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A Maximum Power Point Tracking Converter of Photovoltaic-Solid Polymer Electrolysis System for Hydrogen Production

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Abstract:- We designed a hybrid photovoltaic-solid polymer electrolysis system to produce hydrogen from water based on electrolysis process. To convert the output voltage from photovoltaic panel to the voltage of SPE cell we utilize a PWM Buck DC-DC Converter. Function of the PWM Buck DC-DC Converter is to deliver a optimum power that can yield the maximum output of hydrogen. The system consists of a photovoltaic panel as source of electricity, a dc-dc converter and a SPE cell as load, where the SPE cell that can convert water to be hydrogen and oxygen through electrolysis process. The system has been tested and measured the relation between power output of photovoltaic and hydrogen production. The dc-dc converter performance and hydrogen production performance of this method have been evaluated and discussed based on the results of the experiment.

Keywords:- *hydrogen energy; photovoltaic; solid polymer electrolysis, MPPT, dc-dc converter.*

I. INTRODUCTION

Concerns about environmental issues, such as global warming and the breaching of the ozone layer due to carbon dioxide exhaustion, have recently increased around the world. The Conference on Climate Change (COP26) was held in Glasgow in November 2021. An agreement has been approved that expressly plans to reduce unrestricted coal use and other fossil fuel source energy.

As a result, significant progress has been made in hydrogen production research and development. Such as, Lehman and Chamberlin (1991), Lund and Sakai et al. (1993), and Sakai et al. (1994) reported fundamental studies of solar hydrogen energy systems in which hydrogen is obtained from water by directly connecting a photovoltaic module to a hydrogen generator via a solid polymer electrolyte [1- 8].

In this context, photovoltaic (herein referred to as PV) and hydrogen energy systems for utilizing clean and renewable energy were highlighted to contribute significantly to global warming prevention.

As a clean energy source, hydrogen has piqued the interest of many. Hydrogen is a high-quality, clean-burning fuel that has the potential to replace oil and natural gas in transportation, heating, and power generation. The majority of hydrogen is produced from crude oil or natural gas via steam reforming or partial oxidation. Hydrogen derived from fossil fuels such as oil or natural gas cannot be used in a sustainable and recyclable energy system. If hydrogen is produced using solar photovoltaic (PV)-powered water electrolysis, it is theoretically possible to provide energy on a global scale while emitting virtually no greenhouse gases and emitting very little local pollution.

Water electrolysis with cells containing a solid polymer electrolyte is a highly efficient method of producing hydrogen. SPE water electrolysis technology has demonstrated higher efficiency and current density capability than conventional alkaline water electrolyzers, and has recently been regarded as a promising method for future large-scale hydrogen production [9-15].

Because the PV-hydrogen energy system is costly to construct, it should be operated at maximum output power levels. The output of a PV generating system, on the other hand, is not systemically tracked and is influenced by a variety of factors such as solar insolation, solar cell temperature, and connected load condition. As a result, the effect of these three factors should be considered when designing the PV-SPE system. A MPPT, on the other hand, is required to overcome system adverse effects and to operate the PV panel at maximum power point (MPP) at all times.

In order to address the issues raised above and improve the performance of the PV-SPE system, an alternative simple control scheme is proposed in this paper.

We propose a control method is based on the maximum current searching method, then a control circuit for the PV-SPE system has been realized and tested.

The goal of this research is to design and optimize a PV-SPE system based on maximum power point tracking (MPPT) and maximum power input.

II. PV-SPE SYSTEM

Figure 1 depicts a PV-SPE system with a dc-dc converter; the system consist of a PV Panel, a DC-DC Converter and a SPE Cell.

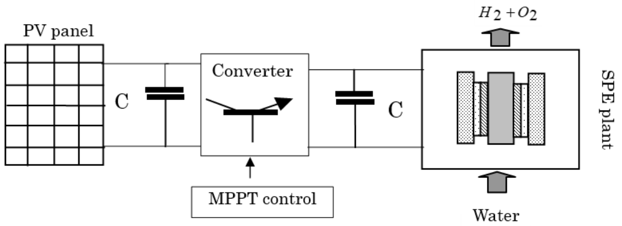

Fig. 1: PV-SPE system circuit diagram with dc-dc converter

The performance of the PV-SPE system can be improved by tracking the maximum power point of the PV panel and matching the SPE voltage with a dc-dc converter. During this process, a step-down dc-dc converter is used to drive a low voltage load from the PV panel's high voltage. The output (SPE) voltage of this converter is always lower than the input PV panel voltage. The on/off duty cycle of the switch controls the power flow from the PV panel to the SPE.

