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Design and Simulation of A Single Current Sensor Maximum Power Point Tracker for Solar Hydrogen System

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Abstract. Renewable energy sources have attracted a lot of research interest in the past decade. Among these, solar energy is regarded as one of the promising energy sources and has been deployed worldwide with the installed capacity continually increasing. Solar-hydrogen systems have been under research for more than two decades. In such system, maximum power point tracking (MPPT) plays an important role to deliver maximum power from solar panels to the electrolyser. In this paper, two simple but effective MPPT methods are developed and evaluated. Differed from most of the existing methods, these methods are only reliant on a single current sensor input to locate the maximum power point of the solar panel.

Key words

Solar, Hydrogen system, Maximum power point tracking, Single current sensor.

1. Introduction

The world is facing an urgent call for alternative energy resources due to the depletion of conventional fossil fuels together with increasing concern of environmental problems caused by excess utilisation of the fossil fuels such as global warming, and pollution. Solar energy which is abundant, free, clean and environmentally friendly is a promising energy source. By 2011, the global total capacity of solar photovoltaic (PV) has reached 40GW with annual growth rates around 50% since 2005 [1]. Hydrogen is a good candidate to act as an energy carrier to fill the gap between the renewable power generation and the end user demand. It is found that when the hydrogen is produced from renewable energy sources, there are no harmful emissions. Hydrogen can be used in almost all applications where fossil fuels are used today, and can be converted into useful forms of energy more efficiently than fossil fuels [2].

Fundamental studies of solar hydrogen system have been reported [3,4]. A solar hydrogen production system can be configured either by directly connecting the solar panels with the electrolyser, or by utilising a DC/DC converter to link the solar panels and the electrolyser. Due to the inherent intermittency and fluctuation of solar irradiation there is a possibility of mismatch between the characteristic of solar power generation and the characteristic of electrolyser if they are directly connected.

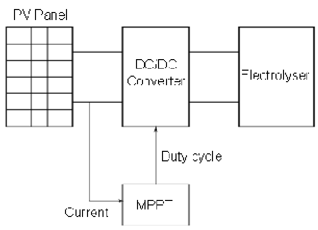
Maximum power point tracking (MPPT) technology is a common practice to generate maximum power from the solar panel under certain light density and cell temperature conditions. It is important not only to improve the system's efficiency but also reduce the cost of installation by reducing the number of solar panels required for desired output power [5]. MPPT technology is a popular research topic and within the past two decades, dozens of different MPPT methods were proposed [6]. Those includes methods such as fractional open circuit voltage method [7,8], fractional short circuit current method [7,9,10], Perturbation & Observation (P&O) method [11-13] and Incremental Conductance (INC) method [11].

In this study, to improve the performance of a solar-hydrogen system, two simple but effective MPPT technologies are developed and evaluated. Differed from methods aforementioned which require two sensors to measure both voltage and current, these new methods only use one sensor to locate the maximum power point of the solar panels.

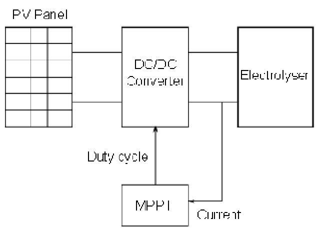
They are designed especially for the solar hydrogen production system, hence, unlike other one voltage sensor MPPT methods [14-15], these methods are straightforward and simple to design and only based on current information extracted from either PV terminal or electrolyser terminal which reduces the overall system cost and the computational burden as well as increases the overall system efficiency by maximising the hydrogen production.

2. System Structure and Modelling

In a stand-alone solar hydrogen system studied in this work, a DC/DC converter provides a link between the PV panel and the electrolyser. The MPPT controller will adjust the duty cycle of the converter to guarantee the maximum power delivered from PV to the electrolyser according to the current information send to the controller. The current information can be extracted from either PV side or the electrolyser side. With this end in view, two different structures of this stand-alone solar hydrogen system using DC/DC converter are presented in Fig.1.



(a) Current information extracted from PV side



(b) Current information extracted from electrolyser side

Fig. 1. System structure of a solar hydrogen system with single current sensor MPPT DC/DC converter

A. Photovoltaic array model

Photovoltaic array converts solar energy to electrical energy. Single PV cells are wired in series or parallel combination to form a module to achieve certain voltage/current level. Numerous modules are interconnected to form an array to achieve higher voltage/current level if necessary. The model of the PV is based on an equivalent circuit which consists of a current source, a diode and a series resister [16] as shown in Fig. 2.

