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Design and control of a stand-alone hybrid power system

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ABSTRACT

This work presents a control of stand-alone hybrid system including photovoltaic (PV), wind turbine, fuel cell (PEMFC), storage systems and a dump load (in our case, an electrolyzer). All these sources are connected by a continuous bus to three phase load through a DC–AC converter. A strategy for the power management is designed for the proposed hybrid system to supervise power amount among various energy resources, the storage system and the dump load. In the design, the PV and wind systems are considered as main power resources, whereas PEMFC is used as an additional support, and the dump load is used for the effect of consumption of the surplus power available from sources (i.e. PV and wind), when the battery has been charged completely. The hybrid system includes a modified control algorithm, which has been developed to maintain the DC bus voltage at its reference through the regulation of the DC–DC bidirectional converter between the battery and DC bus. A dynamic model of various components of stand-alone hybrid system is presented along with a maximum power point tracking (MPPT) algorithms of the PV and wind system. The effectiveness of this modified control algorithm method has been verified using the Matlab/Simulink software.

Introduction

The usage of conventional fuels for instance oil, coal and natural gas in the production of the most frequent energy resource – electricity has become much expensive tool due to the extinction of the natural resources, lack of efficiency and environmentally hazardousness. For these reasons, the renewable and alternative energy resources, so-called wind, solar, biomass and harvester systems have been good resources for some decades, and offered numerous advantages with almost free and environmental-friendly features [1–5]. However, the major disadvantage in renewable energy resources is their unstable nature due to the external climatic conditions [6–10]. The load depending on the annual or daily fluctuations is not necessarily correlated with these resources. To meet the hourly load demands, they should be

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integrated with other different resources for instance diesel, fuel-cell, and storage device. Indeed, such an idea gives the motivation to design and construct the hybrid energy systems (HESs) [9,11].

A HES includes at least two or more different energy types together with the storage system and have been deployed for especially rural electrification in many countries. Strictly speaking, this system is generally used for the generation of electricity in the isolated regions without interruption. Much important thing to build up a HES for the rural electrification is to know the actual energy demand and the sources available at the rural electrification (for instance, the PV system not available at night or in cloudy periods). This will permit to design the HES, which meets the load demands of the located facilities at best.

The main role of a HES is to ensure the required energy by the charge and, if possible, to produce the maximum amount of energy from the renewable energy sources, while maintaining the quality of the energy supplied. There exist two main types of HES: Stand-alone HES and grid connected HES. Stand-alone solar and wind power sources are among the most motivated technological problems for the electrification of remote or far-grid consumers. Accordingly, different control algorithms are proposed to extract maximum power under the changing weather conditions. The maximum power point tracking (MPPT) technique is used within an algorithm controlling the DC–DC converter for the optimization of the efficiency of PV and wind systems [12]. In the literature, there exists various MPPT techniques having different complexities, topologies and hardware implementations [8,13,14]. Because of the disadvantages of the diesel generator such as high continuation costs, greenhouse emissions and low scalability to meet change in load demands, recently, the fuel cell sources become an alternative to the diesel generators.

The fuel cell based on the reverse reaction of electrolysis allows not only electricity generation very high efficiency but also the generation of heat. In addition, the fuel cell system has been characterized with many advantages such as fast load-response, efficiency, fuel flexibility, modular production and low cost [15]. On the one hand, fuel cell powered hydrogen and oxygen does not give a rise to the polluting emissions. Moreover, the operational characteristics of fuel cell are various in terms of operating temperature. Among many types of fuel cell existents, proton exchange membrane fuel cell (PEMFC) [15] is currently favorite one: It has good performance and high efficiency. PEMFC has been much attractive option for the stand-alone power facilities due to its low operational temperatures.

A study of the literature on the HES problem reveals that many optimization methods have been proposed for solving the energy management system problem [12,13,16]. Providing the customers with a qualified and stable voltage form is a vital process in a stand-alone system, due to the fact that the voltage fluctuations are caused by variations in the climatic condition and the electrical load. In the present paper, a modified control algorithm is developed for obtained these objectives:

1. Optimization of renewable energies i.e. PV and wind through an algorithm of the MPPT.
2. Stabilization of the DC bus voltage regardless of variations in the sources of solar and wind or the load.
3. Perform the power management between PV system, wind, fuel cell, battery and electrolyzer.
4. Supervision of the system by automatic monitoring of some components to product the electrical energy in an optimal way.
5. Quality and continuity of energy product.

The block diagram of proposed stand-alone HES consists of the PV panel, wind turbine, fuel cell, classic battery of type lead-acid and electrolyzer. If energy produced by both the PV panel and the wind turbine is not enough to fulfill the load demand, the energy deficit is covered by the battery until the battery limit of state of charge (SOC) becomes low, thereby, the fuel cell begins to produce energy for the load. On the other hand, in case of high power generation and the battery hit its upper limit of SOC, the electrolyzer comes into effect and consumes the surplus power for generated hydrogen. Then, it can be stored and used by fuel cell system if it is required. Therefore the proposed system should maintain the energy management and stabilize the power simultaneously.

This paper is organized by the following sections: While the next section describes the overall hybrid model in terms of equations and their solution strategy, Section Control of hybrid energy system presents the control strategy of the system. The main findings from the simulations are discussed in Section Simulation results and the paper ends with final remarks in the conclusion part.

The proposed design and modeling of the HES

The block diagram of the proposed stand-alone HES including the PV panel, wind turbine, fuel cell stack, battery storage and dump load is presented in Fig. 1. The elements in the block are interconnected through a DC bus. The DC bus collects the energy harvested by both systems (PV and wind), and directs it to the load through an AC–DC converter. According to Fig. 1, the turbine part consists of a permanent magnet synchronous generator (PMSG), a DC–DC boost converter and a rectifier. The PV system comprises several PV panels connected to the dc bus via a DC–DC buck-boost converter, fuel cell (FC) stack attached to the DC bus by a DC–DC boost converter, and the battery is connected to a DC bus through a DC–DC bidirectional converter.

PV system and MPPT controller design

The harvested current from the cell is represented by Ref. [17],

$$I = I_{pv} - I_o\left[exp\left(\frac{v + R_s}{aV_t}\right) - 1\right] - \frac{v + R_s}{R_p} \tag{1}$$

Here, I and v are the harvested current and voltage of the cell; I_{pv} is the solar-generated current; I_o is the saturation current of the diode; a is the ideality factor of the diode, R_s and R_p is the series and parallel resistance respectively and Vt $(= kT/q)$ is the thermal voltage of the cell, k $(=1380 \cdot 10^{-23}$ $J/K)$ is the