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Implementation of maximum power point tracker algorithm based proportional-integrator controller on solar cell with boost converter circuit (Conference Paper)

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Abstract

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Maximum power point tracker algorithm based proportional-integrator controller (PI-MPPT) makes the solar cell worked at optimal condition by tracking the maximum power of solar cell using a PI controller . The result of the simulation shows that PI MPPT algorithm can control the solar cell to work at the optimal condition with boost converter circuit [2]. The result of the experiment shows that PI MPPT algorithm also can control the solar cell to work at the optimal condition with time sampling of PI MPPT 0.00005 seconds and a load of boost converter use four lamps. © 2017 IEEE.

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Implementation of Maximum Power Point Tracker Algorithm based Proportional-Integrator Controller on Solar Cell with Boost Converter Circuit

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***Abstract*—Maximum power point tracker algorithm based proportional-integrator controller (PI-MPPT) makes the solar cell worked at optimal condition by tracking the maximum power of solar cell using a PI controller. The result of the simulation shows that PI MPPT algorithm can control the solar cell to work at the optimal condition with boost converter circuit [2]. The result of the experiment shows that PI MPPT algorithm also can control the solar cell to work at the optimal condition with time sampling of PI MPPT 0.00005 seconds and a load of boost converter use four lamps.**

Keywords* —*MPPT; Boost Converter; Solar Cell; PI Controller

I. Introduction

As a tropical climates country, electrical energy from sunlight can be used as an alternative electrical energy source. Besides the infinite energy from sunlight, this electrical energy does not cause any environmental pollution. It can be placed everywhere as long as it is directly exposed from sunlight, and easy to maintain. Electrical energy source from sunlight uses a solar cell as a converter from sunlight energy to electrical energy. Solar cell works with photovoltaic effect, which photovoltaic effect was first explored in 1839 by French physicist Alexander-Edmond Becquerel. The solar power technology was further developed in 1954 when Bell Laboratories Accidentally found that silicon doped with certain impurities was very sensitive to light [1].

However, Solar Cells has low efficiency in converting sunlight energy into electrical energy, so the output power generated is low. Another characteristic that the power generation of the solar cell depends on is the weather, especially the amount of sunlight received and the temperature. Therefore, it is used a Maximum Power Point Tracker (MPPT) algorithm. This algorithm makes a solar cell worked at optimal condition by tracking the maximum power of the solar cell [2]. MPPT algorithm is commonly used to make a solar cell worked at optimal condition and the method of MPTT algorithm has started to be common practice in the research, but the most commonly used is Incremental Conductance Method (ICM). Incremental Conductance Method tracking the optimal power based on the power to voltage (P-V) curve and power to current (P-I) curve, which that optimal power condition of solar cell reached if the gradient of P-V and P-I curves is zero. The weakness of ICM is that ICM has bad response to get MPP condition and big oscillations at MPP condition because of constant Vref changes [3]. Therefore, to track an optimal condition of the solar cell and make a solar cell work in optimal condition, this research uses MPPT method based on Proportional- Integrator (PI) controller. This method is tracking an optimal condition of the solar cell by PI controller, so the output response of the solar cell can be adjusted as the user desired.

II. Solar Cell System

The solar cell is a electronics device that can generate electrical energy from sunlight energy. The solar cell is formed from a semiconductor material that sensitive with exposure from sunlight. The solar cell using photovoltaic effect to convert from sunlight energy to electrical energy. The photovoltaic effect is a process of a solar cell to collect a photon from sunlight to generate electrical energy. The solar cell has a mathematic model that represents an output current characteristic of the solar cell (Fig. 1) and it is explained in equation (1) [5].

