Performance comparison maximum power point tracking methods using SEPIC converter

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Abstract. MPPT Algorithms such as Incremental Conductance (IC) are designed to maintain operation of Photovoltaic (PV) system at Maximum Power Point Tracking (MPPT) while preventing oscillations steady state that contribute to power loss. IC work based on the power curve to voltage characteristic of PV. IC method works based on the power curve gradient to the characteristic voltage of the solar panel. The maximum working point of PV where worked at maximum power called a voltage at maximum power point (VMPP). Adding a PID controller to the MPPT IC can reduce the reading error at the reference voltage. Error reading on reference voltage will have an impact on the value of the power. If the reference voltage reading error can be reduced, the value power will be better. In this research, results of power generated by PV system used two different MPPT methods, Conventional MPPT IC and MPPT IC-PID. The results of the MPPT IC-PID can effectively improve the steady state accuracy and tracking accuracy.

1. Introduction

Energy consumption has become a crucial problem in the last decades because of the rapid increase in energy demand. Conventional energy sources are taking over almost 80% of global energy consumption. As a renewable energy source, photovoltaic is promising due to its CO₂ free [1]. The main problem of photovoltaic is its small efficiency among other renewable energy sources. The efficiency of photovoltaic depends on temperature and irradiance of sunlight. Recently, the efficiency of photovoltaic cells is about 12–19% in the most promising conditions [1]. Ones approach to increase the efficiency and obtain the optimal working point of photovoltaic are by finding the maximum power point tracker (MPPT).

Incremental Conductance (IC) is one of MPPT method that can search for maximum power points well without being affected by the changing of photovoltaic conditions. The Maximum Power Point Incremental Conductance (MPPT IC) method is used in a DC-DC converter circuit that has function to control the work of photovoltaic to remain at a predetermined optimal point.

The SEPIC converter is a development of the Buck-Boost converter and the Cuk converter. The SEPIC converter provides a converter that can increase and decrease the output voltage with high efficiency. The advantage of the SEPIC converter can produce an output voltage that has the same polarity as the input voltage source [2].
2. Methods

2.1. Photovoltaic
Photovoltaic (PV) module is technology that can produce DC electricity from a semiconductor material when sunlight strike its surface. PV can described in equivalent circuit diagram as shown in Figure 1.

![Figure 1. Equivalent circuit of photovoltaic](image1)

Model mathematic of PV module as shown below Equation 1.

\[ I = I_{ph} - I_s \left( \exp \left( \frac{q(V+IR_s)}{nKT} \right) - 1 \right) - \frac{(V+IR_s)}{R_{sh}} \]  \hspace{1cm} (1)

where, \( I_{ph} \) is the photocurrent, \( I_s \) saturation current, \( K \) is the Boltzmann’s constant, \( n \) is the diode factor, \( q \) is the electronic charge, \( V \) is the voltage across the diode, \( T \) is the junction temperature in Kelvin, \( R_{sh} \) is the shunt resistance and \( R_s \) is the series resistance [3]. The output P-V characteristic of the PV module with the different irradiance and temperature value shown in Figure 2.

![Figure 2. P-V characteristic of the PV module](image2)

2.2. SEPIC Converter
The conventional power converter such as buck, boost and buck-boost converters cannot maintain a wide operation range with high efficiency, especially if up and down voltage conversion has to be achieved. But that problem can be solved by using in a Single Ended Primary Inductor converter (SEPIC). The SEPIC converter is a type of converter that can increase and decrease the output voltage by setting the value of the duty cycle on the gate of the MOSFET for switching. SEPIC converter circuit as shown in Figure 3 [4].

![Figure 3. Circuit diagram of the SEPIC converter](image3)
The design of the SEPIC converter can be obtained from the following formula. The value duty cycle
is given as Equation 2.

\[ D = \frac{V_{out} + V_D}{V_{out} + V_{in} + V_D} \]  

(2)

The inductor value is calculated as Equation 3.

\[ L_1 = L_2 = L = \frac{V_{in}}{\Delta L x f_{sw}} \times D \]  

(3)

The coupling capacitor value is calculated as Equation 4.

\[ C_1 = \frac{D}{R \left( \frac{\Delta V_{cl}}{V_{out}} \right) x f_{sw}} \]  

(4)

The output capacitor value is calculated as Equation 5.

\[ C_2 = \frac{D}{R \left( \frac{\Delta V_{out}}{V_{out}} \right) x f_{sw}} \]  

(5)

