Interleaved boost converter with Perturb and Observe Maximum Power Point Tracking Algorithm for Photovoltaic System

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Abstract: The output power of Photovoltaic (PV) module/array varies due to the changes in atmospheric conditions and this result in variation of maximum power point (MPP). The Maximum Power Point Tracking (MPPT) algorithms are used for converter control so as to adjust the operating point the converter circuit to transfer the maximum power to the load. This paper presents the simulation of interleaved boost converter (IBC) with Perturb and Observe (P&O) MPPT for Photovoltaic system. The PV power system with a two phase IBC is analyzed in this work. The converter circuit is connected with the generalized photovoltaic model and simulated for various atmospheric conditions with and without MPPT controller. The model is simulated in MATLAB and the results are generated for various test conditions. The output power of the converter with and without MPPT is compared with the actual output power of the PV module and the results are discussed.

Keywords: Photovoltaic, Perturb and Observe, Maximum Power Point Tracking, Interleaved Boost Converter, MATLAB.

1. Introduction

The photovoltaic power generation is brought significant attention over the past decades due to its advantages such as zero fuel cost, easy installation, and zero CO$_2$ emission. The PV system has less mechanical parts and therefore it requires very low maintenance. The PV system is widely used for Stand-alone applications such as solar water pumping, solar street lighting and utilized for grid connected application also [1]. The Photovoltaic module has non-linear characteristics. The voltage and/or current output of the PV vary due to change in environmental conditions. Therefore, whenever there is a change in temperature or irradiation level, the output power PV module/array will change. So, the MPPT controllers are used to find the Maximum Power Point (MPP) of the PV output instantaneously and control the operating point of the converter. The MPPT controller ensures the Maximum output power at all situations. Various MPPT algorithms are proposed and implemented. Perturb & Observe algorithm and Incremental Conductance algorithm are widely used MPPT algorithms amongst all the proposed algorithms [2]. The P&O MPPT algorithm is adapted to control the operating point of two phase IBC in this paper.

2. Maximum Power Point Tracking

The PV modules/arrays are having non-linear characteristics, (i.e.,) the output power of the PV module/arrays will change whenever there is a change in temperature or irradiation level. The voltage-current characteristics curve of PV module under different temperature level is shown in fig. 1. The module current $I_{pv}$ increases with increase of irradiation level and vice versa. But, the module voltage $V_{pv}$ is almost constant at irradiation level variations. Fig. 2 shows the voltage-current characteristics for various
temperature levels. In this case, the module voltage $V_{pv}$ is decreasing when the temperature increases and vice versa wherein, there is no much changes in module current $I_{pv}$. Therefore, the module current $I_{pv}$ varies with respect to changes in irradiation level and the module voltage $V_{pv}$ varies with respect to changes in temperature level.

![Fig. 1 Voltage-current characteristics of PV at different temperature level](image1)

![Fig. 2 Voltage-current characteristics of PV at different irradiation level](image2)

The voltage-power characteristics of PV module under various conditions are depicted in fig. 3. The maximum output power of the PV module varies whenever there is a change in temperature or/and irradiation levels. The maximum power point has moved from T1 to T2 when the temperature increased where the irradiation is constant for these cases. Similarly, the maximum power point has shifted from G2 to G1 due to increase in irradiation level in which the temperature is constant. Therefore, it is necessary to change the operating point of the converter to circuit to match the load resistance with the PV source to obtain the maximum power. Many MPPT algorithms were proposed to control the converter circuits. The most popular algorithms are Perturb and Observe [3], Incremental Conductance [4, 5]. Some of the other algorithms proposed are Constant Voltage algorithm [6] and Short circuit current algorithm [5]. Fuzzy based MPPT is also proposed and discussed in many literatures [7].

![Voltage-Power Characteristics of PV Module](image3)

3. **PV System with MPPT**

The stand-alone PV power system has PV Module/array, DC-DC converter and a load. The operation of DC-DC converter is controlled by MPPT controller. A stand-alone PV power system with MPPT controller is shown in fig. 4. The system has PV Module/Array, a DC-DC converter, control circuit and a load. The Interleaved boost converter with resistive load is used in this study. The P&O algorithm is simple and easy to implement. Therefore, P&O algorithm is based MPPT is used in this paper. The complete system shown in fig. 4 is simulated in MATLAB/Simulink and the results are obtained.

