Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Energy Management Strategies in hydrogen Smart-Grids: A laboratory experience

L. Valverde [a,*], F. Rosa [b], C. Bordons [c], J. Guerra [b]

[a] AICIA, School of Engineering, 41092, Seville, Spain
[b] Energy Engineering Department, School of Engineering, University of Seville, 41092, Seville, Spain
[c] System Engineering and Automation Department, School of Engineering, University of Seville, 41092, Seville, Spain

ARTICLE INFO

Article history:
Received 6 March 2016
Received in revised form
25 May 2016
Accepted 29 May 2016
Available online 15 June 2016

Keywords:
Smart Grid
Energy management
Power management
Hydrogen
Energy storage
Experimental

ABSTRACT

As microgrids gain reputation, nations are making decisions towards a new energetic paradigm where the centralized model is being abandoned in favor of a more sophisticated, reliable, environmentally friendly and decentralized one.

The implementation of such sophisticated systems drive to find out new control techniques that make the system “smart”, bringing the Smart-Grid concept. This paper studies the role of Energy Management Strategies (EMSs) in hydrogen microgrids, covering both theoretical and experimental sides. It first describes the commissioning of a new labscale microgrid system to analyze a set of different EMS performance in real-life. This is followed by a summary of the approach used towards obtaining dynamic models to study and refine the different controllers implemented within this work. Then the implementation and validation of the developed EMSs using the new labscale microgrid are discussed. Experimental results are shown comparing the response of simple strategies (hysteresis band) against complex on-line optimization techniques, such as the Model Predictive Control. The difference between both approaches is extensively discussed. Results evidence how different control techniques can greatly influence the plant performance and finally we provide a set of guidelines for designing and operating Smart Grids.

Introduction

It is well known that the demand for energy, especially for electricity, has increased exponentially for years as a result of the industrial and technological development. In particular, developing countries are placing the global energy supply at risk position and are potentially leading to a global energy crisis [1,2]. It is clear that there is a need for increasing our energy supply, while at the same time we must be aware of its effects on the environmental and contribute to reducing global warming. Therefore, any new energy source has to be cleaner. Renewable Energy Sources (RES) are poised to be the solution that satisfies all parties. In fact, major countries are implementing new regulations that make the use of renewable sources mandatory. Twenty-nine states in the United States have already established mandates to generate between 20 and 33% of their electricity from renewables by 2020 [3]. Likewise, the EU's 20-20-20 directive [4] is gradually being adopted in Europe. In addition to this, environmental regulations are restricting the use of coal based plants and after Fukushima accident some countries (such as Germany, Italy, Japan, Sweden, etc.) are limiting their nuclear programs.

* Corresponding author.
E-mail address: lvalverde@etsi.us.es (L. Valverde).
http://dx.doi.org/10.1016/j.ijhydene.2016.05.279

As a result of these policies, RES have experienced a huge development. In particular, wind and solar energy are the most mature and widespread technologies, although not yet economically competitive. This low competitiveness is further reduced by the inherent intermittence of any renewable source. Indeed, the massive introduction of renewable energy into the electrical power system has unveiled two important challenges: One (challenge) is to maintain energy security for end-users; the other is to stabilize the electrical grid so as to avoid disconnections of wind farms and solar fields when there is strong surplus of RES and low demand [5]. The bridge to a sustainable energy future passes through the ability to transform uncontrollable power sources into dispatchable units. Therefore, Electrical Energy Storage (EES) must become an integral element of the renewable adoption strategy.

Indeed, R&D strategies are funding a wide range of solutions for EES. Fig. 1 shows a "Ragone Chart" summarizing the different and most advanced electrical energy storage technologies. This chart is used to illustrate a performance comparison between EES. The specific power/energy of conventional internal combustion engines was added to the chart for further analysis. As it can be seen, fuel cells present high energy density and high power density, only overpassed by IC engines. Besides power and energy capabilities, hydrogen, as a storage medium, has received much attention because of its flexibility. Hydrogen differs from the conventional idea of energy storage in that it separates the hydrogen production, storage and use. Electrolyzers, which provide wind/solar peak shaving whereas producing hydrogen from water, become an attractive solution to RES penetration because they can provide bulk energy storage (Power-to-Gas). Then, at a peak demand, a fuel cell uses the hydrogen to quickly respond to loads and thus providing short-term energy deficit. In addition to being used in fuel cells, hydrogen production can be used for other purposes, such as fueling vehicles or it can be distributed through the gas grid [6].