$$I_{PV} = I_{Ph} - I_S\left(\exp\left(\frac{q(V_{PV}+R_S I_{PV})}{A\,K\,T_C}\right) - 1\right) - \frac{(V_{PV}+R_S I_{PV})}{R_{Sh}} \qquad (1)$$

$$I_{Ph} = (I_{SC} + \alpha(T_C - T_{ref}))\frac{\lambda}{\lambda_{ref}} \qquad (2)$$

$$I_S = I_{RS}\left(\frac{T_C}{T_{ref}}\right)^3 \exp\left(\frac{qE_G\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)}{K\,A}\right) \qquad (3)$$

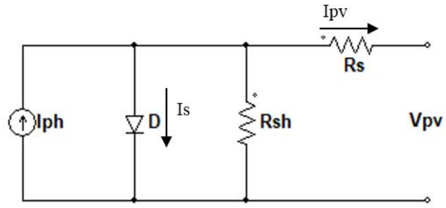

Fig. 1. Simplified Solar Cell Model [4].

$$I_{RS} = \frac{I_{SC}}{(exp(\frac{qV_{OC}}{A\,K\,T_C})-1)} \quad (4)$$

where:

I_{PV} : Solar cell current (A)

I_{Ph} : Cells internal generated photocurrent (A)

I_{SC} : Solar cell short-circuit (A)

I_S : saturation current of diode (A)

I_{RS} : Reverse saturation current of diode (A)

V_{PV} : Solar cell voltage (V)

V_{OC} : Solar cell open-circuit voltage (V)

q : Electron charge (1.60217646 x 10^{-19} C)

α : Temperature coefficient of I_{SC} (A/K)

A : Diode ideality factor

K : Boltzmann constant (1.3806503 x 10^{-23} J/K)

λ : Irradiance (W/m^2)

λ_{ref} : Irradiance reference (1000 W/m^2)

T_C : Cell temperature (K)

T_{ref} : Cell temperature reference (298 K)

E_G : Band gap energy of solar cell technology (Si = 1.3 eV)

R_S : Series resistance (Ohm)

R_{Sh} : Shunt resistance (Ohm)

III. Maximum Power point tracker based PI Controller (PI-MPPT)

To get an optimal condition of the solar cell, the solar cell must be controlled to work at a maximum power of the solar cell. To control the solar cell, it is used the Maximum Power Point Tracker (MPPT) algorithm. This algorithm makes a solar cell worked at optimal condition by tracking the maximum power of solar cell and maintain the solar cell to worked at optimal condition.

PI controller method is a modification of Incremental Conductance Method (ICM) to get variant Vref changes. This PI controller method is tracking an optimal condition by calculating the error from gradient value of a P-V curve. The setpoint of this method is zero because the optimal condition of the solar cell is reached if the gradient of the P-V curves is zero and the feedback is the gradient of P-V curves. This PI controller method has a contrary of error calculation in general, which the set point has a negative value and the feedback has a positive value. Error calculation of PI-MPPT is explained in equation (5).

$$error = I + \frac{dI\,V}{dV} \quad (5)$$

where I is Solar cell current (A) and V is Solar cell voltage (V)

IV. Design of Boost Converter Circuit

This research uses two modules solar cell with a series configuration which the type of solar cell module is Kyocera KC50T. Boost Converter circuit is designed using a three-phase inverter with adding an inductor component, capacitor component, and load. The function of the three-phase inverter as a switching device and as a diode on boost converter circuit. Fig. 2 shows the boost converter circuit by using a three-phase inverter. Table I shows the component values that are used in boost converter circuit.