The typical current-voltage (I-V) characteristic for PV cell is expressed in equation (1)

$$I = I_p - I_s\left(\exp\left(\frac{V + IR_s}{\varepsilon V_t}\right) - 1\right) \tag{1}$$

where I_p is the photo current, I_s is the reverse saturation current which is affected by the temperature of the PV cell, V is the cell voltage, ε is the ideality factor which is approximately equal to 1, V_t is the thermal voltage $V_t = k_B T / q$ with the Boltzmann constant $k_B = 1.38 \times 10^{-23} J/K$; T is the absolute temperature of the diode in Kelvin and $q = 1.6 \times 10^{-19} C$ is the charge represented by an electron, finally, R_s is the equivalent series resistance of the PV array describing an internal resistance to the current flow.

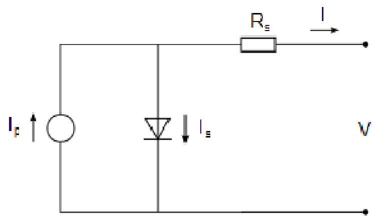


Fig. 2. Equivalent circuit for PV array

All the parameters can be determined by the following equations:

$$\begin{cases} I_p = I_{pr} + K_o(T - T_r) \\ I_{pr} = I_{scr}\dfrac{E}{E_r} \\ I_s = I_{sr}\left(\dfrac{T}{T_r}\right)^{\frac{3}{\varepsilon}} \exp\left(-\dfrac{qV_g}{\varepsilon k_B}\left(\dfrac{1}{T} - \dfrac{1}{T_r}\right)\right) \\ I_{sr} = \dfrac{I_{scr}}{\exp\left(qV_{OCr} / \varepsilon k_B T_r\right) - 1} \\ R_s = -\dfrac{dV}{dI_{V_{OC}}} - \dfrac{1}{X_V} \\ X_V = I_{sr}\dfrac{q}{\varepsilon k_B T_r}\exp\left(\dfrac{qV_{OC_r}}{\varepsilon k_B T_r}\right) \end{cases} \tag{2}$$

where the subscript r represents reference. E is irradiation, K_o is the temperature coefficient of short circuit current which can be found from the manufacturer's data sheet together with T_r, E_r and short circuit current I_{scr}, V_g is the band gap voltage of the semiconductor, it is set at 1.12V in this paper, finally, term $\dfrac{dV}{dI_{V_{OC}}}$ can also be generated from manufacturer's data sheet.

B. Electrolyser model

A 1kW PEM electrolyser model is based on its approximated I-V curve which is expressed as

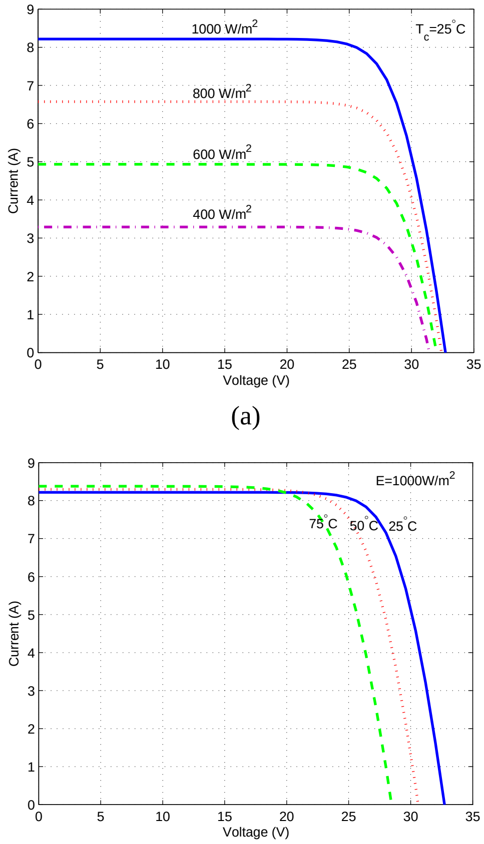
$$V = 1.5995\ln(I) + 6.1409 \quad (3)$$

It should be noted that, when connecting electrolyser as a load to the solar system, the output current and voltage of the converter will always follow the I-V characteristic of the electrolyser.

C. System sizing and the DC/DC converter modelling

The size of the system and the choice of the DC/DC converter are determined by the size of the PEM electrolyser. To support the PEM electrolyser, 6 KC200 solar modules are required to be wired in parallel to form the PV array which provides maximum voltage output at 32V and maximum current output at 50A. The key specifications for the PV modules from manufacturer's data sheet are listed in Table 1. The I-V characteristic for the PV panel with different solar irradiation and cell temperature can be generated from equation (1) and (2) and they are demonstrated in Fig. 3 with the x-axis and y-axis representing the voltage and the current respectively.

