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Control analysis of renewable energy system with hydrogen storage for residential applications

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Abstract

The combination of an electrolyzer and a fuel cell can provide peak power control in a decentralized/distributed power system. The electrolyzer produces hydrogen and oxygen from off-peak electricity generated by the renewable energy sources (wind turbine and photovoltaic array), for later use in the fuel cell to produce on-peak electricity. An issue related to this system is the control of the hydrogen loop (electrolyzer, tank, fuel cell). A number of control algorithms were developed to decide when to produce hydrogen and when to convert it back to electricity, most of them assuming that the electrolyzer and the fuel cell run alternatively to provide nominal power (full power). This paper presents a complete model of a stand-alone renewable energy system with hydrogen storage controlled by a dynamic fuzzy logic controller (FLC). In this system, batteries are used as energy buffers and for short time storage. To study the behavior of such a system, a complete model is developed by integrating the individual sub-models of the fuel cell, the electrolyzer, the power conditioning units, the hydrogen storage system, and the batteries. An analysis of the performances of the dynamic fuzzy logic controller is then presented. This model is useful for building efficient peak power control.

Keywords: Renewable energy; Fuel cell; Fuzzy logic; Electrolyzer; Hydrogen; Energy conversion

1. Introduction

The global energy situation tends to become more complex as the demand grows faster than the offer. With many developing countries lacking the resources to build power plants and distribution networks and the industrialized countries that face insufficient power generation and greenhouse gas emission problems, new solutions to the energy issue are needed. Distributed generation system that use renewable energy resources could be a part of the solution [1–12]. These systems address both the economical and environmental issues of the problem. The Hydrogen Research Institute (HRI) has developed and implemented an autonomous renewable energy systems (RES) that uses wind and solar energy to power a load autonomously (Fig. 1). This is done by storing the excess energy produced by the sources in hydrogen by using an electrolyser and to provide on-peak energy by reconverting this hydrogen into electricity with a fuel cell when the weather is bad. There is also a battery stack that is used to maintain a constant the DC bus voltage and to store short-term energy. A control system was developed to determine when to produce hydrogen and when to convert it back to electricity. The control algorithm is based on the batteries' state-of-charge (SOC) and it relies on fixed SOC limits to determine when to start the electrolyzer or the fuel cell [2,6,12,13]. However, this method presents two important shortcomings: it does not take into account the system's state except for the batteries' SOC and it does not allows for the control of the hydrogen's rate of production or consumption, which could help manage the energy in the system. Vosen and Keller [12] also presented a control method based on neural networks. This controller uses the system's state to control the hydrogen storage loop but it presents an important weakness: the controller must be provided with high quality

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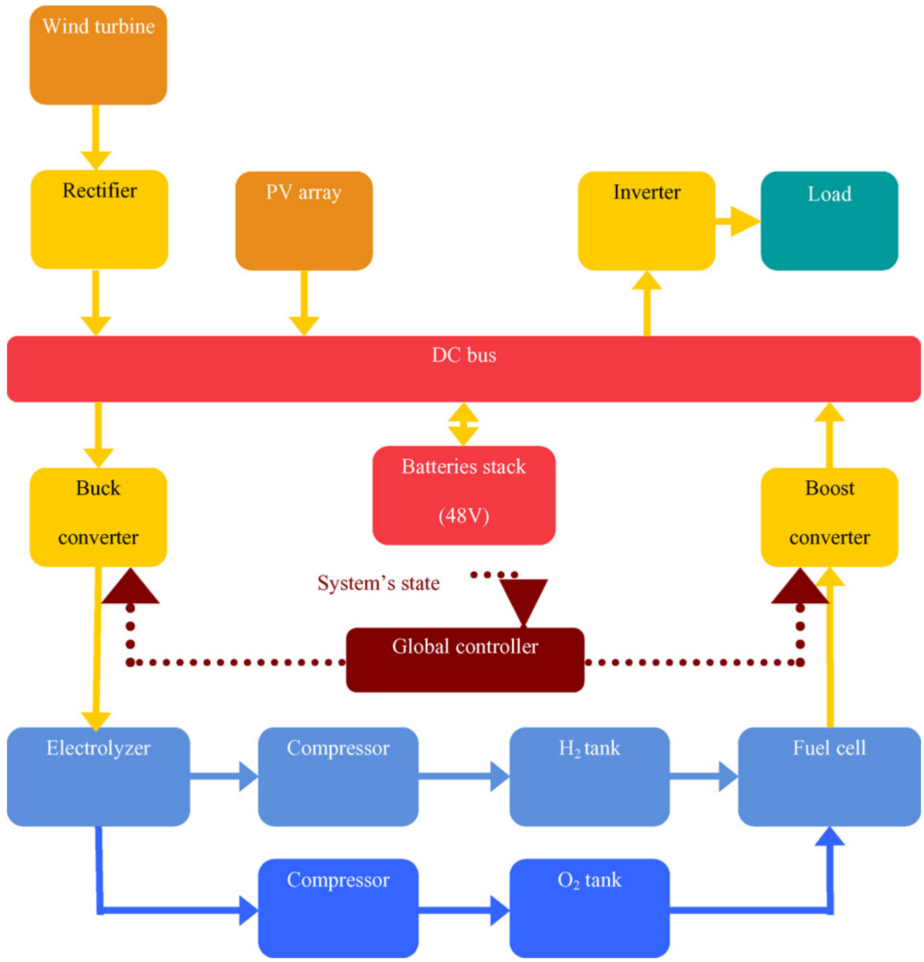

Fig. 1. Renewable energy system.

historical data to be efficient. This paper presents a dynamic controller that overcomes these issues by using fuzzy logic. The proposed fuzzy logic controller (FLC) determines the appropriate hydrogen's rate of production/consumption as a function of the system's power inputs and outputs and the batteries' SOC. The chosen rate is then applied to the electrolyzer or the fuel cell by using local power control loops around these devices. A model of the RES used to design and validate the proposed controller is first presented. The design of the FLC itself is then presented. The simulation parameters that were chosen to test the controller and the results analysis are finally given.

2. System's model

A complete model of the RES was developed in order to design and validate an adequate controller. The model was built using sub-models for each individual component. The model described in [14] was used as a base but a few modifications were made to include the new control system. Among them, the most important is the addition of local power controllers for the electrolyzer and the fuel cell. These controllers are implemented using the buck converter for the electrolyzer and the boost converter for the fuel cell. The power converters' duty cycle were thus eliminated as a variable in the system and then replaced by their output power. Moreover, since the converters' dynamic is considered to be much faster than that of the system, it was neglected and the converters are treated as devices providing a fixed output power (this output power is determined by the set point decided by the FLC).

2.1. Batteries model

The batteries stack is the element linking together each component of the RES. Since it is connected in parallel with the DC bus and it acts as an energy buffer, the current flowing into or from the batteries is defined by (1):

$$I_{\text{B}}(t) = I_{\text{PV}}(t) + I_{\text{Wind}}(t) + I_{\text{Bo}}(t) - I_{\text{Bu}}(t) - I_{\text{Load}}(t) \quad (1)$$

where $I_{\text{PV}}(t)$ is the photovoltaic array's current (A), $I_{\text{Wind}}(t)$ is the wind turbine's current (A), $I_{\text{Bo}}(t)$ is the boost converter's current (A), $I_{\text{Bu}}(t)$ is the buck converter's current (A), and $I_{\text{Load}}(t)$ is the load current (A).

This current is positive when the batteries are charging and negative otherwise. Knowing the current, it is possible to