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3.1. PV Source

Simulation of generalized model for PV module using MATLAB/Simulink is presented in many literatures [1,8]. The equivalent circuit for the appropriate model of PV cell is shown in fig. 5. The general model of PV cell has a parallel resistor “$R_p$”. The parallel resistor “$R_p$” is ignored in the appropriate model since; it has a very high value. The output current of the PV cell is given in equation (1)

$$I = I_{pv} - I_s \left\{ \exp \left( \frac{qV}{AkT_c} + IR_{sc} \right) - 1 \right\}$$  

(1)

The current generated by PV cell $I_{pv}$ is expressed as

$$I_{pv} = [I_{sc} + K_i (T_c - T_s)] \cdot G$$  

(2)

The diode saturation current $I_s$ and cell’s reverse saturation current $I_{rs}$ are presented in equation (3) and equation (4) respectively.

$$I_s = I_{rs} \left( \frac{T_c}{T_r} \right)^3 \exp \left[ \frac{qE_s}{Ak} \left( \frac{1}{T_c} - \frac{1}{T_r} \right) \right]$$  

(3)

$$I_{rs} = \frac{I_{sc}}{\exp \left( \frac{q}{AkN_sV_{oc}} \right) - 1}$$  

(4)

The PV module is modeled based on Equation (1) in MATLAB/Simulink in [8] and same model is used in this work. Solarex MSX60 PV Module is selected for analysis. The main parameters required to simulate the model are open circuit voltage (Voc), short circuit current (Isc), number of cell connected in series (Ns), required to simulate the model are taken from the datasheet.
3.2 P&O MPPT Algorithm

The P&O MPPT algorithm changes the perturbation in a regular interval based on the output of the previous state. The flow chart of P&O MPPT algorithm is presented in figure 6.

![P&O MPPT Algorithm Flow chart](http://dx.doi.org/10.17758/UREBE.U0115219)

The operation of P&O MPPT algorithm can be simply described as follows:
(a) If the perturbation of previous state was positive and the power is increased, then continue the perturbation in the same direction.
(b) If the perturbation of previous state was positive and the power is decreased, then the new perturbation should be in opposite direction.
(c) If the perturbation of previous state was negative and the power is increased, then continue the perturbation in the same direction.
(d) If the perturbation of previous state was negative and the power is decreased, then the new perturbation should be in opposite direction.

3.3 DC-DC Converter

The DC-DC converter circuits are employed between the PV source and the load as power conditioning units. DC-DC Boost converters are mostly employed. The amount of ripple in input current and output voltage of the boost converter is high. The boost converters are connected in interleaved fashion to reduce the ripple in input current and to increase the output current [9]. The Interleaved boost converter
significantly reduces the input current ripple and the ripple of output voltage. A two phase IBC with output voltage of 24V at STC of PV module is designed for this study. The value of load resistor is 10Ω.

4. Simulation Results and Discussion

The complete model of MPPT based PV system built in MATLAB is shown in fig. 7. The model has PV source block, P&O MPPT block and two phase IBC also as a block. The circuit of 2 phase IBC modeled in MATLAB is shown in fig. 8.

The PV Module is simulated under various temperature and irradiation levels and the results such as output voltage, current and power of PV module, Inductor current of IBC and the output current, voltage and power of the converter circuit are obtained. The temperature and irradiation level of the PV module are varied as shown in fig. 9 and fig. 10 respectively.
The temperature is considered as 25°C from t=0 sec to 0.1 sec. But at the same time the irradiation level is 1kW/m² from 0 to 0.05sec and between 0.05sec and 0.1 sec it is 800W/m². Then, for t=0.1sec to 0.2sec, the irradiation is maintained as 1kW/m². The temperature has changed to 35°C at t=0.1sec and maintained as same until 0.15sec and from 0.15sec to 0.2sec the temperature is 45°C. The MPPT controller automatically adjusted the duty cycle of the converter with respect to the changes in temperature and/or irradiation level as shown in fig. 11. The output power of the MPPT based converter for various conditions are is shown in fig. 12. The voltage across the load and the output voltage of PV module are depicted in fig. 13.

