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Power management strategy for hybrid autonomous power system using hydrogen storage

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ABSTRACT

In this paper, we present an autonomous Hybrid Power system (HPS) whose main goal is to ensure the electricity production without interruption in any remote areas. To achieve this goal, the system is composed of two energy sources one, as a renewable energy, serves to primary load feeding while the other, based on hydrogen conversion, works as a backup system. Thus, the system includes two kinds of energy storage devices one is used to chemical form energy storage (H_2 gas) while the second, based on ultracapacitor storage, is dedicated to electricity power saving. The functioning of system depends on a smart energy management that is based on the decision making and the control of all the system components states to achieve a high efficiency and better performance. Hence, the reliability and the effectiveness of the proposed system are tested by Matlab/Simulink environment, from which, the obtained results have been presented and discussed in details.

Introduction

The price of natural resources in the global market is increasing year by year. Natural resources like oil, coal and natural gas are being consumed massively by human beings resulting into a sharp decrease in the availability as well as accessibility of the resources. And, on the other hand, this massive consumption is resulting into serious environmental pollution. Therefore, it is causing greenhouse effect [1] too. The renewable energy sources have been proven to be efficient alternatives for the conventional energy production based on nonrenewable resources, mainly fossil fuels. Solar energy is one of the most promising renewable power generations. The solar energy source is being widely used, since it is easy, clean and abundantly available in nature. Its technology has now been well developed. However, because of its fluctuating nature, to supply power continuously, a solar energy component (SEC) can be integrated with other alternate power sources and/or storage systems, such as electrolyte, hydrogen storage tank, Fuel Cell component and Ultra capacitor bank to overcome the problem of solar system intermittence.

In comparison to commonly used battery storage, electrolytic hydrogen (H_2) is well suited for seasonal storage

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applications because its inherent high mass energy density leakage from the storage tank is insignificant, and it is easy to be installed anywhere [2]. In addition, the fuel cell generator, especially the PEMFC, is a good option to integrate with the SEC power since it is characterized with many good features such as high efficiency, fast response, modular production and fuel flexibility [3]. The combination of Fuel cell component with the ultra capacitor component is an attractive choice due to their high efficiency, fast load-response, flexibility and modular structure for the use with other alternative sources such as PV systems or wind turbines [4].

In the literature, there are a few studies related to Solar/Hydrogen Hybrid Power System. For example, the authors in Ref. [5] proposed three terms of use of a hybrid system based on solar energy with different storage medium as battery and fuel cell. Their study contains a development of a management strategy addressing the different operating condition including a thorough study of system efficiency and operating cost. However, the studied work given by Ref. [6] focuses on the integration of photovoltaic fuel cell and ultra-capacitor systems for sustained power generation. It gives a description about each system component followed by its modeling. The work contains also an evaluation of a management strategy dedicated to the adopted system. The authors in Ref. [7] have presented an original control algorithm for a hybrid energy system with a renewable energy source integrating a polymer electrolyte membrane fuel cell and a photovoltaic array with a super ultra-capacitor module. They have studied the dynamic response of the system followed by a control strategy. Hence, their application can be dedicated to hybrid electric vehicle. In addition, the presented work in Ref. [8] made a study of the different hybrid systems including fuel cell systems. Then, they presented a study of system behavior with a hybrid fuel cell photovoltaic generator integrating battery as a secondary medium storage. The work has been included also a suitable power conditioning units used to control the system operation. Finally, the studied system given by Ref. [9] included a photovoltaic energy source with fuel cell and battery. Hence, the work has treated different ways of system controlling followed by a comparison between the efficiency made by each control strategy.

Compared to the study cited above, we can say that our work fits in the study of a hybrid system with a few improvements regarding:

- The system and its components: relative to researches using battery as storage means, we renew their studies by replacing the battery with the ultra-capacitor bank which owns a instantaneous power much higher than the battery which makes it quicker considering the response time (charging/discharging) and more efficient.
- The applied energy management strategies: we noticed that the encountered management strategies are based on a condition of use of each component as well as the control of the power excess and deficit. However, the improvement occurred of our work was the control of the system elements functioning through decision variables that facilitate the rapid reaction against any fluctuation. Hence, the strategy of the system management will be based on decision making.
- The overall system efficiency, our work evaluates the efficiency of the system determined by the applied energy management approach whose study is ignored by some research articles.

The paper has been organized in the following way. Configuration and modeling of the hybrid power system is given in Section 2. Section 3 presents the control strategies developed for the energy management system of the adopted system. In the Section4, we describe the system efficiency way. Then, the simulation results have been evaluated and discussed in Section 5, and finally, Section 6 establishes the conclusions.

Modeling of HPS

One of the goals of this paper is to simulate the operation of hybrid power system as accurately as possible so that the realistic optimal control strategies can be found. To achieve this aim, one needs a set of relatively detailed models. In this section, the individual mathematical model for each component was developed in MATLAB, and the model, simulation and control of the systems was developed using Simulink (see Fig. 1). The SEC works as a primary source feeding a load through a DC converter. The second working component is the hydrogen production unit namely energy storage component (ESC). In fact, when there is excess of solar generation available, the electrolyzer is turned on to begin producing hydrogen which is sent to a storage tank. The produced hydrogen is used by the third working component, namely energy recovery component (ERC), characterized by use of fuel cell stack which converts H_2 gas to an electrical energy to cover the power necessities of the remote. The use of the ultracapacitor storage component (USC) is necessary, in one hand, to solve the problem of the slow response of the ERC in the transient events. In the other hand, the presence of the USC can maintain the system storage when the ESC is enabled to do that. The balancing between each system component can be monitored by the energy management strategy.

Modeling of the SEC

A SEC system consists of many PV cells connected in series and parallel to provide the desired output terminal voltage and current, and exhibits a nonlinear I–V characteristic which varies with the radiant intensities and cell temperatures [10]. The voltage–current characteristic equation of a solar cell is given as:

$$I_{SEC,STC} = I_{PH} - I_S\left[e^{(q(V_{SEC}+I_{SEC}R_S)/kT_CA)} - 1\right] - \frac{(V_{SEC}+I_{SEC}R_S)}{R_{SH}} \tag{1}$$

The SEC includes also a DC–DC boost converter that with MPPT enables the component to work at the maximum power point in a highly fluctuated environment. Indeed, the SEC normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power through the converter to the load when there are variations in irradiation and temperature [11]. The efficiency of the SEC can be deduced from the following expression (see Eq. (2))