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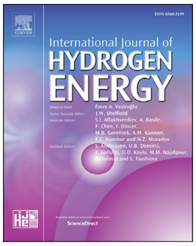

Experiment and simulation of electrolytic hydrogen production: Case study of photovoltaic-electrolyzer direct connection

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ABSTRACT

Hydrogen as an energy currency, carrier and storage medium can contribute to solve the problem of intermittent availability of renewable energies. In this paper, we study the production of hydrogen by a proton exchange membrane (PEM) electrolyzer (WE) using photovoltaic energy (PV) as source of electricity. Experiments were performed to model and optimize the direct-coupling system. Mathematical and empirical models based on experiments were used to simulate the system. RMSE was about 2% for the PV and WE. Optimization of direct connection was carried out to improve the system efficiency. However, it was noticed that the simulation of the system does not fit well the experimental results. Nevertheless, the RMSE is about 7%. In this study, we emphasize the need to develop appropriate models for hydrogen production system that operates in direct connection mode.

Introduction

The main obstacle to the development of renewable energies is their intermittent availability. Therefore, to promote renewable energies, a good energy vector is essential. Over the last decades, new applications of hydrogen as an energy carrier, for example, in the storage of energy obtained from renewable energy sources, were developed [1,2]. Hydrogen is used to store energy obtained from renewable energy sources, in order to use later (seasonal storage) or transported to remote location. The production of hydrogen by electrolysis is suitable for systems based on renewable energy (solar, wind, surges, tides ...) that are not integrated into the network [3]. However, the cost of hydrogen-based storage is higher than other alternative solutions (batteries, thermal storage ...). It is necessary to make efforts to reduce costs of hydrogen production, storage and delivery to promote it as an energy carrier of the future [4,5].

Hydrogen can be produced using electrical, thermal, biochemical, photonic, electro-thermal, photo-electric, and photo-biochemical primary energy sources. Photonic energy based hydrogen production (photocatalysis, photoelectrochemical method, and artificial photosynthesis) is environmentally benign. Thermochemical water splitting and hybrid thermochemical cycles also provide environmentally

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attractive results. Photoelectrochemical method and PV electrolysis are the cleanest way to produce hydrogen [2,6]. The hydrogen obtained by electrolysis is very pure, requiring no chemical nor specific treatment for use in fuel cells.

The I–V characteristics of the photovoltaic module and electrolysis cell are influenced by variations in the meteorological conditions. The direct coupling was studied in Tokyo, Japan; and a method to design a solar hydrogen energy system, providing the most cost-effective hydrogen generation, was developed [7]. The functionality of a matched direct-coupled PV array and PEM electrolyzer stack has been successfully demonstrated in Victoria, Australia [8]. Direct coupling was also studied in Beijing, China; and a dynamic model was developed to simulate the performance of system [9]. In this context, direct coupling of PV-Electrolyzer will be studied in Algiers, Algeria, in order to model and optimize the system.

A typical PVE system contains a photovoltaic generator, electrolyzer and several elements between them (batteries, control and regulation device, MPPT ...). The most fragile element in this photovoltaic system is batteries and electronic devices. The battery failure is unpredictable. In addition, they are very sensitive to temperature. Electronic devices breakdown most often and unpredictably. The way in which the system is monitored requires considerable strengthening [10]. The direct coupling between the photovoltaic panel and the electrolyzer makes it possible to avoid these problems, while reducing the overall cost.

Commonly the direct coupling between a PV system and a stack electrolyzer is achieved by carrying out the working points near its MPP in the range of 600–800 W/m^2 of irradiance. This is possible by a correct design of the PV array. Simulation could be used for prediction of coupling the PV system and the electrolyzer under such situation [11]. Optimal configuration can be equivalent to 96% MPP converter efficiency [12]. However, the environmental conditions such as solar intensity, ambient temperature and module surface temperature have a large effect on the system performance and the rate of hydrogen production [13].

By combining the electrolyzer cells in series and in parallel it is possible to closely match the electrolyzer polarization curve to the curve connecting PV system's maximum power points at different irradiation levels. With such method, it is possible to achieve the power transfer efficiency of up to 99% [14]. This method is based on linear approximation of both curves, which improve the system performances in contrast to the traditional approaches involving the design of the system with working conditions close to the MPP during the year. This allows savings of about 2500 €/kW, which is roughly the electronic device price [15]. Energy-efficient direct coupling is advantageous economically since the costs of an electronic coupling system are avoided entirely [16].

The lower efficiency of the direct coupling system is caused by the mismatch between working points and MPP of the PV modules during its working period. There are few specific concepts mentioned to guide and evaluate the connection method of photovoltaic modules and electrolyzer [9]. The studies that have been conducted use mathematical models to simulate the production of hydrogen by electrolysis using a photovoltaic generator as a source of electricity [8]. The more accurate are the models prediction of the I–V characteristics of the components of the system, more accurate is the design and the prediction of the behavior of the system and thus, better is the optimization of the system. The model most commonly used to describe the behavior of the photovoltaic panel is the one-diode model with shunt and series resistors. The most common model for the electrolyzer is the model derived from Nernst equation, or an empirical model using experimental results. To simulate the system a simple combination of equations is performed. The resolution of this system of equations makes it possible to obtain the operating point of the system. From this point, the parameters of the system are determined. The studies tend to minimize the difference between the operating point and the maximum power point of the photovoltaic generator in order to optimize production efficiency [9]. However, a complete evaluation of the hydrogen production chain has not been carried out by previous studies and the efficiency of this method has not been studied in depth.

In this work, the production of hydrogen by a proton exchange membrane (PEM) electrolyzer will be investigated. The electrolyzer is fed by pure water and produce only hydrogen and oxygen. It is directly connected to a photovoltaic panel that supply electric power needed to operations. The system operates as and when the sun shine, thus do not use batteries for energy storage. To optimize the system operation, mathematical model will be used to simulate the operation. The most accurate models will be used to characterize the photovoltaic panel and PEM electrolyzer. Then, the system will be simulated to evaluate the accuracy of the model in order to improve it.

Description of the system

Experiments were carried-out. The data were integrated to mathematical models in order to optimize the direct-coupling system. The schematic drawing of the experiment is shown in Fig. 1. The photovoltaic panel was directly connected to the electrolyzer. The input voltage and input current of the

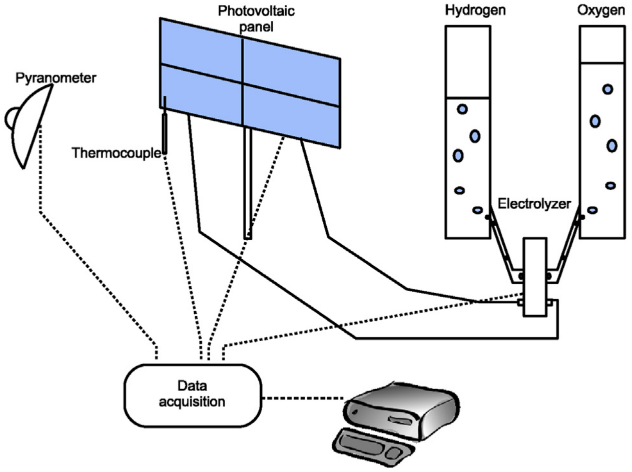

Fig. 1 – Schematic diagram of direct coupling of solar PV array and PEM electrolyzer.