Maximum power point tracking using lagrange interpolation method to optimized photovoltaic on dc microgrid system

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Abstract. Electrical energy is very important for everyday life. The need of electrical energy increasing every year. However, the solar panel source has a weakness. The output power of solar panel is still fluctuating depending on ambient temperature and solar irradiations on the solar panel. Irradiation is the radiant of energy that comes from the sun. To overcome the problem the Maximum Power Point Tracking is needed so it can make solar panel work at its optimum point. This Maximum Power Point Method is looking for the largest current and voltage read by solar panel using the Lagrange Interpolation method. By using Maximum Power Point Tracking, the output power is expected to be optimal with constant voltage and current so that the battery’s lifetime is not damaged quickly. This method can track Maximum Power Point whenever irradiation changes occur. The converter used in this Maximum Power Point Tracking is the SEPIC Converter. This converter can convert DC to DC voltage in higher or lower voltage without changing its polarity. In this paper, Lagrange Interpolation method has average error in output power of 1.96%.

1. Introduction
In the industrial era 4.0 technological progress is very rapid along with the demand for electricity every day. The main source of electricity is from fossil fuels. If fossil fuels continue to be used to generate electricity, it will run out. Many people do research to be able to replace fossil fuels in order to produce electricity, one of which is to develop the use of renewable energy namely solar panel. By using energy from sunlight, it can produce an electrical power. But the transfer of energy that produced by solar panels is still low. The output power of solar panels is very depend on the light temperature and light intensity of solar panels [1]. One method to increase the effectiveness of the output power of solar panels is MPPT [2]. MPPT uses algorithms that can track the maximum power produced by solar panels [3-4]. One method commonly used is the P & O method. So in this paper the algorithm used will be compared with the P & O algorithm.

![Figure 1. Block Diagram of Proposed System](image)
2. System Description
Solar panel is a power plant that is able to convert solar energy into electricity. It is basically a PN semiconductor junction diode [5]. In commonly, Solar panel module is consisting of 36 cells. In this system used PV with 130 Watt, the parameters of solar panel can be seen in table 1. Block diagram of proposed system is shown in Figure 1. The output power of the solar panel into a SEPIC converter input that controlled by the lagrange algorithm for determine the value of PWM duty cycle to obtain the maximum power point[6].

2.1. P\text{v} modelling
Photovoltaic is a tool that convert solar lighting into electrical power. The power output PV depending on solar irradiation and the ambient temperature that received by PV. The PV model is a simple circuit that consist of a current source represent a solar panel that connected in parallel with one diode and two resistors as shown in Fig. 2. The mathematical equations of each cell are shown in equation 1 until 5.

![Figure 2. The series of Solar panel equations](image)

\begin{align}
I_{PH} &= (I_{SC} - K_1(T_c - T_{Ref})) G \quad (1) \\
I_L &= N_p I_{ph} - N_p I_S \exp \left(\frac{qV}{N_s K A} - 1\right) \quad (2) \\
I_S &= I_{RS} \left(\frac{T_c}{T_{Ref}}\right)^{3} \exp \left[q E_B \left(\frac{1}{T_{Ref}} - \frac{1}{T_c}\right) / K_B A\right] \quad (3) \\
I_{RS} &= \frac{I_{SCE}}{\exp \left(\frac{qE_B}{N_B K A T_c}\right) - 1} \quad (4)
\end{align}

Where
- $I_{PH}$ = Photo-current
- $I_L$ = Current at the output terminal
- $I_S$ = Saturation current of the diode
- $I_{RS}$ = Reverse saturation current
- $T_c$ = Cell working temperature
- $T_{Ref}$ = Reference temperature
- $R_{RS}$ = Series Resistance
- $K$ = Boltzmann’s Constant ($1.3806.10^{-23}$ J.K$^{-1}$)
- $G$ = Solar Insolation
- $q$ = Electron charge

