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Management of excess energy in a photovoltaic/ grid system by production of clean hydrogen

Sanae Dahbi [a,*], Abdelhak Aziz [a], Abdelhafid Messaoudi [b], Imane Mazozi [a], Kamal Kassmi [a], Naima Benazzi [a]

[a] Laboratory of Electrical Engineering and Maintenance (LEEM), Higher School of Technology Oujda, BP, 473, 60000, Morocco

[b] National School of Applied Sciences AL Hoceima, BP:03, Ajdir, CP 32003, Morocco

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ABSTRACT

In this article, the authors design a new clean storage device for a photovoltaic system (PV) reinforced by the electrical grid. The photovoltaic system supplies power to a DC load. When the power of the photovoltaic source is insufficient, the electrical grid compensates the energy deficit. On the other hand, if the load is satisfied and the PV source is still able of supplying energy, the energy excess is diverted to an own storage unit materialized by an electrolysis which produces gaseous hydrogen by the process of electrolysis of water. The authors show that the quantity of hydrogen produced is proportional to the photovoltaic energy excess and also to the flow of water injected into the electrolysis. In this case, it is a question of designing an electrolysis with specific characteristics, which takes into account the quantity of energy excess and the flow of water injected into it. The authors abandon the idea of controlling the water flow by means of a pumping-electrovalve system, and initiate the idea of replacing the function of the pump by the action of gravity. The work focuses on the development of an electrolysis optimization approach using the water flow control in its alliance with the PV power excess which is also maximized. For an optimized use of the global system (load and electrolysis), the authors present an architecture based on energy-converting structures (DC/DC and AC/DC). In addition, to increase the reliability and safety of the system, the authors finish by developing a power management strategy (PMS) in the designed system. This power management strategy organizes the energy flow and selects the appropriate path of this flow between the two energy sources (PV and electrical grid) and the two possible energy receivers (load and electrolysis). A complete modeling of the system is developed in the Matlab/Simulink environment. The simulation results show that the hybrid system (PV and electrical grid) is able to permanently supplying the load and potentially storing the excess of the PV energy in the form of hydrogen gas.

* Corresponding author.
E-mail addresses: dahbisanae@hotmail.fr (S. Dahbi), aziz.abdelhak67@gmail.com (A. Aziz), messaoudi1968abdelhafid@gmail.com (A. Messaoudi), imanemazimane@gmail.com (I. Mazozi), kassmikamal@yahoo.fr (K. Kassmi), benazzin.ifmeree@gmail.com (N. Benazzi).
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Introduction

In recent years the use of renewable energy sources has attracted increased interest due to the limitations of fossil fuel reserves and the pollution generated by the use of this form of energy. The search for new clean energy sources, such as photovoltaic, is strongly solicited by government. The aim is to improve the security, reliability and sustainability (satisfaction of peoples and nations in energy) on the planet with respect to the environment. One of the major challenges for the photovoltaic energy system is the inadequacy between intermittent energy supply and dynamic energy demand. The most obvious solution is the integration of storage systems with these types of intermittent energy sources to balance between demand and production.

The most common energy storage devices currently used with photovoltaic are batteries [1–4]. The diesel generator can also be an alternative when the PV source is unable to cover the energy demand, especially during night or bad weather. Each of these two devices has its own disadvantages such as pollution, noise, maintenance and fuel costs. For ecological and economic development, the connection of the photovoltaic system to the grid is interesting. This set is called in the literature hybrid system. In this article, it should be noted that the use of hybrid terminology is quite pragmatic. It is not a photovoltaic injection in an electrical grid but simply, the electrical grid intervenes to compensate for the photovoltaic energy deficit when it took place. On the contrary, when the PV energy production is greater than that required by the load, the excess of the PV energy is stored by a clean process in the form of hydrogen. This hybrid system ensures the permanent energy supply of the load and stores PV energy excess; hence the necessity to develop an energy management strategy in the system. This article focuses on two aspects: the design of a clean storage device (based on hydrogen production) and the development of an energy management strategy in the system.

The production of electrolytic hydrogen using electrolysis of water from PV energy as a primary source is a sustainable process, clean and complies with the environmental [5–9]. In addition, hydrogen is viewed as an energy carrier vector whose use is very diverse. The most promising use is to use it as a fuel that replaces all conventional fuels [10–12]. The possibility of using hydrogen as an energy source has been studied by many researchers. Chen [13] studied a configuration of a hybrid system (solar-hydrogen-fuel cell) to supply electric vehicles; the electric energy acquired from photovoltaic cells placed on vehicle roofs is accumulated in the form of hydrogen gas via electrolysis to be used by a fuel cell to power an electric vehicle. Yunez-Cano and al [14] studied the feasibility of integrating a hybrid photovoltaic/hydrogen (PV/H_2) system into a house in Mexico. The PV/H_2 system supplies the load with the electrical energy produced by the primary source (PV) and the excess energy is supplied to the electrolysis to generate hydrogen, while the energy deficit is covered by the fuel cell. Kely and al [15]. Studied the applications of high pressure hydrogen produced by water electrolysis in fuel cell electric motors. However, further research has shown the possibility of using hydrogen gas in other areas without the use of fuel cells. Topriska and al [16], describes the development of a semi-empirical numerical model for a solar hydrogen system consisting of a proton exchange membrane electrolysis (PEM) supplied by photovoltaic panels to produce hydrogen as fuel for cooking applications. Melaina [17] studied the possibility of mixing hydrogen gas in natural gas networks for use in existing heat and power plants. Ohta [18] revealed the feasibility of using hydrogen gas in therapeutic strategy.

On the other hand, and since the designed system involves more than one component, it is natural to make it more efficient and effective. This requires multiple actions and at different levels of the system. In the literature, different adaptation and control algorithms and energy management strategies have been proposed for different configurations of hybrid systems [19–23].

However, in the literature, there is a very little result concerning the management of the excess energy of a hybrid system integrating the PV and the electrical grid by a clean storage in the form of hydrogen, and optimizing the process of hydrogen production by controlling the flow of water to be injected into the electrolysis. These two strategies for improving the hybrid system are the subject of this article.

We therefore focus on the design of the improved and optimized electrolytic process and the development of an optimal energy management strategy in a hybrid system integrating the PV and the electrical grid to supply a load. Indeed, the photovoltaic energy produced during the day is used to power a DC load. Given the intermittent behavior of the photovoltaic source and in case that it is not enough; the electrical grid intervenes to compensate for this energy deficit and ensures the continuity of the load supply. When the load requirements are fully covered and there is still an excess of energy, this excess is sent to the water flow control system to inject the optimum flow into the electrolysis by an electrovalve, to produce the maximum hydrogen and store it in tanks for later use in different ways, away from the designed system. As for the power management strategy in the hybrid system, it is developed in terms of mechanisms controlling the available power, the power required and possibly the power in excess or in deficit. These mechanisms reflect the path and distribution of power in the system using a specific logic. This ensures constantly power supply of the load and needle excess energy to the electrolysis. To do this, we provide each block constituting the system with:

- A local power optimization algorithm (in particular the MPPT algorithm).
- A control of the flow of water injected into the electrolysis.
- A management blocks containing the different mechanisms of energy distribution and the modes of interconnection of the two sources of energy to the load. This block also determines the best compromise of energy distribution in the system.

The different commands in the blocks are developed, using the power of the C language, in the Matlab/Simulink environment.

Synoptic representation of the system

The "Fig. 1" shows the configuration of the hybrid system proposed in this work to continuously supplying DC load and

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