We obtained a electrical model of SPE cell, based on our experiment, where the general equation of SPE as follow:

$\mathbf{v}$=1.936+ 0.0183$\mathbf{I}$-0.012$\mathbf{T}$ (1)

Where $\mathbf{v}$ is SPE cell voltage, I is SPE cell current and T is water temperature that used in the process of electrolysis.

As a result, the step-down DC-DC converter used in this system should have the following relationship between input and output [16]:

$$V_{in} * I_{in} * \eta = V_{out} * I_{out} \quad (2)$$

Because the DC-DC converter's input is connected to the PV panel and its output is connected to the SPE, then the equation (2) becomes:

$$V_{PV} * I_{PV} * \eta = P_{PV} = V_{SPE} * I_{SPE} = c * I_{SPE} \quad (3)$$

Where V_{PV}, I_{PV}, V_{SPE} and I_{SPE} are voltages and currents of the PV panel and the SPE respectively. P_{PV} is the power of PV panel. Since V_{SPE} remains almost constant this value can be replaced with a constant, c .

Therefore, with an assumption that the system is ideal with η=1, then: P_{max}

(In PV panel side) = $V_{PV\max} * I_{PV\max}$ = $c * I_{SPE\max}$ (In SPE side) (4)

From eq. (4-5) if I_{SPE} reaches a maximum value, then P_{PV} will also have a maximum value.

$P_{\max}$, $V_{PV\max}$, $I_{\max}$ are power, voltage and current respectively of the PV at the maximum point of operation.

There is only one control parameter for a step-down DC-DC converter, and that is the duty cycle D of the power electronics switch. The duty factor, D, of the step-down DC-DC converter is expressed as follows:

$$D = \frac{V_{in}}{V_{out}} = \frac{V_{PV}}{V_{SPE}} = \frac{I_{SPE}}{I_{PV}} \quad (5)$$

And then we get,

$D * I_{PV\max}$ = $P_{PV\max}$ (In PV side) = $c * I_{SPE\max}$ (In SPE side) (6)

We can see from eq. (6) that by maximizing the output current of the converter with SPE as load, we can track the maximum power point of the PV panel by controlling the duty factor of the DC-DC converter.

We can implement a maximum current controller block diagram using equation (6) as shown in Figure 2. The underlying principle of this system is as follows: A proportional integrator (PI) controller generates an error voltage proportional to the results, which is then integrated and transmitted to the comparator. A sawtooth voltage is used to compare the transmitted signal. As a result of the compared signal, IC TL 494 generates a PWM signal to control the duty factor of the power electronic switch. The PV panel power can be controlled by varying the duty factor of the switch. Because PV power can be controlled, so can the lighting. If the error voltage does not equal zero, the signal to the comparator will continuously increase, causing the duty factor to change in such a way that the error voltage will be reduced to zero.

Because the voltage reference is greater than the value of, the error will never be zero. As a result, the controller will continue to track in order to obtain the highest of. The system will run smoothly if the aforementioned theory is incorporated into the design. We can get the MPPT on the PV side if we can track the highest (maximum) current on the SPE side.

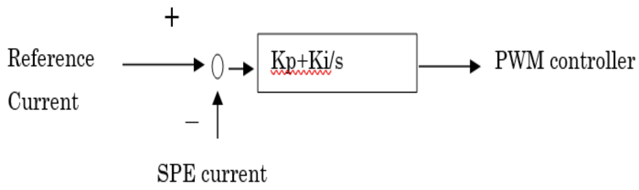

Fig. 2: Block diagram of maximum current controller

III. DC-DC CONVERTER PERFORMANCE

Figure 1 depicts a PV-SPE system with a controller of dc-dc converter; the system consists of a PV Panel, a DC-DC Converter and a SPE Cell.