Equations 1 until 4 are using in PSIM simulations software to obtain the characteristics of solar panel is shown in Figure 3 and figure 4. The curve is showing that the characteristics of the Solar panel are nonlinear and influenced by solar radiation and ambient temperature. Generally, there is an optimum point on the I-V curve and on the P-V curve, that is called Maximum Power Point (MPP)[7-9]. Where, on that point Solar panels work at maximum efficiency and produce the most output power. The appropriate values for voltage and current in each maximum power are called Vmp and Imp [10-13].
Figure 3. Graph of Difference Irradiation on PV Output Power

Figure 3 is shown the effects on difference irradiation in output power and output voltage of Solar panel. The larger solar irradiation produce the solar panel output power otherwise the lower solar irradiation produce the output power smaller.

Figure 4. Graph of Current and Voltage on PV Module

Figure 4 is shown the effect of the ambient temperature of Solar panels on curve I-V. When the irradiance is constant at 1000 W/m² and temperature varies from 25°C to 60°C. With the increment in the temperature short circuit current increases but the open circuit voltage is decreases. So the I-V curve characteristics range to the left to previous. The output power of cell is also decreased [14-16].

2.2. Lagrange Interpolation Method

Control system detects the open-circuit voltage $U_{oc}$ of photovoltaic (PV) cells. The initial MPP reference voltage is set as $0.8U_{oc}$ according to papers related. Record PV’s current voltage and power as $(U, P)$. A perturbation voltage $\Delta U_{ref} = 0.01U_{oc}$ is given to achieve two different operation point $U_a = U_b - \Delta U_{ref}$ and $U_c = U_b + \Delta U_{ref}$. The data is recorded as $(U_a, P_a)$ and $(U_c, P_c)$ respectively. The next perturbation direction is determined by the relation between $P_a$, $P_b$, $P_c$ and $U$, $U$ , $U$. Given $P_a < P_c < P_b$ and it means $U$ is the proximal point to the MPP[17-18].
Figure 5. Solar Panel Output Power and Voltage

The origin point of PV is \((U_b, P_b)\). \(U_a\) and \(U_c\) are obtained with the perturbation voltage \(\Delta U_{ref}\). Suppose the irradiation increases at \(U_a\) point and the P-U curve of PV transfer from A to B. The output power of PV at \(U_a\) point is \(P_a\).

When the PV’s operating point is near the MPP, for the reason of turn round measurement method, three points of PV cells are obtained at the same moment. That makes it possible to restore PV’s P-U curve when it is near the MPP and the error will be decreased significantly. With Lagrange Interpolation Formula, PV’s P-U curve are fitted by three operating point near the MPP.

Assume the interpolated point are \((U_a, P_a)\), \((U_b, P_b)\) and \((U_c, P_c)\). The interpolation polynomial of PV’s P-U curve is as follow:

\[
L_2(U) = P_a I_a(U) + P_b I_b(U) + P_c I_c(U)
\]

Among which:

\[
I_a(P) = \frac{(U-U_b)(U-U_c)}{(U_a-U_b)(U_a-U_c)}
\]

\[
I_b(P) = \frac{(U-U_a)(U-U_c)}{(U_b-U_a)(U_b-U_c)}
\]

\[
I_c(P) = \frac{(U-U_a)(U-b)}{(U_c-U_a)(U_c-U_b)}
\]

The proposed method using a Lagrange Interpolation, will shown in Figure 6. Figure 6 is shown a flowchart of Lagrange Interpolation (Proposed System) used to get the highest point in MPP of the P-V curve. By Counting the current and the output voltage of the solar panel with lagrange equation. That equation will be obtained solar panel output power highest by switching the value of duty cycle. When it’s \(\Delta P/\Delta U = 0\) MPPT will be stopped because that is a highest point.

