Energy Conversion and Management 105 (2015) 377–392

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Dynamic control and advanced load management of a stand-alone hybrid renewable power system for remote housing

Tareq Alnejaili [a,*], Said Drid [a], Driss Mehdi [b], Larbi Chrifi-Alaoui [c], Rafik Belarbi [d], Aziz Hamdouni [d]

[a] *Laboratoire LSPIE, University of Batna, Rue Chahid M^ed El-Hadi Boukhlof, Batna, Algeria*
[b] *Laboratoire LIAS, University of Poitiers, Bât. 25, 2 Rue Pierre Brousse, BP 633, 86022 Poitiers, France*
[c] *Laboratoire LTI, Université de Picardie Jules Verne, GEII, IUT de l'Aisne, 02880 Cuffies, France*
[d] *Laboratoire LaSIE, Université de La Rochelle, Avenue Michel Crépeau, 17042 La Rochelle, France*

ARTICLE INFO

Article history:
Received 5 March 2015
Accepted 29 July 2015
Available online 19 August 2015

Keywords:
Power management
Dynamic control
Hybrid power system
Load profile
Energy efficiency

ABSTRACT

This paper proposes an advanced energy management strategy for a stand-alone hybrid energy system. The considered hybrid system includes a photovoltaic panel, a fuel cell, an electrolyzer, a battery bank and a supercapacitor. The proposed power management system aims to control the energy flow within the system and decides the amount of the load power shared with each power source. The system control is implemented in two parts: a central power flow controller that provides overall control of the power system and a local loads controller, which controls the different loads according to the energy balance of the system. The hybrid power system has been tested by simulation using models implemented in Matlab/Simulink software. The simulation is performed over a short and a long period of time in order to evaluate the performance of the dynamic controllers and the effectiveness of the management strategy. For a long simulation period, a house located in the province of Batna (35°33′N 6°10′E) has been taken as a case study with a deep study on real load profile for an average house with all required weather data with respect to the location. The simulation results confirm the efficiency of the proposed control strategy, as it increases the reliability of the system and improves its energy balance.

1. Introduction

During the last two decades, the electrical energy consumption in the world has increased significantly. That enormously increasing in the energy demand brought renewed interest in renewable energy (RE) sources such as solar, wind, hydro power, biomass and hydrogen.

Among the different RE technologies, solar and hydrogen energy sources are considered to be one of the most favorable options, as they can work in a complementary way. The solar energy technology as the photovoltaic (PV) system can be employed effectively in a different hybrid energy systems On the other hand, the output power of a PV system depends strongly on the fluctuating weather conditions. Consequently, the cloudy and night periods represent a real challenge to their utilization in hybrid energy systems. Moreover, there are a lot of difficulties related to the storage of the generated PV power. The performance of the PV system can be improved; by its integration with other power sources and/or storage systems as battery bank, fuel cell (FC), wind, electrolyzer (EL) and diesel generators.

An FC power plant is a power generation system that generates electricity, heat, and water from oxygen and hydrogen, it can be used for different application such as residential, vehicles and commercial applications [1–3]. The hydrogen could be obtained throughout proton exchange membrane (PEM) electrolyzer system. PEM electrolyzer cells offer many advantages like being environmental friendly and high hydrogen purity, compared with conventional hydrogen production processes including fossil fuel reforming and alkaline water electrolysis [4,5]. Generally the FC is characterized by its high efficiency and reliability, but its dynamics are limited by the hydrogen/oxygen delivery system. Therefore, a fast response auxiliary power source is needed to compensate its slow dynamic which can be achieved by the utilization of a supercapacitor bank.

A different hybrid renewable power production structures have been studied in many research papers. Khanand Iqbal [6] presented an investigation on a standalone wind-hydrogen hybrid energy system. The aim of their work was the analysis of the system behavior under sudden load variation and wind speed change. Carapellucciand Giordano [7] developed a simulation tool for

---

* Corresponding author. Mobile: +213 797358743.
E-mail address: tareq.elnejaili@univ-batna.dz (T. Alnejaili).

http://dx.doi.org/10.1016/j.enconman.2015.07.080
0196-8904/

testing energy and economic performance of renewable energy islands. An economic optimization approach was also proposed to minimize the unit cost of electricity. Castañeda et al. [8] discussed a new sizing method for a stand-alone PV/FC/EL hybrid system. The technical optimization was performed to efficiently utilize the energy sources integrated with the hybrid system.

The utilization of renewable energy technology requires a comprehensive energy management strategy (EMS) that achieves an optimal fuel economy with a minimum impact on the life cycle of a hybrid power system.

Semaoui et al. [9] proposed a new EMS for a stand-alone PV system, the control strategy was intended to control washing machine, fans and lights. Their results showed that the suggested load management strategy improves the performance and the reliability of the stand-alone PV system. In the same line, Clastres et al. [10] presented an advanced energy management for residential application, their management strategy relies on data forecasts on the operating plan for a 24 h period. To improve the reliability of a PV hybrid system, Alnejaili et al. [11] proposed a new EMS for a stand-alone PV-Wind-Diesel power system. The control strategy was intended to control air conditioning system and lights. Their result showed that the reduction in the peak consumption is about 20% using the proposed management strategy.