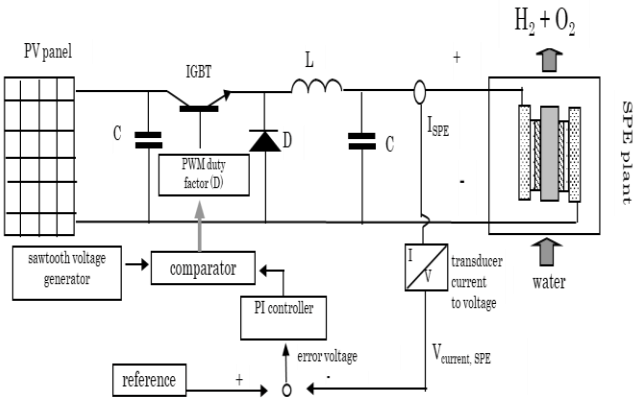

Fig. 3: PV-SPE system circuit diagram with control mechanisme

Complete circuit of dc-dc converter with PI controller shown in figure 4.

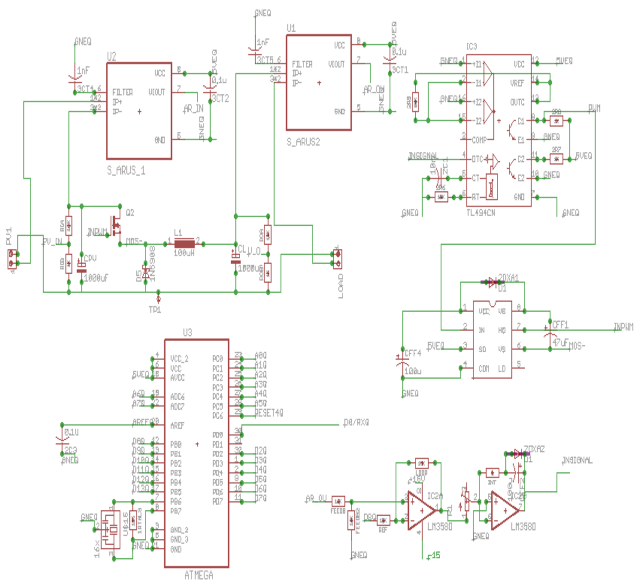

Fig. 4: A schematic diagram of DC-DC Converter with PI Controller

We fabricated the complete of DC-DC Converter with PI Controller as shown in Figure 5.

Fig. 5: A fabricated DC-DC Converter with PI Controller.

Figure 4 shows the circuit diagram of a dc-dc converter using maximum current control method, it is clear that the circuit consists of the following:

- A DC-dc converter that used in here is buck converter type.
- A proportional integrator controller consists of an operational amplifier, capacitor and variable resistor. The equation function of the proportional integrator is T(s) equal with where K is the proportional gain and T is the time constant of the controller. The designed PI controller has the equation function as T(s)= $K(1+\frac{1}{sT})$
- MOSFETS, diodes, capacitors, and an inductor make up X. The PWM and MOSFET driver section is primarily made up of a PWM IC TL494, which functions as a comparator and a sawtooth voltage generator the step-down DC-DC converter.
- Procedure work of microcontroller to control this converter, based on flowchart that shown in Figure 6. Where the controller that we used in here is Atmega 328P to generated reference voltage and to read current value from SPE., and method to program this microcontroller use Arduino IDE. An algorithm has been implemented to make this controller works as described in a flowchart in Figure 6. When the microcontroller gets analog signal (current) from output of DC-DC Converter, where this current is converted to the voltage value as analog input of microcontroller. When this value is compared with previous value. Based on the Figure 6, when the old SPE Current > the New SPE current, then the microcontroller will add new reference=old reference +0.2; This New reference will be used as input signal to PI controller. But when SPE Current < the New SPE current, then the microcontroller will add new reference=old reference -0.2; This New reference will be used as input signal to PI controller.

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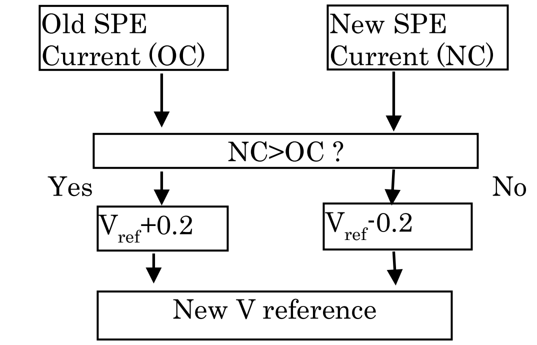

Fig. 6: A Flowchart of programming algorithm to controk the DC-DC Converter

IV. EXPERIMENT OF THE OPERATION OF PV-SPE SYSTEM

The prototype for aforementioned MPPT for a prototype PV-SPE system using maximum current controller schema were built and tested.