Besides all component in Table I, this boost converter also uses a current sensor and diode at the input. A current sensor that used in boost converter circuit is LEM CKSR-25 with the maximum current that can be detected at 25A. Boost converter circuit use 5 diodes with parallel configuration, which the type of diode is 1N4007. The load of boost converter circuit consists of the load and the safety load, which a load of the boost converter is a lamp with specification 100 W/220 V and the safety load is a resistor with specification 1K Ω/100 W. Fig. 3

TABLE I. Component Values of Boost Converter Circuit

Component	Value
Inductor (L)	500 µH
Capacitor Input (Cin)	470 µF
Capacitor Output (Cout)	940 µF

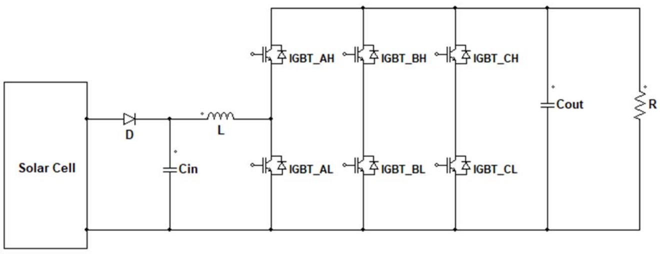

Fig. 2. Boost converter circuit using a three-phase inverter circuit.

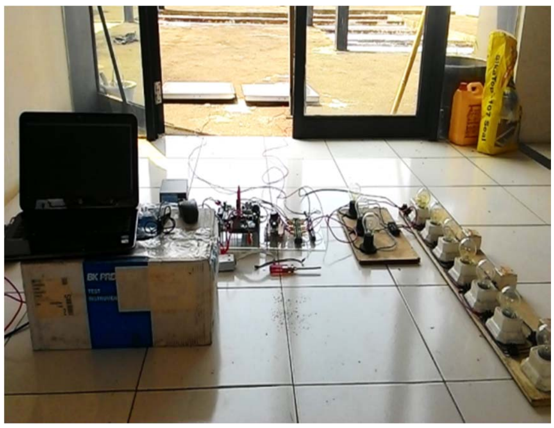

Fig. 3. Solar cell module and boost converter circuit with lamp as a load.

shows the solar cell module and boost converter circuit with the lamp as a load.

V. Experimental Result dan Analysis

A. *Experiment of Solar Cell Characteristic with Boost Converter Circuit*

The purpose of this experiment is to get characteristics of the solar cell which is used in this research. This experiment uses boost converter circuit to control the current output and the output voltage of the solar cell. The control of the current output and voltage output of the solar cell is done by controlling the duty cycle on switching device, so the output characteristic of the solar cell can be obtained. The load of boost converter circuit that is used in this experiment is 4 lamps and 1 safety load in a parallel configuration with the total value of load is 108 Ω/500 W. Fig. 4 until Fig. 7 shows the output characteristic of the solar cell and the boost converter.

From Fig. 4 and Fig. 5, it can be seen that the addition of duty cycle is increasing the output current of solar cell and decreasing the output voltage of solar cell, which the maximum output current of solar cell around 2.5 A. This corresponds to the I-V curve of solar cell, which the output current exceeds the optimal condition of solar cell. The output voltage can be decreased until the solar cell can not generate the voltage. The output power of the solar cell is not directly related to duty cycle on switching device, that output power directly is related to the output current and output voltage of the solar cell. From Fig. 6 and Fig. 7, it can be seen that the maximum output power of the solar cell is around 65 W and the maximum output voltage of the boost converter is around 58 V.

B. *Experiment of Controlling The Output Voltage of Solar Cell*

The purpose of this experiment is to determine whether the output voltage of solar cell can be controlled or not using boost converter circuit. In this experiment, the output voltage of a solar cell is controlled at 30 V with the load that used is 4 lamps and 1 safety load in a parallel configuration with the total value of load is 108 Ω/500 W. Fig. 8 and 9 show the output result of controlling the output voltage of the solar cell.