Therefore, a buck DC/DC converter is chose to drive a low voltage electrolyser from a high voltage solar panel. The MPPT is designed to adjust the duty cycle of the converter in order to enhance the performance of the system by generating maximum solar power.



(a)

(b)

Fig. 3. I-V Characteristics of solar panel with different radiation levels (a), different cell temperature levels (b)

Table 1. Key specifications of KC200

Dimensions	
Length	$1425(\pm 2.5)mm$
Width	$990(\pm 2.5)mm$
At $1000W/m^2$ **(STC)**	
Maximum Power	$200W$
Maximum Power Voltage	$26.3V$
Maximum Power Current	$7.61A$
Open Circuit Voltage (V_{OC})	$32.9V$
Short Circuit Current (I_{SC})	$8.21A$
At $800W/m^2$ **(NOCT)**	
Maximum Power Voltage	$23.2V$
Maximum Power Current	$6.13A$
Open Circuit Voltage (V_{OC})	$29.9V$
Short Circuit Current (I_{SC})	$6.62A$
Temperature Coefficient of V_{OC}	$-1.23\times10^{-1}V/°C$
Temperature Coefficient of I_{SC}	$3.18\times10^{-3}A/°C$

3. Single Current Sensor MPPT

Power P delivered by a buck converter to the electrolyser is given by

$$P = I^2 R \quad (4)$$

where I is the current input to the electrolyser and R is the equivalent resistance of the electrolyser. Hence, when the maximum power is delivered to the electrolyser by buck converter,

$$\frac{dP}{dt} = \frac{d(I^2R)}{dt} = \frac{dI}{dt} = 0 \quad (5)$$

It is assumed that the buck converter in continuous conductance mode, then equation (6) holds,

$$I = \frac{1}{D} I_{PV} \quad (6)$$

where I_{PV} is the output current of the PV panel and D is the converter's duty cycle.
Substitute equation (6) into (5),

$$\frac{d(I_{PV}/D)}{dt} = 0 \quad (7)$$

Hence, at MPP

$$\frac{dI_{PV}}{dD} = \frac{I_{PV}}{D} \quad (8)$$

The characteristic of I_{PV}/D with the converter duty cycle with different solar irradiation is shown in Fig. 4.

Similarly, an even simpler algorithm can be derived by using only input current to the electrolyser.
Substitute equation (6) into (8),

$$\frac{dDI}{dD} = \frac{DI}{D} \quad (9)$$

Finally,

$$\frac{dI}{dD} = 0 \quad (10)$$

This characteristic can be seen from Fig. 5 for different solar density input.

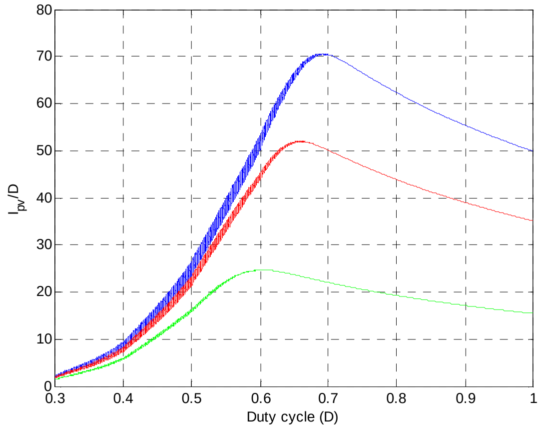


Fig. 4 Characteristic of duty cycle (D) and I_{PV}/D

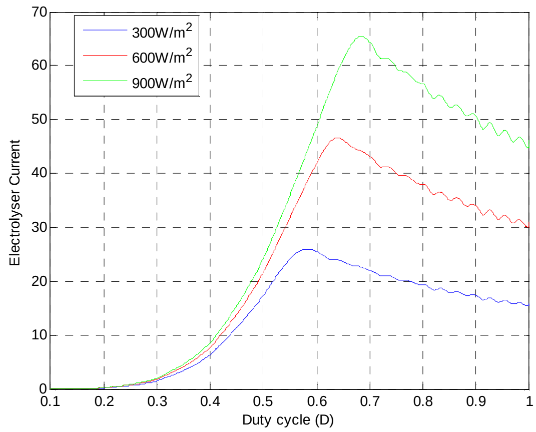


Fig. 5 Characteristic of duty cycle (D) and electrolyser current I

Hence, according to equation (8) and (10) together with Fig. 4 and 5, two single current sensor MPPT methods can be developed.