The experimental setup as shown in Figure 7 All measured data will be acquired and analyzed by computer.

A PV panel that used in here is with specification is listed on Table 1, was installed on a rack tilted 30° toward south. The surface's PV panel temperature was measured by a thermocouple which was laminated on the surface of PV panel, Total solar insolation on the plane of PV was monitored with an actinometer.

Type	C8P-4516 (Sanyo)	**V_{oc} at 25 oC**	20.88 Volt
R_s	0.028 Ω	**I_{sc} at 1.0kW/m2**	3.0 Ampere
R_{sh}	1 kΩ	**Number of cells**	36

Table 1: Specification of PV panel

A. Measurement of dc-dc converter performance

In this work a step-down dc-dc converter is used that has performance as shown in Figure 7. The performance was measured with measures current and voltage for each input and output side respectively. As load using an Electronic DC Load. To measure performance by changing the PWM switch of converter and the load value of Electronic DC load

Based on Figure 7, we can see that the dc-dc converter work with good performance. The efficiency of this dc-dc converter depends on V_{out}/V_{in} ratio. If V_{out}/V_{in} ratio close to 1, then the efficiency of the converter will increase to 100%.

B. Measurement of MPPT converter performance

We measure the performance of MPPT converter of PV-SPE system, at PV surface's temperature 41.4 °C and insolation 0.8 kW/m^2. The performance was measured with measures current and voltage for each input and output side respectively. As load using a Solid Polymer Electrolysis Cell. The procedure to measure performance of MPPT converter is by change the connection switch, at initial condition the switch make open circuit of PV panel, after that we change the connection, where the PV panel we connect to the input of dc-dc converter and then the output of dc-dc converter we connect to SPE cell. Figure 8 shows results of the performance of MPPT converter.

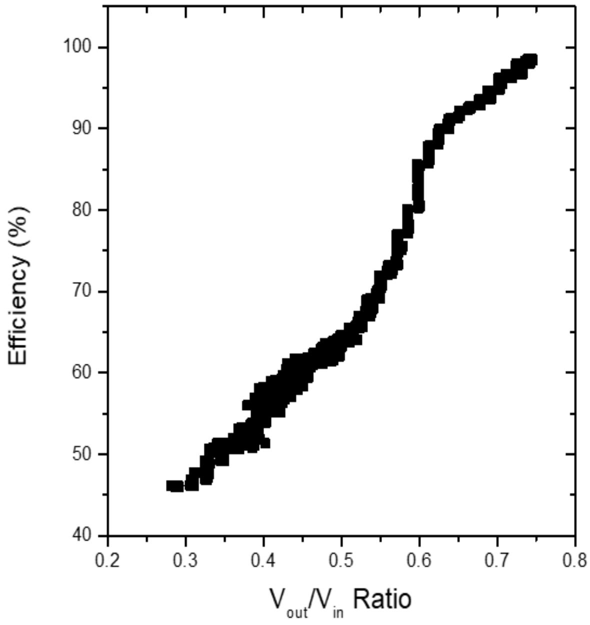

Fig. 7: Measurement results of performance dc-dc converter.

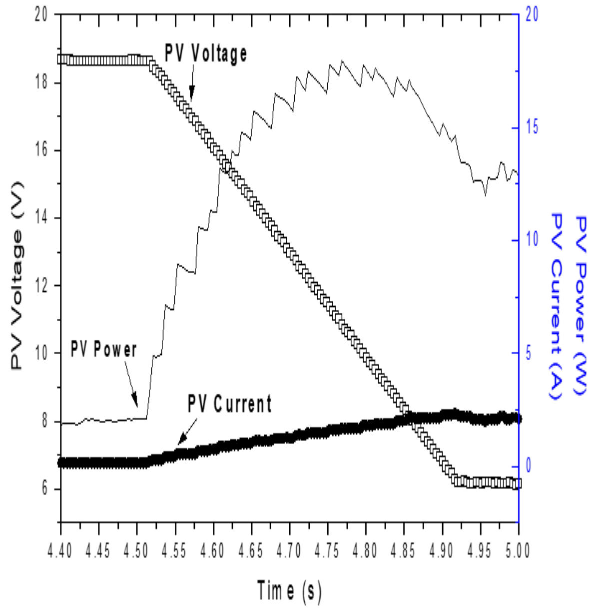

Fig. 8: Measurement results of performance MPPT Controller

At the time 4.5 we start to change switch connection, and the time MPPT converter start work.

