storage, with an excellent energy efficiency (no compression). Some metals or alloys have the property of forming reversible bonds with hydrogen atoms leading to the formation of metal hydride. By using different temperatures and low pressures, hydrogen is either absorbed or desorbed by the metal. Magnesium hydride has been selected by McPhy in order to store massive amount of hydrogen (energy). This magnesium hydride offers unique advantages in terms of:

- **efficiency** with magnesium hydrides provide a much higher volume density than compressed or liquid gas.
  No compression is required during the loading/unloading process. With a very high output efficiency, McPhy products allow significant energy, cost and maintenance savings compared with existing gas storage solutions for which 10–25 % of the energy content of the gas is used for compression;
- **safety** with stored at 10 bar pressure, magnesium hydrides storage makes possible to get away from the logistic and traditional safety constraints encountered in the case of transportation of hydrogen in liquid or gaseous form.
- **carbon footprint** with magnesium is an abundant and affordable material without any environmental impact, improving the ecological balance of hydrogen energy.

Figure 1: Four Hydrogen storage blocks containing 150 kg H_2 each (Source: McPhy Energy)

2.3 INGRID project, solid state storage "at large scale"

INGRID aims to demonstrate the feasibility of solid state storage "at large scale"; but also the economical relevance of the business model generated.

To this purpose, five blocks, presenting each one a hydrogen storage capacity of 150 kg, contain the McPhy disks. Two filling stations are also installed on the INGRID site, allowing filling the blocks with the hydrogen produced by the on-site electrolysis unit. Then, the unloading station implemented on the final customer's site allows the application of the blocks in order to release the stored hydrogen and use it for new energetic applications **(Figure 1)**.

Another filling/unfilling station is installed on the INGRID site to allow to store hydrogen from the electrolysis unit and to deliver hydrogen to the Fuel Cell, which transforms H_2 into electricity for electric cars and LV grid balancing the CL **(Figure 2)**.

3. INGRID TECHNOLOGIES: POWER TO GAS

3.1 Grid scale water electrolysis: enhancing the penetration of renewable energies by converting excess power

INGRID project aims to exploit on a large industrial scale a hydrogen storage technology, by decomposing molecules of pure water into oxygen and hydrogen via water electrolysis.

Figure 2: A filling station (Source: McPhy Energy)

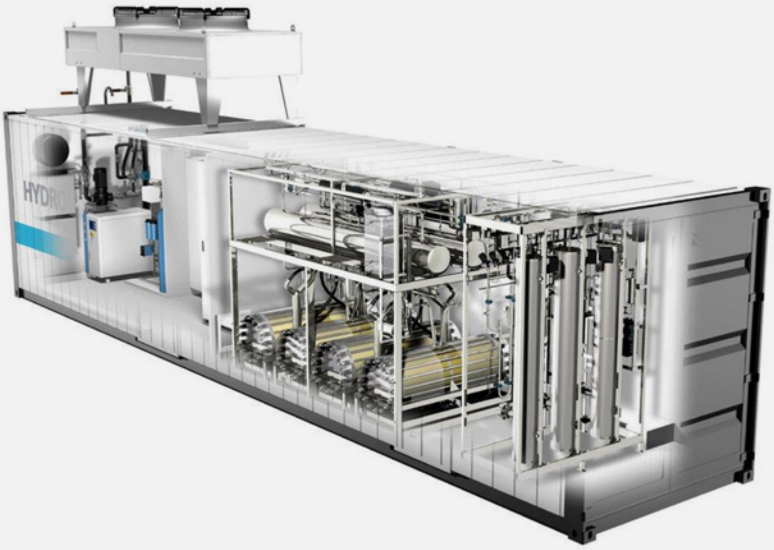

Figure 3: Water electrolyzer (Source: Hydrogenics)

Figure 4: Water electrolyzer unit development (Source: Hydrogenics)

Roughly 55 kWh of electricity and nine liters of water are required to produce 1 kg of hydrogen. **Figure 3** shows a typical unit with a total power of 300 kW with all its utility systems.

Water electrolysis systems are modular, thus they can be easily grouped to produce hydrogen and store energy over wide scales, ranging from few kilowatts to hundreds of megawatts.

For INGRID project, Hydrogenics has engineered, built and tested their largest single electrolyzer to date based on this robust alkaline technology. The unit is a 1 Megawatt self-sufficient hydrogen production plant **(Figure 4)**.

Besides the water electrolysis modules, it contains a gas-liquid separation system for both hydrogen and oxygen, and a purification system yielding a 99,999 % grade pure hydrogen product. Additionally all the power conditioning is being done inside the system, transforming high voltage AC of green origin taken from the grid to a DC voltage suited for electrolysis. A high performance water purification system treats the incoming city water so that the volume of split water is made up and added into the processing unit. An integrated control and safety system takes care of the communication with the surrounding equipment.

