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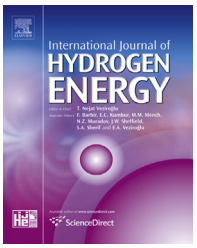

Autonomous hybrid system and coordinated intelligent management approach in power system operation and control using hydrogen storage

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ABSTRACT

Autonomous hybrid power systems are attractive research questions that deliver electricity to isolated consumers without being connected to the power grid. The deployment of autonomous hybrid power systems is considered as an option to improve energy security. For this reason, the main objective is to ensure the efficient production of electricity without interruption. To achieve this goal, we have proposed an accurate simulation system in which a solar energy component serves as a primary load supply, and an energy recovery component is based on a fuel cell. A long-term energy storage component comprises a water electrolyzer which is considered a primary storage and an ultracapacitor storage component deployed as a short-term storage of energy. To achieve the correct system operation, a new schema approach for intelligent energy management based on a multi-agent system is developed and discussed. The main task is to define the architecture of the multi-agent system and to define the functions of all the agents according to the characteristics of the energy needs and the production costs. Thus, in order to prove the reliability and effectiveness of the applied control strategy and its impact on the operation of the system, the proposed system is simulated using the Matlab/Simulink environment by referring to an extracted experimental database of the Tunisian Meteorological Service.

Introduction

Conventional fuels such as natural gas, oil and coal are rapidly depleting and pose a great threat to the environment. To solve these problems, renewable energy sources (such as: tide, wind, solar, etc.) are an alternative energy source [1]. Among these sources, solar energy has been widely applied in low power industrial applications and it is chosen as promising candidate for research and development [2,3]. However, this kind of energy sources complains of kit difficulties which the most important is related to its inability to provide reliable power during critical periods at night. In this regard, the use of

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storage components seems of fundamental importance for continuous feeding [4]. So, solar system has integrating several alternative power sources – storage systems (such as: fuel cell, ultracapacitor, electrolyte, hydrogen storage tank) to overcome its problems [5,6].

Many industries has benefited from solar power exploitation to automatically deliver the required power to homes or isolated areas. However, stand-alone hybrid power becomes an attractive solution for increasing power production and decreasing natural resources consumption. Many topologies compete for autonomous hybrid power for different load requirements. For example, in Ref. [7], the authors proposed a FC hybrid system with energy management. Whereas in Ref. [8], the authors proposed a hybrid system using the predictive control model. The developed system includes solar PV and PEMFC using hydrogen storage for a long time. The work given by Ref. [9] discussed a hybrid generation system (PV/Wind/PEMFC) in which the subsystem sizes are optimized. A hybrid system includes PV source and fuel cell is detailed and discussed in Ref. [6]. The proposed system links hydrogen production and storage with the demand of PEMFC at the same time.

The PEMFC ideally fits the supply for start-up power cases [10]. It can save the required power when the solar energy appears insufficient to meet the requirements. However, the frequent start-stop modes degrade the reliability and performance of the PEMFC and the electrolyzer [11,12]. To overcome this problem, the combination of PEMFC with ultracapacitor appears to be an attractive requirement and track due to their flexibility and their modular structure to offer with other alternative systems (such as: wind turbines) [13,14].

Additionally, to improve the reliability of energy supply, hydrogen (H_2) is well suited to seasonal storage applications as chemical batteries because of its many advantages (such as Density-Leak and High Mass Energy). In addition, the hydrogen system is used in a wide variety of applications, mainly in the industrial sector [15]. For this, integrating hydrogen with solar energy is considered as a perfect solution in behalf of its sustainability to meet the energy demand for various applications. Thus, the hydrogen storage system, based on a PEMFC, is chosen as a good long-term storage.

This article discusses an autonomous hybrid power system combining hydrogen and ultracapacitor as an energy storage respectively for a long and a short period of time. The proposed system, including solar photovoltaic, PEMFC and UCap to power electrical load, is simulated by bringing an experimental data profile (solar radiation, temperature and user energy consumption demand). In addition, the selected load profile complies to many electrical load installed in a house (such as: leisure appliances (TV, Audio, laptop,…), lighting, appliances (washing machine, refrigerator, cooking,…)).

Through this work, we are looking on the one hand for the improvement of the system performance by applying an intelligent energy management unit based on a multi-agent system. On the other hand, we aim to achieve an economical analysis of the different system elements.

The remainder of this paper is arranged as follows: Section 2 discusses related works; Section 3 gives the design of the autonomous hybrid system followed by a brief review of the multi-agent system; Section 4 outlines our intelligent energy management unit; Section 5 is devoted to the analysis of the simulation results and concluding remarks are discussed in Section 6.

Literature review and contributions

In the literature, many configurations, highlighting hybrid energy system, have been evaluated to ensure electricity production for an isolated site. For example, in Ref. [16], the authors presented a stand-alone system, including PEMFC and an electrolyzer to power an isolated area without accounting for the slow behavior of hydrogen gases. The integration of solar energy and storage devices in the hybrid system is developed and discussed in Refs. [17,18]. Whereas, the problem of Minimizing-Frequency-Deviation using ultracapacitor and BESS/FESS/SMES is treated by Ref. [19]. In Ref. [20], the authors proposed an efficient hybridization between solar energy and the fuel cell. In this study, the fuel cell provides the power required for the ultracapacitor to keep them charged. Then, the ultracapacitor is used as an energy storage unit to control the dynamics of the fuel cell during fast power.

An interesting combination between the solar and fuel cell components is discussed in Refs. [21,22] with respect of system efficiency and cost/scalability. The work presented in Refs. [23,24] deals with the application of solar energy for the remote area optimization and feasibility. A hybrid power system (Solar-PEMFC) is developed in Refs. [25,26] using a recovery unit to improve energy use for a residential. In addition, an original control algorithm is developed for the hybrid (solar fuel cell) power system combining an ultracapacitor module to control the dynamic response of the system in Refs. [27,28]. In Refs. [29,30], the authors presented an autonomous system, including PV, PEMFC and wind turbine. A battery bank is included as a short-term backup. The drawback of the detailed system requires a high installation cost. Finally, a hybrid system (Solar-Fuel Cell) which integrates a battery as secondary unit storage is studied in Ref. [31]. Indeed, suitable power conditioning units have been developed to manage the operating modes of their system.

Compared to these previous related works, the main contribution expected by this work is to propose an efficient autonomous hybrid system with an intelligent energy management approach based on the following enhancements:

- The renewal of the previous developed approaches by replacing the battery use by other storage devices like Hydrogen and ultracapacitor in order to compensate power fluctuation and to oversee the transient events.
- The proposal of a smart energy management unit based on a multi-agent system that seems to be more efficient than previous works as the control of energy production and consumption requires the assistance of all system components. Whilst, the envisaged approach guarantees the flexibility of power distribution according to system state (power excess/deficit) in order to keep reliably the energy demand.
- The evaluation of the proposed energy management referring to numerous constraints as (i) load demand, (ii) storage level of hydrogen system and ultracapacitor, (iii) operation of each element, (iv) excess and deficit power states.

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