As it has been stated, the underlying concept of storing excess energy to deliver it later on is very simple. However, there is a great technological challenge in the automation of the control system and the way it coordinates and manages the different equipment used within an RES to EES concept.

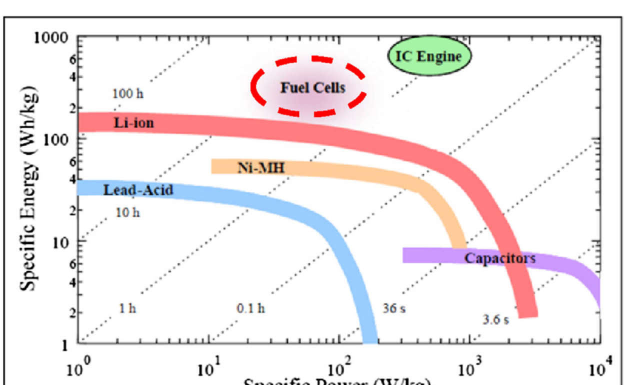

Fig. 1 – Energy storage technologies comparison. Source: Energy storage for power grids and electric transportation: a technology assessment [7].

Ultimately, and depending on the control strategy of the equipment, different performances can be obtained in the RES/EES plant performance.

An Energy Management Strategy (EMS) has to balance the power production from the renewable source and satisfy the demand by means of the energy storage. At the same time, ideally, an EMS would have to optimize the system efficiency and to minimize the operational cost. Despite the key roles that have been indicated, the fact is that in the past, EMSs for Smart-Grids (SGs) were quite simple and often neglected. It can be attributed to the pursuit of simplicity and/or the lack of previous experience. It is important to note that in SGs there is a substantial lack of experimental validation, which is essential to build confidence and acceptance on this technology both for industry experts and for public.

Further to the above, and after a decade of demonstration projects, operational experience has reinforced the idea that system performance is highly subjected to the control strategy and has not been up to the mark [8]. As literature on the subject points out, EMS is linked to the economic viability of the plant, since equipment lifetime is closely related to the way it is operated [9–11]. Therefore, challenges ahead are translated into innovative control strategies that can benefit efficiency and cost reduction to make this technology more competitive.

The aim of this paper is to bring the laboratory experience in the validation of Energy Management Strategies for Smart-Grids, which incorporates renewable energy and hybrid energy storage based on hydrogen and batteries. This experience could be a valuable resource to build and scale-up future plants. Key findings were obtained through the achievement of a series of steps aimed towards optimization of Smart-Grids operation. First step was the commissioning of an experimental platform with flexibility to test a variety of controllers. This process is fully explained in Section HyLab: Smart-Grid laboratory system. Following this, it was necessary to characterize all the equipment in order to know their operational curves and parameters. The characterization results of static and dynamic behavior are described in Section Characterization of equipment dynamic and static behavior. Next step was to develop a set of models capable to replicate with sufficient accuracy the real system in order to simulate and refine EMSs. This step is depicted in Section Modelling tool. Finally, a deep study of EMSs is provided. The study covers from most basic operation modes to recent advances in optimal control strategies, such as Model Predictive Control. Section Operational results of Energy Management Strategies in the hydrogen Smart Grid fully covers this study while Section Lessons learned and experience remarks the experience gained and lessons learned. Final conclusions of this research are given in Section Conclusion and recommendations.

HyLab: Smart-Grid laboratory system

The motivation for the construction of the HyLab laboratory was the development of a versatile experimental facility that allows research to be performed on the integration of renewable energy with the hydrogen vector under a Smart-Grid concept.