The over-all efficiency of the electricity-to-hydrogen conversion has been verified in factory acceptance tests and ranges from 60 to 80 % for this type of units, depending on the exact operating point. Water electrolysis thus becomes a corner stone in many of the new technologies that are able to store excesses green power by either using hydrogen gas as such, or by using the hydrogen for further chemical processing.

4. INGRID TECHNOLOGIES: ICT VISION

4.1 ICT vision supporting interaction between DSO and EMS

The INGRID Energy Management System (EMS) has been finalized by Engineering along with the Human Machine Interface (HMI) for plant administrators and maintenance operators. Moreover, the ID (Intelligent Dispenser) for the green e-mobility has been released, to monitor the two recharging columns which will be placed beside the INGRID plant by ENEL Distribuzione, for electric vehicle supply.

The INGRID plant is modelled by the EMS as a multi-carrier hub in the context of the smart grid. The plant can be viewed as a prosumer able to consume energy in form of electricity, transform and store it in form of hydrogen using the Water Electrolyzer and the Hydrogen Solid-state Storage, and produce energy in form of hydrogen and electricity, as well, using the Fuel Cell. An optimizer, built upon this model and based on genetic algorithm, is responsible for elaborating the optimal power flow inside the plant. The EMS tries to optimize the power flow considering the different requirements coming from the Distributor Service Operator (DSO), in terms of expected power consumption profile, and the ones linked to the actual business of the plant itself, i.e., the hydrogen sale. In this way, the INGRID plant is able to chase its own profit, providing ancillary services to the grid at the same time. Every hour a series of set points are elaborated for the different INGRID devices. The EMS is provided with a Decision Support System (DSS) which allows to send the desired set points to the corresponding INGRID devices. The DSS allows to select between DSO-oriented and profit-oriented solutions, i.e., set points which try to follow the DSO requests or to maximize the revenue of the plant. A medial solution is always proposed by default, which represents a trade-off between the two trends. The HMI monitors the plant activities 24 hours, seven days a week. The interface can be used both for monitoring and security purposes, in order to have an overall and complete view of the plant state and its operations. In its turn, the ID monitors the recharging stations, and is ready to be used also for further scenarios, in the context of the green e-mobility. For this reason, the ID is compliant with the Electro-Mobility Management (EMM) services, made available by ENEL Distribuzione **(Figure 5)**.

A specific simulation tool has been developed for predicting and describing INGRID plant behavior before there is any building on the field. It is divided in several modules with different shared inputs and outputs that create a whole simulation tool. In particular, there are two main blocks: the first one represents the EMS and its inputs/outputs, the second one includes the Green Energy Storage System (GES) created to simulate the plant. The GES block includes the models for a water electrolyzer, hydrogen solid-storage systems and a fuel cell.

Two operation modes are considered: the Closed Loop refers to the scenario when the hydrogen storage system is connected to a fuel cell to generate electricity; in the Open Loop, the hydrogen is stored in order to sell it in a container to external customers.

The INGRID simulator requires an EMS in order to provide control data for the real plant and make it work and adapt its outputs to the electricity market. The EMS establishes the power set-points for the water electrolyzer and the fuel cell based on the surplus power production, the estimation of hydrogen demand and the power demand of electric vehicles. The simulator is thus a key tool to fine tune the EMS and anticipate the INGRID plant behavior under different conditions. The INGRID simulator takes into account two functioning possibilities attending to whether it is connected to a real EMS or to a simulated one. When a real or physical EMS is constructed, it can be connected to the rest of the plant (simulated or real) and work in consequence. While the complete EMS is under development, a simple and functional EMS has been designed in order to provide control inputs to the field simulator **(Figure 6)**.

Figure 5: EMS architecture (Source: Engineering)

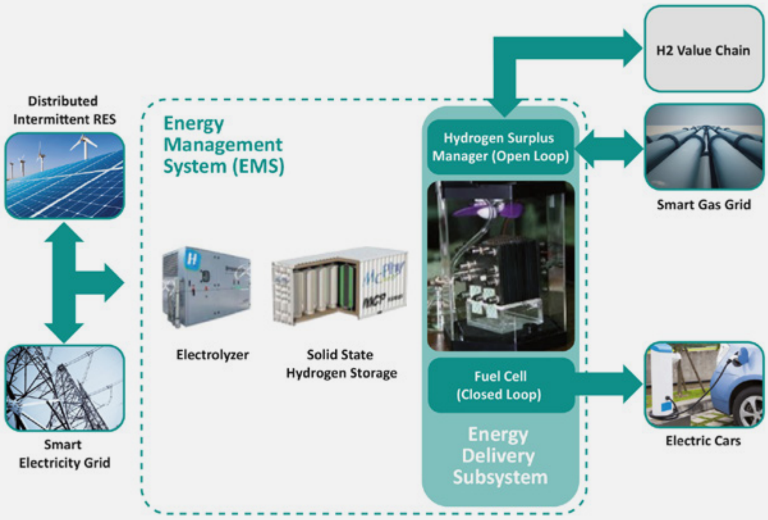

Figure 6: INGRID demonstrator plant (Source: INGRID Consortium)