To analyze the performance of the MPPT based PV system, the model is simulated by giving constant duty cycle to the gate of both switches SW1 and SW2. The duty cycle of the converter circuit is calculate by using

$$D = 1 - \frac{V_s}{V_o}$$

(5)
where, $V_s$ is the source voltage which is 17V in this case and $V_o$ is the output voltage. The output voltage of the converter is 24V and therefore, the duty cycle is D=0.3.

The IBC in the PV system without MPPT is operated with constant duty cycle. The temperature and irradiation levels applied for MPPT based system is applied for this case also. Fig. 14 shows the output power of IBC converter with MPPT and without MPPT. A considerable variation in output is observed for all the cases. The output power of MPPT is higher in all the cases comparing to the converter circuit operated without MPPT. The power generated by the stand-alone MSX 60 PV module for the test conditions without converter circuit is presented in figure 15.

![Fig. 14 Power output of IBC with and without MPPT](image1)

![Fig. 15 Voltage-Power Characteristics of stand-alone PV module](image2)

The outputs of PV module, the output of IBC with and without MPPT are tabulated in table 1. The graph is plotted for the tabulated test conditions as shown in figure 16.

<table>
<thead>
<tr>
<th>Test</th>
<th>Temperature and Irradiation of PV Module</th>
<th>Power in Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stand-alone PV Module</td>
<td>IBC with MPPT</td>
</tr>
<tr>
<td>A</td>
<td>T=25°C, G=1000 W/m²</td>
<td>59.86</td>
</tr>
<tr>
<td>B</td>
<td>T=25°C, G=800 W/m²</td>
<td>47.73</td>
</tr>
<tr>
<td>C</td>
<td>T=35°C, G=1000 W/m²</td>
<td>57.21</td>
</tr>
<tr>
<td>D</td>
<td>T=45°C, G=1000 W/m²</td>
<td>54.48</td>
</tr>
</tbody>
</table>

![Fig. 16 Comparison of Output Power](image3)

The line graph in the figure is the output of stand-alone PV module. The dark bars are the output of IBC with MPPT and the light bars in the figure are the outputs of IBC for the given test conditions with constant duty cycle control. The graphs show that the output of the P&O MPPT based two phase IBC coincides with the actual power of PV module. Because, the operating point of the converter is automatically adjusted by the P&O MPPT controller to receive the maximum power the PV source whenever the changes occurred due
to changes in temperature and/or irradiation level. At the same time, the output of converter without MPPT does not coincide with the actual output of PV except the standard test conditions. The duty cycle of the converter is set for the STC and hence the output of converter is less than the maximum power in other test conditions.

5. Conclusion:

The Perturb and Observe MPPT based two phase interleaved boost converter for PV power system is simulated using MATLAB/Simulink. The model for PV module, P&O algorithm and two phase IBC were built individually and integrated. The PV power system with interleaved boost converter is simulated for various test conditions with MPPT controller and without MPPT controller. The results of stand-alone PV module is also obtained for similar test conditions. The results are compared and analyzed. The PV power system with P&O MPPT produces maximum power during all applied test condition and the output power of MPPT controlled converter coincides very well with the actual output power of PV module, wherein this is not the case with Non-MPPT converter. The output power of the converter is less than the actual power during all test conditions other than STC.

6. Nomenclature:

- $I_{pv}$ - light generated current
- $I_{sc}$ - short-circuit current of cell at STC
- $K_I$ - short-circuit current temperature co-efficient of cell
- $T_c$ – operating temperature of cell in °K
- $T_r$ - reference temperature in °K.
- $I_s$ - saturation or leakage current of the diode
- $q$ - electron charge [1.60 x 10^{-19} eC]
- $k$ - Boltzmann constant [1.38x10^{-23} J/K]
- $A$ - ideality factor of diode.
- $R_s$ – Series resistor
- $R_p$ – Parallel resistor
- $I_{rs}$ - reverse saturation current of a cell
- $E_g$ is the band gap energy of the semiconductor used in the cell

7. References

8. Bibliography

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