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Energy evaluation of a solar hydrogen storage facility: Comparison with other electrical energy storage technologies

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ABSTRACT

Storage of electricity from renewable energy sources is one of the main challenges to be overcome to ensure a proper integration of renewable technologies into the power grid, paving the way for their gradual introduction into future energy scenarios.

The use of hydrogen as an energy carrier is a potential and promising option among the different technologies that can be used to store electrical energy from renewable sources on a large scale. Typical hydrogen facilities used to store renewable electricity are currently based on electrolysis systems connected to the power source, mainly wind or photovoltaic. Hydrogen is stored in accordance with the facility requirements for its use in stationary fuel cells for electric power production.

This article presents the evaluation, in terms of energy-related parameters, of a hydrogen storage system, connected to a renewable energies power plant. The system is located at INTA R&D facilities in Huelva, SW of Spain. These parameters will be representative of the real performance of the system, and can be used as indicators to compare different electrical energy storage systems based on hydrogen and other technologies.

Introduction to electrical energy storage systems

Energy storage will be a key issue in future decentralized electrical production, from several sources, and low-carbon energy scenarios. In Europe, energy storage technologies have been identified as one of the key EU technology challenges for the next years, in the context of moving towards decarbonization of the energy system. Findings solutions to energy storage issues is a key element for achieving the EU's energy policy objectives [1]. Energy storage has been also included among key developments that need to be considered in the framework of the energy technologies and innovation policy [2].

In addition, main stakeholders of the European energy sector, including industry, have contributed to pin point

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Nomenclature

BES	battery energy storage
BoP	Balance of Plant
CAES	compressed air energy storage
DC	direct current
EU	European Union
FES	flywheel energy storage
HESS	hydrogen based energy storage systems
HHV	higher heating value
INTA	Spanish National Institute for Aerospace Technology
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
PHES	pumped hydroelectric energy storage
PV	photovoltaic
RES	renewable energy sources
SCES	supercapacitor energy storage
SMES	superconducting magnetic energy storage

energy storage as a priority area in the development of the future European energy landscape, highlighting unambiguously a future need for energy storage capacity in Europe, the size of which will depend on many aspects of the energy system such as penetration of renewable energy, electricity transmission capacity, penetration of demand side management and alternative back-up power availability, etc. [3].

Electrical energy storage is a well-established concept (pumped hydroelectric energy storage has been in use since 1929), but the current challenges of the electricity sector will require innovative approaches and technologies in this field, in order to provide different services for the power system, both at end-users and utility scale level. In particular, most of recent developments in electrical energy storage are intrinsically linked with the growth of electrical production from renewable energy sources (RES). According to the different sets of measures, plans and roadmaps proposed in different countries and regions, it is expected that main energy systems will have to be based on the rational use of traditional resources and greater use of renewable energy in the next years [1,3].

Renewable resources are in many cases intermittent or variable, fluctuate independently from demand. However, a future electricity system predominantly supplied by renewable sources would have to guarantee the fundamental stability requirement of electrical networks, matching constantly supply and demand. To solve this gap, electrical energy storage offers the potential to store electrical energy once generated from low and zero carbon sources and to subsequently match supply and demand as required, smoothing the output from RES plants into the power grid, and allowing in this way an optimal system operation.

Different energy storage technologies coexist because their characteristics make them attractive to different applications. Electrical energy storage includes a broad range of technologies, which either directly or indirectly provide electrical energy storage via an electrical input and output. Among these technologies, most common are pumped hydroelectric energy storage (PHES), compressed air energy storage (CAES), flywheel energy storage (FES), supercapacitor energy storage (SCES), superconducting magnetic energy storage (SMES), battery energy storage (BES) and hydrogen based energy storage systems (HESS) [4,5].

INTA, the Spanish Public Research Organization specialized in aerospace research and technology development, has been working on projects in the renewable energies field since 1978. Thanks to its technological experience in the field of solar energy for use in space, INTA is a pioneer in Spain in the development of new forms of clean generation and storage of energy. INTA's remit in this field is to conduct tests and to integrate and develop renewable energy-based systems and components, paying special attention to renewable energy storage systems, in particular in HESS, but also in batteries, both for stationary and mobile applications.

Electrical energy storage technologies can be intended for high power ratings with a relatively small energy content making them suitable for power quality; or can be designed for energy management, as shown in Fig. 1.

Fig. 1 illustrates typical discharge time and power ratings for energy storage technologies, in order to demonstrate their suitability for power quality, energy management, or both applications. According to the figure, power quality and reliability oriented systems usually are rated in the range from kilowatts to a few megawatts, with typical short discharge times, from seconds to minutes, with the objective to ensure the quality of the power delivered or the service continuity when switching from one source of electricity to another. Supercapacitors (SCES), SMES, flywheels (FES) and small-medium scale batteries are placed in this category, whereas PHS, CAES, large-scale batteries, flow batteries and HESS fall into the category of energy management applications, which require large power and energy capacity, with discharge time in the range of hours and even days or weeks [6,7]. The Figure shows also the current status of significant HESS demonstration project, in terms of storage capacity and discharge time [8,9].

Regarding this area covered by HESS current demonstration projects in Fig. 1, other energy technologies offer similar features in terms of power rating, in particular Li ion or lead

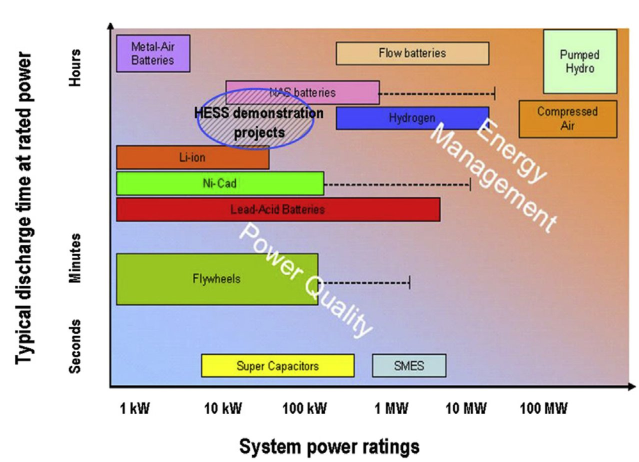

Fig. 1 – Typical discharge time and power ratings for energy storage technologies (adapted from Ref. [1]).

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