From Fig. 8, it can be seen that the output voltage of the solar cell has been controlled at 30 V from the earlier output voltage is 38 V. Fig. 9 shows that the output voltage of boost

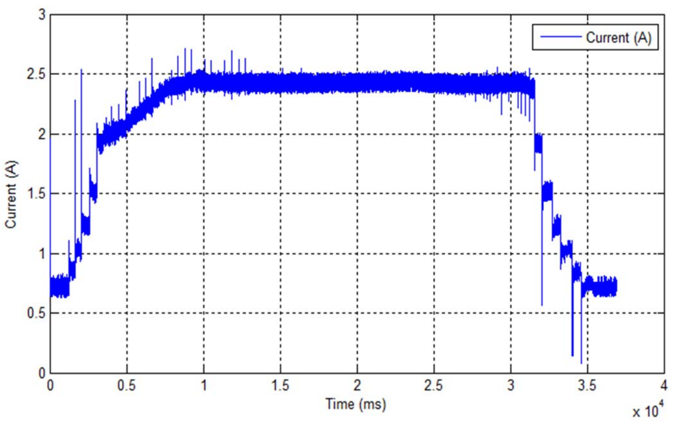

Fig. 4. Current output of solar cell.

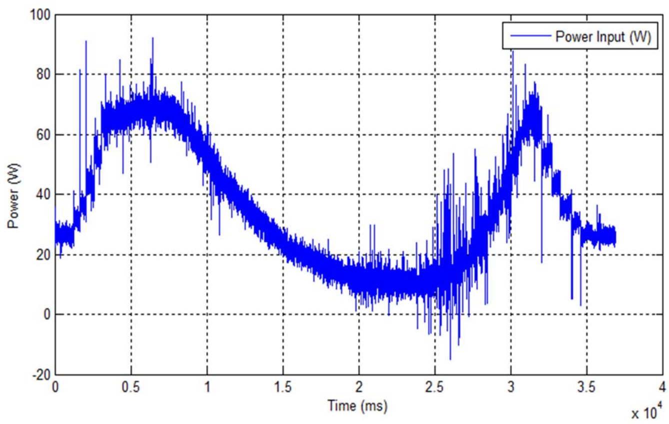

Fig. 6. Power input of boost converter circuit/power output of solar cell.

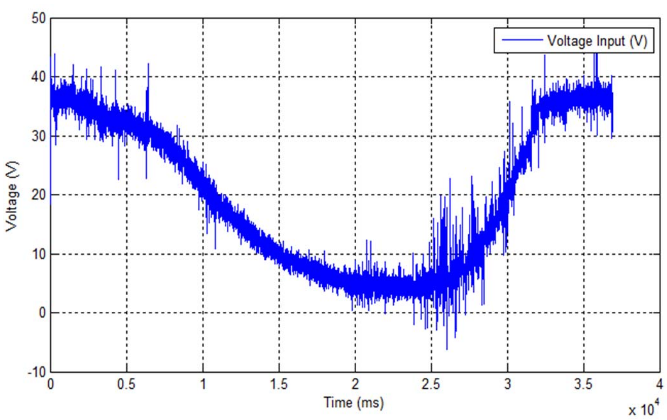

Fig. 5. Voltage input of boost converter circuit/voltage output of solar cell.

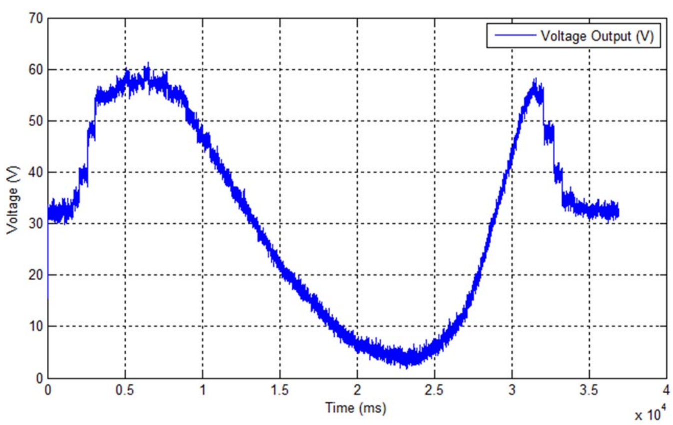

Fig. 7. Voltage output of boost converter circuit.

