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A low-cost power management system design for residential hydrogen & solar energy based power plants

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ABSTRACT

This study focuses on developing a low-cost power management system for residential solar–hydrogen power plants. The proposed power management system is designed as a hybrid control system consisting of a microcontroller and a Labview data acquisition card. Most of the controllers have some boundaries for power management, and providing a practical solution for hybrid power plants has some limitations. The proposed controller checks the total energy demand of the hybrid power plant in real time and operates the solar/hydrogen energy based power plant for the local load. The implemented electronic control card monitors the hybrid system and operates the related switches to select the proper energy source for the local load. The proposed real-time management system also provides a low-cost power management for the residential power plants, and the experimental results prove that the developed hybrid power management system is easy to implement and is suitable for residential applications.

Introduction

The hybrid renewable energy sources (HRES) are the combination of the wind, hydrogen, solar and other renewable energy sources operating at the same time [1,4]. The phrase of HRES is also used to provide the required electrical and thermal energy demand of the consumers by combining different energy technologies [2,3].

The solar energy is a continuous source, and it is also easily accessible in nature. Thus, the photovoltaic (PV) systems have been widely used in the applications of generating electrical energy recently instead of the fossil fuels. PV systems have an ability to generate DC without being affected by the pollution

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and weather conditions [5,6]. An optimal operation strategy is proposed in Ref. [5] to store solar energy efficiently. Designing and modeling the solar power generation plants [6] is also required for optimization of the hybrid power plants. Besides, the primary issue of the PV systems is having an interruptible power generation because of the weather just like in the nights and cloudy days. Therefore, a sustainable power flow is required for an off-grid PV system, so an energy storage device or system is essential to provide a continuous power to the consumers [7]. The optimization strategy is proposed in Ref. [7] to maximize the efficiency of the hybrid system.

A sustainable power management is necessary for the customers, because of coming up in the world and the high demand of the electricity in residential plants. Consequently, designing a PV plant as a primary source of a plant, does not supply the whole electrical energy demand of the residential plants. Thus, some auxiliary and backup systems are required to provide a sustainable energy to the residential plants, both in a standalone and in a grid connected system design [8]. PLC (Programmable logic controller) is used in Ref. [8] to control the proposed hybrid power plant. The PLC controller has many inputs in the study, thus, the cost increases, and it needs a wide area for the controller in the whole control system. A fuel cell stack system operating with hydrogen is suitable to support the primary energy source for sustainable power flow as an auxiliary system. The usage of the hydrogen in residential plants is also an alternative method to supply the energy demand of the fixed and portable electrical devices.

A solar–hydrogen energy based hybrid power energy system is an alternative and sustainable energy solution for the residential plants which fills the deficiency of the individual PV power generation system [9]. A PLC controller is proposed to control the whole system in Ref. [9]. PLC controller provides stable control for the hybrid system, but when the inputs of the controller increase, it is required more extension modules for the system. As a result, this condition increases the controller cost. There are several methods to produce hydrogen from the solar energy, and today the most common method for this by generating hydrogen to electrolyze the water at low temperatures [10]. A microcontroller system is also presented in Ref. [10] to control the hybrid system. The proposed circuit decreases the controller cost, but the outputs of the current and power is restricted in this controller.

Recently, there are many residential applications about Photovoltaic (PV), wind and fuel cell (FC) systems. FC and PV hybrid systems have a significant evolution, and they are frequently used around the world in residential applications for sustainable power generation. Thus, the monitoring and management of a hybrid system are also required. The power control and management are also an essential subject to meet the electrical demand of the customers for residential applications.

A solar–hydrogen energy-based power management system for an off-grid hybrid system was proposed in Ref. [11]. In the study, an electrolyzer, a hydrogen storage tank and the batteries were designed to constitute the hybrid system. A fuzzy logic controller was proposed in Ref. [11] to use the solar power to meet the power demand, then utilize any addition power to maximize the hydrogen production, and minimize the usage of battery at the same time. A similar study was performed in Ref. [12] for a stand-alone power system, and the obtained experimental results from the proposed power management system were presented. Also, different logical control flow diagrams were presented in this paper. It is clear that the management control strategies usually depend on the climatical conditions. The grid connected, and standalone operational performance of the hybrid system was also researched in other studies [7,13,19], and the properties of a polymer electrolyte membrane (PEM) electrolyzer were examined in these studies. PV-battery, PV-FC stack, and PV-FC-battery off-grid hybrid systems were designed in Ref. [14] to optimize and to specify the different storage technologies in this study. Besides, most of these studies are restricted with some power flow charts and consist of simulation studies.

A grid-connected hybrid system consisting of PV-FC and solar collectors for a residential plant was researched into [15]. The proposed system decreases the primary energy consumption of the hybrid system according to the conventional hybrid systems. The optimum capacity of the hybrid system was also obtained from the simulation results. A PI controller was used to control FC voltage, and the converter is controlled by the generated SPWM signals.

Another standalone hybrid system consisting of a PV array, a PEM FC stack, and a wind turbine was proposed in Ref. [20]. Providing the maximum output power of the system, decreasing the voltage fluctuation and the increasing the energy quality of the hybrid system is the primary design and simulation issues researched in this study. Labview, data acquisition system, was used in Ref. [20] for monitoring and controlling the hybrid system. The experimental results show that this controller is suitable for experimental studies, and it is also easy to implement.

A Matlab, Simulink model of a grid, connected 1.2 kW PEM FC stack was presented in another study [17]. In this study, the analysis of the FC system is investigated, and the FC system is the sole source of the system. The simulation of a grid connected PV-FC system with Matlab, Simulink is also studied in Ref. [16]. A Matlab simulation model and the analysis of a hybrid power plant consisting of a PV array and a PEM FC stack was also presented in Ref. [17] to supply the energy demand of a greenhouse. There is also some different studies [21,22] research the effects of electronic components on renewable energy-based power plants. The power management control strategies are presented as a significant issue in all the examined studies in this paper, but the experimental studies on the subject are very limited. Thus, new control strategies are required for solar and hydrogen energy based power plants.

There are many control systems used in hybrid power plants, but there have been some limitations for selecting the proper control system for a hybrid power plant. A comparison of the fundamental control systems is presented in Table 1. The data acquisition systems have some abilities about controlling and monitoring a hybrid power plant. Thus, Labview data acquisition systems have more capacity for implementation of a power control system and a monitoring system. Table 1 also shows a comparison of the fundamental control systems for PV-FC hybrid power systems by discussing the controller cost compared to PV-FC hybrid power plant total cost.