2.3. Modeling of SEPIC Converter

Image of the SEPIC converter topology is in Fig 7. Sepic converter has very good efficiency and can reach the wide region for MPPT [19-20]. SEPIC converter is operated in continuous conduction mode (CCM) [21] resulting in a reduced stress on its power devices and components. The SEPIC converter consisting of a two capasitors, two inductors, one diode, one mosfet as a switch, and a load[22-23]. There are two state circuit in SEPIC converter in one switching period. The first state is when the switch in close condition (ON), and the second state, the switch in the open condition (OFF)[24]. In the first state, the two inductor is L1 and L2 are in phase charging energy, the second state inductor L1 and L2 are releases the previously discharging energy (energy discharge)[25-27]. The energy that has been released from the inductor L1 is used to charging the capacitor C1, while the energy from inductor L2 is transferred to the load[28].
Figure 6. Flowchart of The Proposed System

\[ D = \frac{V_{out}}{Vin + V_{out}} \]  \hspace{1cm} (9)

\[ L1 = L2 = \frac{Vin \times D}{\Delta i \times Ts} \]  \hspace{1cm} (10)

\[ C1 = \frac{Vin \times D}{RAV_{C1} \tau} \]  \hspace{1cm} (11)

\[ C2 = \frac{Vo \times D}{RAV_{Vo} \tau} \]  \hspace{1cm} (12)

Figure 7. SEPIC Converter
The frequency switching is 40 KHz. By using the high frequency the output signal from SEPIC converter will be smoother when compared to buck-boost converter. In Table 1 is shown the specifications of the SEPIC converter used according to calculations using equations 9 to 12.

| Parameter Design And Specification SEPIC Converter |
|-----------------------------------------------|
| **Parameter** | **Symbol** | **Value** | **Unit** |
| Switching Frequency | f | 40 | KHz |
| Current Ripple | ∆IL | 0.1 | % |
| Voltage Ripple | ∆Vc | 2 | % |
| Rated Output Power | Po | 130 | W |
| Input Voltage | Vi | 17.4 | V |
| Output Voltage | Vo | 14.4 | V |
| Capacitor 1 | C1 | 2000 | uF |
| Capacitor 2 | C2 | 2000 | uF |
| Inductor 1 | C1 | 195 | uH |
| Inductor 2 | C2 | 195 | uH |

3. RESEARCH AND DISCUSSIONS
3.1. Design Overall System
The proposed system for searching the MPP points is using Lagrange Interpolation Method. These method has a fast tracking to reach the MPP on solar panels. This MPPT use a SEPIC converter. Solar panel specifications that used is shown in Table 2.

| Solar Panel Specifications |
|-----------------------------|
| **Item** | **Value** |
| Nominal Maximum Output (Pin) | 130 W |
| Nominal Open Circuit Voltage (Voc) | 22 V |
| Nominal Short Circuit Current (Isc) | 8.09 A |
| Nominal Maximum Output Voltage (Vmpp) | 17.4 V |
| Nominal Maximum Output Current (Impp) | 7.48 A |

Table 2 is specification of the solar panels used in this paper. Expected that the output power is always maximum at 130 Watt with Vmpp 17.4 Volt and Impp 7.48Ampere.

3.2. Simulation and Results

![Figure 8. Simulation Graph of The Output Power](image)
Figure 8 shows the output power of the solar panel in each irradiation. The output power of solar panel is compared to PV output power using Lagrange Interpolation method and P&O method. With Lagrange interpolation method Almost produce the same value between PV module output power and Lagrange Interpolation shows that the the method is able to looking for the maximum output power of PV in every difference irradiation. Table 9 shows the error value of the power output obtained from the difference between the PV output power that using the Lagrange Interpolation method and using P&O method. From the result the percent error data from the Lagrange Interpolation is lower than P&O method.

4. CONCLUSIONS
MPPT method using Lagrange Interpolation on MPPT-SEPIC was presented, this method can be used to find the the MPP on the solar panel. The simulation results show that the Lagrange Interpolation method has an output power error of 1.96% and the P&O algorithm has an output power error of 15.6%. It can be concluded that the Lagrange Interpolation method is better than P&O method and Lagrange Interpolation method has the output power that is closest to the maximum output power of PV.

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Journal of Physics: Conference Series 1367 (2019) 012050 doi:10.1088/1742-6596/1367/1/012050

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