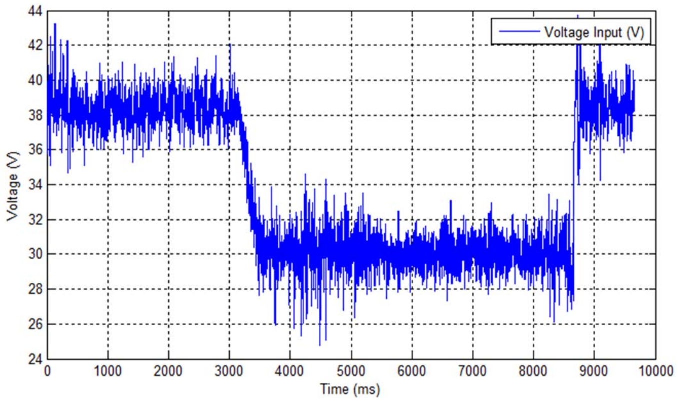

Fig. 8. Voltage input of boost converter circuit/voltage output of solar cell.

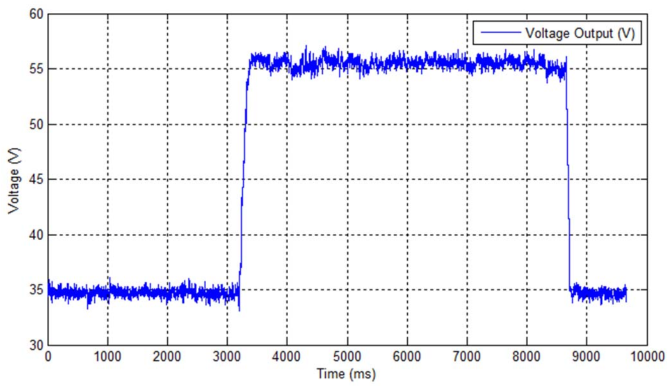

Fig. 9. Voltage output of boost converter circuit.

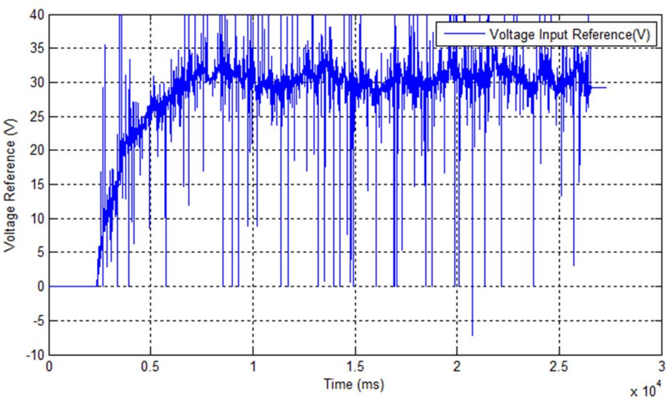

Fig. 10. Voltage input reference of boost converter circuit / voltage output reference of solar cell.

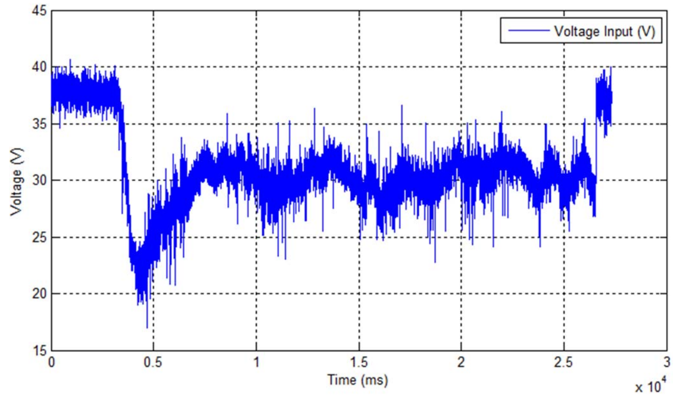

Fig. 11. Voltage input of boost converter circuit/voltage output of solar cell.

