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Optimization and sensitivity analysis of a photovoltaic-electrolyser direct-coupling system in Beijing

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ABSTRACT

Hydrogen as a clean energy carrier for solar energy can be produced by using photovoltaic-electrolyser (PVE) direct-coupling system that is well known as a kind of simple and low investment but unstable system for solar energy conversion. The key to improve hydrogen yield of a direct-coupling system is to keep its working points around maximum power point (MPP) of photovoltaic (PV) modules. The coupling of three different connection patterns of six PV modules with one electrolyser were investigated in summer, autumn and winter, three typical seasons in a year, to seek the optimum arrangement for higher system efficiency in Beijing (116°E, 40°N). A corresponding mathematics model of the system is applied to simulate and analyze the instantaneous efficiency of the system, which agreed well with the experimental results. The variation rate of the system instantaneous efficiency varies with the solar irradiation intensity, the ambient temperature and the resistance of the electrolyser. The working point that distinguishes the variation trends of the system efficiency is called the efficiency changing point (ECP). The author use a parameter V/V_m, the ratio between the voltage of the working point to the voltage of the maximum power point, to analyze the respective ECP of each factor above. It can be concluded that the variation rate of system instantaneous efficiency changes little with the above factors when the value of V/V_m of working point is smaller than that of the ECP and is sensitive to those factors when the value of V/V_m is larger than that of the ECP. Following the annual historical climate data in Beijing, the result of the annual analysis is that the best scheme for the experiment system with a 1 m^2 PV panel covering 1.05 m^2 areas of ground can convert 78.4 kWh of solar energy to hydrogen energy in 2012.

Introduction

Green energy becomes a more important element in the world since 1990's. About 85 million barrels of oil and 104 trillion cubic feet of natural gas are consumed per day resulting in releasing greenhouse gases (GHGs) that cause to global warming [1]. The world seriously needs alternative energy resources for the needs of environmental protection

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such as solar energy which is a common clean energy that can be obtained everywhere. Since solar energy is an intermittent energy, an energy carrier is essential. Hydrogen is well known as a clean energy carrier for intermittent energy resource. A simple method to convert solar energy to hydrogen energy is photovoltaic electrolysis technology. The PVE system consisting of a photovoltaic generator, an electrolyser and some auxiliary equipment is an attractive system for its green. The coupling between the PV modules and the electrolyser is still a challenge because that the output of a PV generator depends on many factors such as climate condition. There are many investigations focused on the operation of PVE system [2–5].

In literature the main methods to optimize the PVE system are: (1) the PV generator and the electrolyser coupled through maximum power point tracker (MPPT) and direct current to direct current (DC–DC) converter [6–11]; (2) optimizing the direct coupling of the PV generator and the electrolyser to make MPP as near as the system working point [12–15]. The former system applied in most cases is complicate and expensive. The latter system that this paper concerns is more simple and cheap with a satisfied performance.

Some researchers compared the direct-coupling system and the system with MPPT and DC–DC converter [16–19]. They concluded that the lower efficiency of the direct-coupling system is caused by the mismatch between working points and MPP of the PV modules during its working period. To address these dilemmas, some patterns of combinations between the photovoltaic modules and the electrolyser wired have been investigated in literature [20]. Whereas there are few specific concepts mentioned to guide and evaluate the connection method of photovoltaic modules and electrolyser. Additionally, the actual working points of a direct-coupling system vary with weather changing. That brings difficulties to designing a direct-coupling system and predicting its system operation because that all the designing works have to be based on the local historical climate data. This paper proposes an optimum scheme to the existed PVE system. After that, a parameter analysis is performed by using the index V/V_m to analyze the effect of the working factors on the existed system operation.

PVE system

PV model

Many models have been developed to simulate the operation of solar cells [22–24]. The one-diode model of the PV cell shown in Fig. 1 is used in this paper. The model with series and parallel resistance consists of a diode wired in parallel to a current source. The current equation can be defined as follow [21]:

$$I = I_{ph} - I_r * (\exp((V + I * R_s)/a) - 1) - (V + I * R_{sh})/R_s \quad (1)$$

Where I represents the output current of the PV module; I_{ph} represents the photo-generated current. I_r represents the diode reverse saturation current. V represents the output

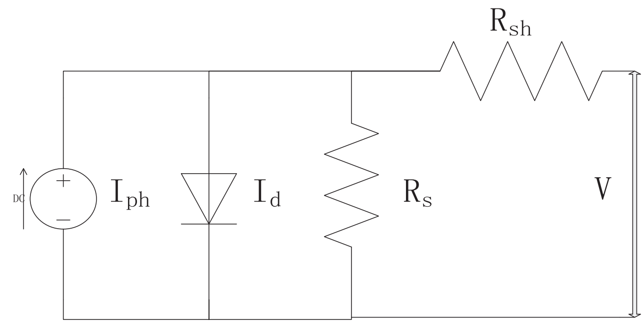

Fig. 1 – Equivalent circuit of the PV cell model.

voltage of the PV module. a represents the activity of species. R_s represents the solar cell series resistance. R_{sh} represents the solar cell parallel resistance.

This expression is a semiempirical model which expresses the relationship between PV operating current and operating voltage. In order to study the relationship between I and V, I_{ph}, I_r, a, R_s, R_{sh} are the 5 essential parameters to be determined first. The solution to Eq. (1) is presented in the Appendix. The maximum power output of the PV module can be obtained as

The maximum power output of the PV module can be obtained as

$$P_m = I_m * V_m \quad (2)$$

Where P_m represents the maximum power of the PV module; I_m represents the current of the MPP; V_m represents the voltage of the MPP.

The efficiency of the PV module is evaluated by the expression as follow:

$$\eta_{PV} = (I * V)/(G * A) \quad (3)$$

Where η_{PV} represents the efficiency of PV module; G represents the solar irradiation; A represents the effective area of the PV module.

The PV module used in this study is a commercial module. The detail information about this module will be presented later in Experimental setup. R_s and R_{sh} in Eq. (1) should be fitted by a set of experimental data. The fitting experiment was conducted under $G = 842$ W/m^2 and $T_{PV} = 316$ K. Table 1

$G = 842$ W/m^2 and $T_{PV} = 316$ K are regarded as the reference conditions for this simulation. The relative reference parameters are used to predict the operation of the PV module in this experiment under other conditions.

Table 1 – Parameter of the PV module.

Parameter	STC	$G = 842$ W/m^2 $T_{PV} = 316$ K
I_r (A)	1.03819E-17	6.4325e-016
R_s (Ω)	0.0822	0.1109
R_{sh} (Ω)	10,000	6.2791
a	0.0302	0.032

Ir is the diode reverse saturation current of the PV module. *Rs* is the series resistance of the PV module. *Rsh* is the parallel resistance of the PV module. *a* is the activity of species of the PV module.