2.3. Incremental Conductance

Incremental Conductance (IC) use the slope of the P-V curve to detect the Maximum Power Point
(MPP). The algorithm of Incremental Conductance determines the position of the operating point of the
PV module in the P-V curve by using two values, instantaneous conductance and incremental
conductance. PV module works at the MPP condition shown in Equation 6. The PV systems works at
right side of the MPP shown in Equation 7. Meanwhile, PV module works at left side of the MPP shown
in Equation 8.

\[ \frac{dl}{dV} = -\frac{l}{v} \]  

(6)

\[ \frac{dl}{dV} < -\frac{l}{v} \]  

(7)

\[ \frac{dl}{dV} > -\frac{l}{v} \]  

(8)

The flowcharts of Incremental Conductance shown in Figure 4. The current and the voltage of PV
module are read by MPPT controller. Duty cycle of the converter is increased if Eq. 7 is satisfied and
duty cycle of the converter is decreased if Equation 8 is satisfied. Duty cycle will no change if Equation
6 satisfied and MPP has been achieved [5].

At the MPP conditions, the value of zero slope by Incremental Conductance is rarely achieved, so
that contribute oscillation on steady state. If there changes the value of irradiance input PV module, it
will affect the time to reach the MPP and the value of the MPP that will be achieved caused delay
tracking the new MPP [6].
2.4. Proposed SEPIC and MPPT Incremental Conductance PID

In this MPPT Incremental Conductance method can be modified by adding a controller. PID controller has function that can reduce oscillation steady state. Oscillation steady state influenced reading voltage reference ($V_{REF}$) at MPP condition ($V_{MP}$). PID control has function reduce the reading error of voltage, so it can give contribute to give accurate for $V_{MP}$ [7].

![Flowchart IC](image)

**Figure 4. Flowchart IC**

![Proposed SEPIC and MPPT IC-PID](image)

**Figure 5. Proposed SEPIC and MPPT IC-PID.**
The MPPT IC system provides reference voltage $V_{REF}$. $V_{REF}$ is the voltage value when the power value at its maximum point. Then, $V_{REF}$ will be the reference voltage on the PID controller [8]. The function of the PID controller in the MPPT IC system is to improve the work of the MPPT system so it gains the set-point of the maximum photovoltaic. The output of the PID controller has connected to the PWM signal generator. The PWM signal has function for switching MOSFET in SEPIC converter. The proposed of PV system MPPT IC-PID shown in Figure 5.

3. Results and Discussion

Inputs of PV system are irradiance and temperature. In this research, temperature set on 25°C. Contain data about irradiance which is varied rapidly for an overall range of 600 W/m$^2$ to 1000 W/m$^2$ shown in Table 1.

| Stage Number | Irradiance range (W/m$^2$) | Time range (s) |
|--------------|-----------------------------|----------------|
| 1            | 0 $\rightarrow$ 800        | 0 $\rightarrow$ 2.5 |
| 2            | 800 $\rightarrow$ 600      | 2.5 $\rightarrow$ 2.7 |
| 3            | 600 (fixed)                | 2.7 $\rightarrow$ 5 |
| 4            | 600 $\rightarrow$ 1000     | 5 $\rightarrow$ 5.2 |
| 5            | 1000 (fixed)               | 5.2 $\rightarrow$ 7.5 |
| 6            | 1000 $\rightarrow$ 800     | 7.5 $\rightarrow$ 7.7 |

The SEPIC converter has maximum voltage from the PV with MPPT IC using PID system. The output power of converter to contain has less oscillation as possible. The output SEPIC converter is shown in Figure 6. The result shows that SEPIC converter by using MPPT IC using PID has increased the power output.

Table 2 shows that the response time of the comparison IC and IC-PID. The results show that response time of the IC is about 0.16 s when the irradiance 800 W/m$^2$ to 600 W/m$^2$. But compared with IC-PID, the stable power is 0.17 s and increase average output power is about 9 watt higher.

| MPPT  | Average output power (W) | Response time (s) | 600 to 1000 W/m$^2$ |
|-------|--------------------------|-------------------|---------------------|
| IC    | 120.22                   | 0.24              | 0.16                |
| IC-PID| 129.91                   | 0.27              | 0.17                |
4. Conclusion
Design of SEPIC converter using MPPT IC-PID for maximum power point tracking in photovoltaic has been presented. The result shows that SEPIC converter using MPPT IC-PID can reduce oscillation steady state and increase average output power. The following conclusions are obtained that MPPT IC-PID controller can effectively improve the steady state accuracy and tracking accuracy.

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