The flowchart of these two proposed single current sensor MPPT methods are shown in Fig. 6 and 7, respectively.

4. Numerical Results

Efficiency is a commonly used factor to evaluate the performance of a MPPT method. The efficiency is defined as [16]

$$\eta_{MPPT} = \frac{\int P_{actual}(t)dt}{\int P_{\max}(t)dt} \qquad (11)$$

Where P_{actual} is the actual power produced under the control of specific MPPT method, and $P_{\max}$ is the theoretical maximum power the PV array can generate under given illumination and cell temperature.

In this section, the aforementioned two single current sensor MPPT methods are designed and implemented in MATLAB/Simulink. The performances of the proposed MPPT methods are compared with conventional P&O method with two different fixed perturbation size $\Delta D = 0.015$ and $\Delta D = 0.005$.

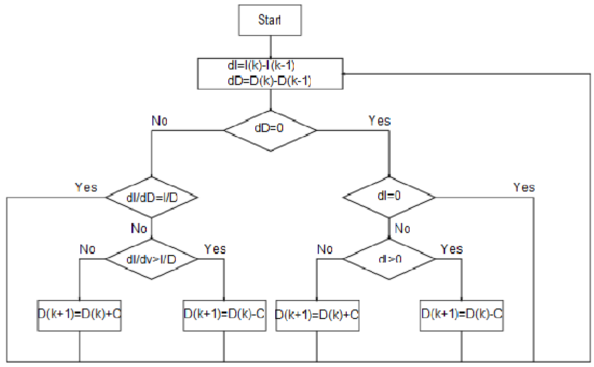


Fig. 6 Flowchart of the proposed single sensor MPPT method based on PV current input

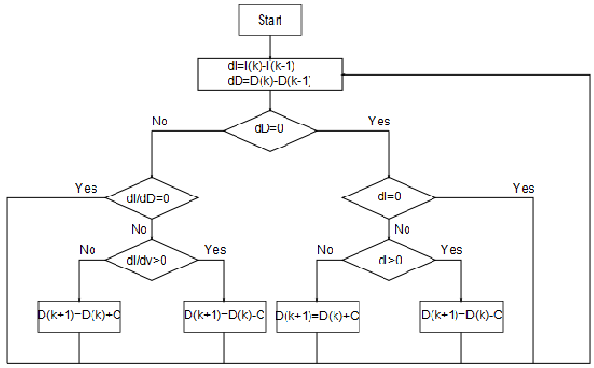


Fig. 7 Flowchart of the proposed single sensor MPPT method based on electrolyser current input

The solar irradiation level is set at $0.2kW/m^2$ with the theoretical maximum power output of $226.7898W$. The theoretical maximum power together with the generated solar power under the control of the conventional P&O method and the developed single current sensor MPPTs are illustrated in Fig. 8. From the figure, it is clear that the two proposed methods have much better performance compared with the conventional P&O method. The power from the solar panel is successfully delivered to the electrolyser at all times by the converter.

Using equation (11) to calculate the steady state efficiency, the efficiency are 98.35% and 94.23% for single current sensor MPPT method with electrolyser side current input and PV side current input, respectively.

It can also be seen from the figure that, the MPPT method with PV side current input has slightly faster response compared with the method using electrolyser side current input. This is due to the delay cause by the DC/DC converter. But the later method has a better steady state efficiency which will yield more hydrogen in a longer term.

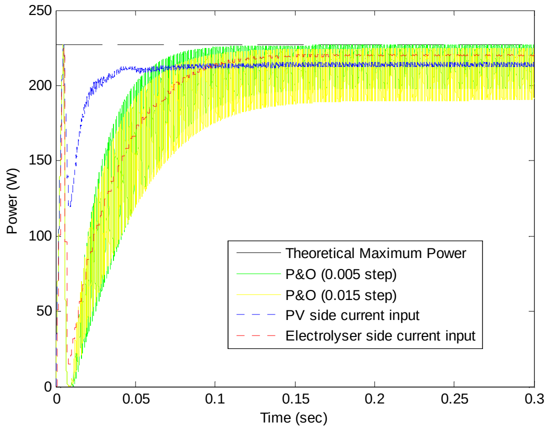


Fig. 8 Tracking performance comparison of two single sensor MPPTs with conventional P&O method

5. Conclusion

In this study, two single current sensor MPPT methods are developed and evaluated using numerical results. Differed from other methods, these two methods only require one current sensor input which reduce the overall system cost and the complexity of the MPPT strategy. The numerical results also proved that under the regulation of these single sensor MPPT methods, a good tracking performance for the solar-hydrogen system can be achieved.

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