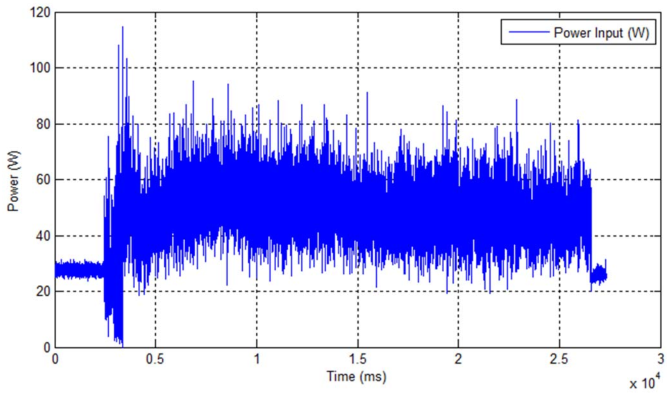

Fig. 12. Power input of boost converter circuit/power output of solar cell.

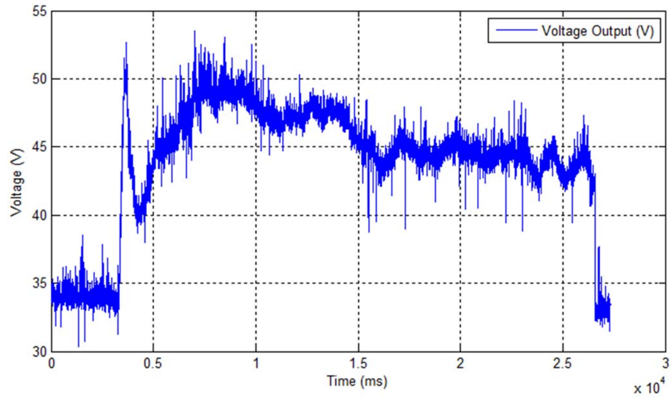

Fig. 13. Voltage output of boost converter circuit.

converter from the output voltage of the solar cell is 56 V.

C. Experiment of PI MPPT Algorithm

The purpose of this experiment is to determine whether PI MPPT algorithm can be implemented or not on the solar cell with boost converter circuit. PI MPPT generates the output voltage reference of the solar cell, then the output voltage of the solar cell is controlled based on the output voltage reference of the solar cell. The time sampling of PI MPPT that is used in this research is 0.00005 sec with the load is 4 lamps and 1 safety load in a parallel configuration with the total value of load is 108 Ω/500 W. Fig. 10 until Fig. 13 shows the output result of PI MPPT algorithm on the solar cell with the boost converter circuit.

From Fig. 10, it can be seen that PI MPPT algorithm can generate the output voltage reference of the solar cell around

30 V, which this output voltage reference is the output voltage on a maximum power condition of the solar cell. Then, the output voltage of the solar cell is controlled by the output voltage reference of the solar cell. It can be seen in Fig. 11 that the output voltage of the solar cell has been controlled around 30 V, that is corresponding to the output voltage reference of the solar cell. From Fig. 12 and Fig. 13, it can be seen that the maximum output power of the solar cell is around 50 W - 55 W and the output voltage of boost converter is around 44 V – 49 V.

VI. CONCLUSIONS

Maximum power point tracker algorithm based proportional-integrator controller (PI-MPPT) makes the solar cell worked in optimal condition, which time sampling of PI MPPT 0.00005 seconds. The output characteristic of the solar cell depends on the load of boost converter circuit, which the best output characteristic of solar cell is using 4 lamp and 1 safety load in parallel configuration with total value of load is 108 Ω/500 W. The designed boost converter circuit can only control the output voltage of solar cell with output voltage reference smaller than the output voltage of the solar cell.

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