Concerning load management for a standalone Renewable/Fuel Cell Hybrid energy system, Uzunoglu et al. [12] presented a modified power flow controller for PV/FC/EL hybrid power system. Their control strategy manages the power flow among the power source and optimizes the operation of the hydrogen storage system. In [13], Behzadi and Niasati evaluated the performance of three different power management strategies with three different sizing methods for a standalone PV/FC/Battery hybrid energy system. The best combination of a power management strategy and sizing method has been outlined depending on the battery state of charge and hydrogen tank pressure. Dursun and Kilic [14] presented a three different power management strategies for an isolated PV/FC/Wind/Battery hybrid energy system. The main aim of the different strategies was the evaluation of the battery energy efficiency.

In this paper, we propose a stand-alone hybrid power system made up of a PV panel and a FC as energy sources, an EL as a hydrogen storage system, a lead acid battery bank as a long term storage element and a supercapacitor (SC) as a short term energy storage element. The main contribution of this work is to present an energy management algorithm according to the following constraints: (i) weather condition fluctuations, (ii) load demand, (iii) battery state of charge (SOC), (iii) pressure of the hydrogen tank, (v) energy balance of the system. The considered strategy offers many power flow possibilities according to four operating modes of the hybrid system. Each operating mode contains several sup-mode to cover all the circumstances. In addition to that, an advanced load management strategy is developed in order to meet the energy constraints and to increase the overall efficiency of the system. This paper is organized as follows. Section 2 describes the fundamentals of hybrid systems. Section 3 describes the modeling of the system components. Section 4 presents the design of the system dynamic controller. Section 5 describes the proposed management strategy. Section 6 presents the dynamic simulation results and discuss a case study.

2. Hybrid system description

2.1. System representation

Fig. 1 shows the proposed structure of the hybrid power system (HPS), which comprises a solar module, a PEM fuel cell stack, an electrolyzer, a lead acid battery bank, and a super capacitor. The system specifications are summarized in Table 1. The components of the system are linked to a common DC bus through appropriate DC–DC power converters and assumed to be controlled by independent control system. The PV array is the primary source of the HPS, it is connected to the DC bus through DC–DC boost power converter, which achieves the PV Maximum Power Point Tracking (MPPT) control. The FC is sized to be the main backup source when the power generated by the PV or stored in the battery is insufficient to support the loads. It is connected to the DC bus through DC–DC boost converter Generally a FC is characterized by its high efficiency and reliability, but its dynamic is limited by the hydrogen/oxygen delivery system. Therefore, a fast response auxiliary power source is needed to compensate its slow dynamic, which can be achieved by the utilization of supercapacitor bank. The electrolyzer is connected to the DC bus via DC–DC buck converter, when the battery is fully charged the excess power is transferred to the electrolyzer unless the H_2 storage tankis full. The battery bank is mainly sized to support the low power demand, it is connected to the DC bus via bidirectional converter, which is controlled to follow the reference of charge or discharge current and to regulate the DC bus voltage (or super-capacitor SOC). The super-capacitor (SC) is directly connected to the DC bus in order to compensate the slow dynamic of the FC and support the sharp load. The SC has a greater power density, which allows it to supply the power over a short period [15]. Utilizing the super capacitor has many advantages, such as reducing the size of the battery, improving the performance of the FC and stabilizing the DC bus voltage under fast load changes. Since the energy balance represents a real challenge in such standalone power system, a load management unit is added in order to shift the electricity demand during the peak periods and achieve maximum energy efficiency with maximum degree of consumer comfort.

2.2. Hybrid system management and control methodology

In the integrated power system, the power flow between the different sources is controlled by a central controller. It provides overall control of the power system and sets the power reference for the different converters that control the power system components. Moreover, the main controller cooperates with a local loads controller, which controls the different loads, according to the energy balance of the system. It can reduce a part of the home power demand when the system is under stress by disconnecting the offered controllable loads.

3. System modeling

3.1. Photovoltaic system modeling

The photovoltaic system can be modeled by a currentsource, a diode and a combination of a series and a parallel resistance. The output current of the cellcan be given by [16,17]:

$$I_{PV} = I_{ph}(t) - I_{rs}(t)\left[\exp\left(\frac{q(V_{pv}(t) + I_{pv}(t)R_s)}{A_c KT(t)}\right) - 1\right] \tag{1}$$

where I_{ph} is the photocurrent, I_{rs} is the cell reverse saturation current, V_{PV} is the voltage level on the PV cell terminals, q is the electron charge, R_s is the intrinsic cell resistance, A_c is the cell deviation from the ideal pen junction characteristic, K is the Boltzman constant and T is the cell temperature. The photocurrent of the PV cell can be expressed as [16]:

$$I_{ph}(t) = \frac{(I_{sc} + K_l[T(t) - T_r])\lambda(t)}{100} \tag{2}$$