5. INGRID DEMONSTRATOR IN PUGLIA

The INGRID demonstrator is currently under construction in Troia Municipality, in Puglia. Puglia is a region located in the South-East of Italy, with about 4 million inhabitants,

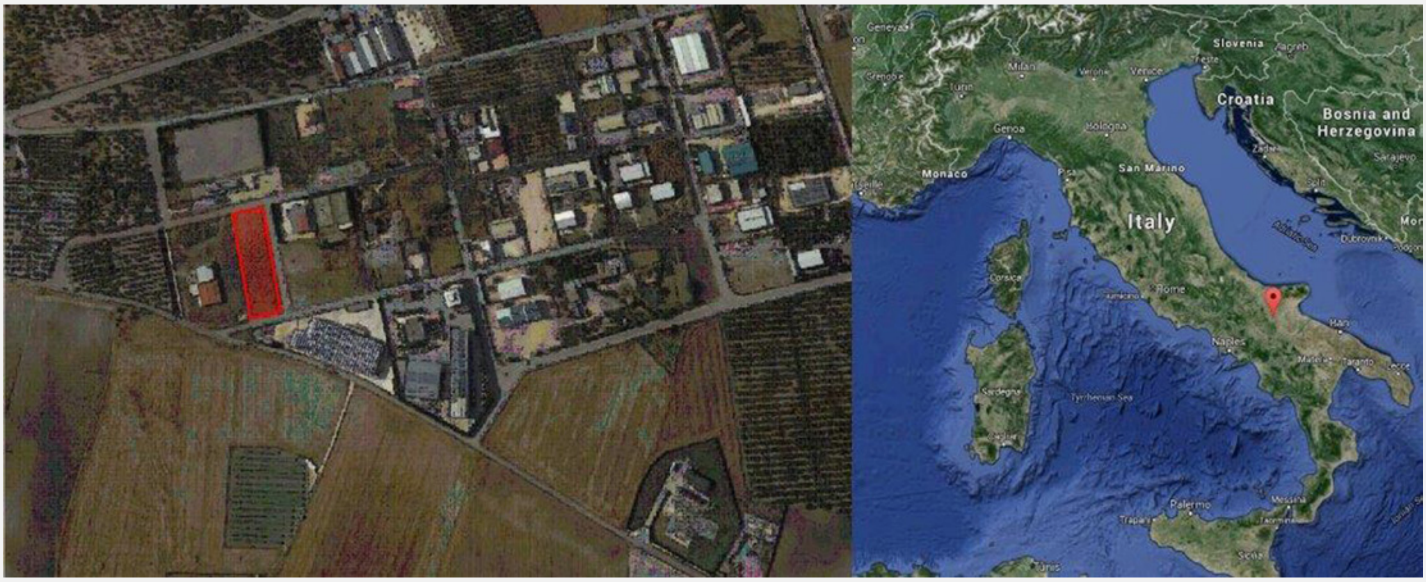

Figure 7: INGRID Demonstrator Localization (Source: ARTI Puglia)

which can be considered an excellence in the green economy in the Mediterranean area, thanks to favorable climatic and market conditions and a long administrative and political work on these subjects. It is ranked in the first positions among the Italian regions in renewable energy production (except hydroelectric). Such leadership has been achieved in less than a decade: the ratio between electricity consumption and electricity production from renewable sources increased from 0.5 % in 2000 to about 40 %.

In the last years, the regional electric grid, both at transmission and distribution level, has encountered important constraints connected to the mismatches between the huge RES generation and local demand.

In particular, in Troia the electricity reverse flow is the highest among the regional primary substations (62 %). Troia is indeed a small municipality (7,000 inhabitants) characterized by the presence of several big wind farms and PV plants, connected to MV network. For this reason, Troia administration is very oriented to further development of storage and electric balancing systems and is supporting the INGRID project offering for free the land where the demonstrator is being realized. The regional administration, with the support of its Agency ARTI, has also strongly supported INGRID and it is really interested in energy storage and smart grids. The new Regional Environmental and Energy Plan, that sets the objectives of Puglia Region to the 2020 in the theme of energy, has considered INGRID as both a good practice and a possible model of energy storage to be developed during the programming period **(Figure 7)**.

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