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Modeling and control of photovoltaic and fuel cell based alternative power systems

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ABSTRACT

Photovoltaic (PV) systems and fuel cells (FCs) represent interesting solutions as being alternative power sources with high performance and low emission. This work presents a modeling and control study of two power generators; photovoltaic array and fuel cell based systems. An MPPT approach to optimize the PV system performances is proposed. The PV system consists of a PV array connected to a DC-DC buck converter and a resistive load. A maximum power point tracker controller is required to extract the maximum generated power. Based on Incremental Conductance (INC) principle, the idea of the proposed control is to use a Fuzzy Logic Controller (FLC) that allows the choice of the duty cycle step size which is used to be fixed in conventional MPPT algorithms. The variable step is computed according to the value of the PV power-voltage characteristic slope. The second working system comprises a controlled DC-DC converter fed by a proton exchange membrane fuel cell (PEMFC) and supplies a DC bus. The mathematical model of the PEMFC system is given. The converter duty cycle is adjusted in order to regulate the DC bus voltage. Obtained simulation results validate the control algorithms for both of studied power systems.

Introduction

The population increase worldwide has resulted on the increase of energy needs. Furthermore, fossil fuels reserves, uranium, gas, etc. are limited in quantities, the fact that has progressively developed the research attention to alternative sources [1]. Solar energy represents one among the most promising sustainable energy sources as being clean and freely available everywhere. It is considered as an appropriate choice adopted for various applications, such as irrigation and electrification, thanks to its ability to be directly converted into electrical energy using solar cells [2]. Indeed, Fuel Cells (FCs) are considered as important power sources that provide reliable and continuous supply.

PV cells convert the sunlight through a semiconductor under photovoltaic effect. The generated power of solar cells is non-linear and depends on the ambient temperature and the irradiance intensity [3]. There is a single operating point called Maximum Power Point (MPP) that changes with respect to temperature and radiation fluctuations. Therefore, in order to ensure permanent transfer of energy from the PV panel to

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the load, an adapter device is needed to provide this maximum power point [4]. Thus, a DC-DC converter controlled by an MPPT controller is commonly used. Great efforts have been made in order to ameliorate the maximum power operation of the solar cell array. Many studies have focused on the development of MPPT techniques considering parameters variation (temperature, insolation, load). The most known algorithms are Hill-Climbing, Perturb and Observe (PO) and Incremental Conductance (INC) [5], which are widely applied due to their simple implementation. Short circuit current and Open circuit voltage are also simple algorithms which have been developed in literature [6,7]. Other intelligent techniques based on fuzzy logic and neural network are investigated in many works [8,9]. In fact, fuzzy logic is very appropriate especially for nonlinear system control as it is one of the most promising control schemes adopted for unpredictable PV systems, however, it needs a priori knowledge of the system input/output relationship [21]. Different researches have been carried out using artificial intelligence techniques such as in Refs. [18–20]. Conventional algorithms such as PO and INC, which are the most commonly adopted, use a fixed step size to reach the maximum power. In fact, PO principle is to make a perturbation on the PV array voltage, then observe its influence on produced power and hence decide whether to increase or decrease the reference voltage by increasing or decreasing the duty cycle. However, the INC operation principle is based on the slope value of power-voltage characteristic. The use of fixed step size leads to slow convergence to the MPP and important oscillations around this point. Hence, in order to tune the step size properly, fuzzy logic controller can be efficient and suitable for such case since it deals mainly with uncertain problems. In fact, it is simple to design and does not need complex mathematics or an accurate model of the system.

FCs convert chemical energy into electrical energy and supply constant DC power. While fuel (hydrogen and oxygen) is available, FC keeps producing DC electricity with important efficiency. Several types of FCs are studied in literature like alkaline fuel cells (AFC), phosphoric acid fuel cells (PAFC), solid oxide fuel cells (SOFC) [14]. The proton exchange membrane fuel cells (PEMFC) are the most appropriate for standalone applications. FCs can be classified on the basis of their operating temperature. The low-temperature FCs (between 50 °C and 250 °C) as PEMFC, AFC and PAFC. High temperature FCs (between 650 °C and 1000 °C include MCFC and SOFC. Many papers describe the PEMFC modeling such as in Refs. [15–17].

In this paper, an improved method for PV system is firstly proposed based on INC algorithm and using fuzzy logic concept in order to reduce the drawbacks of using a fixed step. The proposed controller generates a variable step size. It allows the step size selection with respect to the slope computation value which ensures finding the maximum power point quickly. Fuzzy logic concept has proven its effectiveness as demonstrated in Refs. [10 and 11] since it handles the system nonlinearity and it does not need an accurate mathematical model. Then, the second FC power system is proposed and studied in terms of gases utilization, stack consumption and efficiency. The paper is organized as following: in the second section, a description of the PV system is firstly presented. Then, the MPPT control scheme is detailed; the INC algorithm is recalled, then the proposed FLC technique is presented. The FC power system is modeled and studied in third section. Section 4 is reserved to simulation results. Finally, a set of conclusions that could be drawn from this work ends the paper.

Photovoltaic system

Modeling

The photovoltaic system is composed of a solar panel coupled to a DC-DC converter as illustrated in Fig. 1.

PV panel. A photovoltaic panel includes n_s cells placed in series and/or n_p cells in parallel which are modelled by current source coupled in parallel with a diode according with series and shunt resistor R_s and R_p [13]. The characteristic current-voltage of a photovoltaic array conducts as a function of cell temperature and solar irradiance. It is described by the following expression [12]:

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{k_{pv}(V+R_s I)}{n_s}\right) - 1\right] - \frac{V+R_s I}{R_p} \tag{1}$$

where: $k_{pv} = \frac{q}{pKT}$, $q = 1,6.10^{-19}C$ is electron charge, $K = 1,38.10^{-23}JK^{-1}$ is Boltzmann constant, T is the cell instantaneous temperature (°K), and p is the p-n junction characteristic factor. I_{ph} and I_{rs} represent respectively the cell photocurrent which is proportional to the solar radiation, and reverse saturation current. Their expressions are given as:

$$I_{ph} = (I_{sc} + K_I(T - T_r))\frac{G}{G_r} \tag{2}$$

where: T_r represents the reference temperature (°K), G is the instantaneous solar irradiance (W/m^2), G_r is the reference solar irradiance (W/m^2), I_{sc} is the short-circuit cell current at reference temperature and irradiance (A) and K_I is the short-circuit current temperature coefficient.

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\frac{qE_{gp}\left(\frac{1}{T_r} - \frac{1}{T}\right)}{pK} \tag{3}$$

where: I_{rr} is reverse saturation current at reference temperature and E_{gp} is the semiconductor band gap energy (J).

The photovoltaic produced power is given by:

$$P = I \cdot V \tag{4}$$

If internal shunt and series resistances are neglected and remplacing I by its expression, the output power is then obtained as:

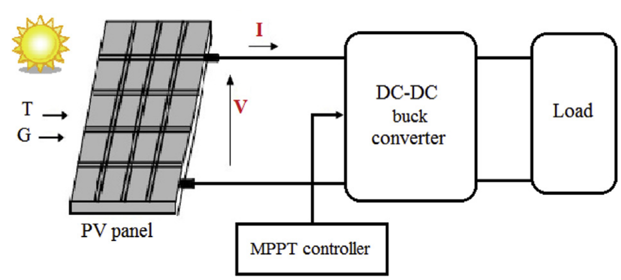

Fig. 1 – PV system diagram.

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