Based on Figure 8 The MPPT converter successfully track the maximum power point. It is clear that the MPPT converter searched for the maximum power point of the solar from open-circuit voltage to the maximum power point. The MPPT process for searching from initial point at 4.5s to the maximum power point at 4.9 needed time 0.3 s.

C. Measurement of PV-SPE performance

We measure the performance of PV-SPE system using the MPPT converter of PV-SPE system, at PV surface's temperature 41.4 ºC and insolation 0.8 kW/m^2. The performance of this system obtained from measurement of current and voltage for each input and output side respectively. As load we use a Solid Polymer Electrolysis Cell.

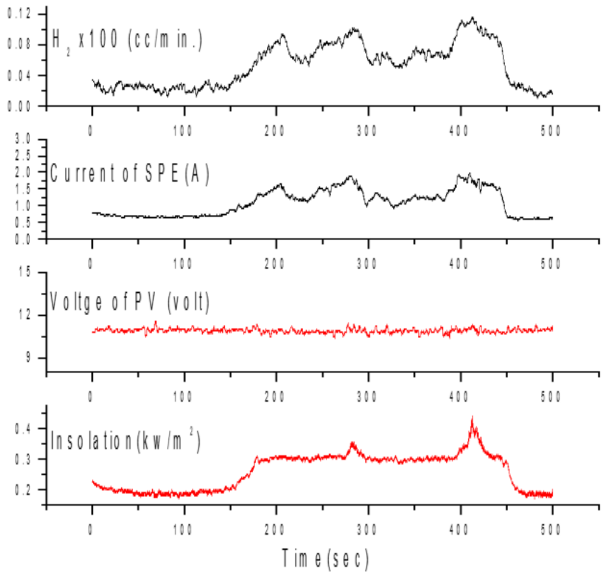

Fig. 9: Measurement results of performance PV-SPE System.

Figure 9 depicts the operation of the PV-SPE system with a maximum current controller for 15 minutes. The input voltage and current, cell temperature, insolation, and hydrogen production rate were all measured using a data acquisition system. The experiment demonstrates that the PV panel's power can successfully deliver the maximum power to the SPE at all times.

V. DISCUSSIONAND CONCLUSION

Based on process design and experimental as have been mentioned in above, that this PV-SPE system use MPPT converter has been tested. The table II. Based on table II we can conclude that using this MPPT controller can increase power until 68% and also make increase of hydrogen production to 37%.

Items	Results
Average Insolation	0.35 kW/m^2
Average Surface temperature of PV panel	35 ºC
Used PV Power using converter	13.3 W
Used PV Power without converter	4.2 W
Advantage Power using Converter	68%
Production Rate of H_2 using converter	13.5
Advantage of Prod. of H_2 using converter	37%

Table 2: Comparison of the experimental result between using converter

VI. CONCLUSION

Since the intensive use of fossil fuels has caused an increase in pollutants and the greenhouse effect in the atmosphere. And using hydrogen is a method of reducing global warming and replacing the fuel of a fossil cell.

As a clean energy source, hydrogen has piqued the interest of many. Hydrogen is a high-quality, clean-burning fuel that has the potential to replace oil and natural gas in transportation, heating, and power generation.

The majority of hydrogen is produced from crude oil or natural gas via steam reforming or partial oxidation. Hydrogen derived from fossil fuels such as oil or natural gas cannot be used in a sustainable and recyclable energy system. If hydrogen is produced using solar photovoltaic (PV)-powered water electrolysis, it is theoretically possible to provide energy on a global scale while emitting virtually no greenhouse gases and emitting very little local pollution.

Because the PV-hydrogen energy system is costly to construct, it should be operated at maximum output power levels. The output of a PV generating system, on the other hand, is not systemically tracked and is influenced by a variety of factors such as solar insolation, solar cell temperature, and connected load condition. As a result, the effect of these three factors should be considered when designing the PV-SPE system. A MPPT, on the other hand, is required to overcome system adverse effects and to operate the PV panel at maximum power point (MPP) at all times.

This paper proposes a hydrogen production system based on the maximum current control scheme.

The following are the main findings of this study:

- The proposed control methods for the PV-SPE system have been realized and tested using the maximum current searching method.
- The maximum current control scheme was successful in increasing the output of the hydrogen production rate.
- The economic analysis of the introduced system revealed that the price of hydrogen using the PV-SPE system is lower than the market price.

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