Performance analysis of DC/DC Boost converter with Maximum Power Point Tracking for Grid connected Photovoltaic Systems

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Abstract: Due to unlimited existence, eco-friendly nature and sustainability solar photovoltaic has become an alternative measure of renewable green power, energy conservation and demand-side management. Solar photovoltaic has nonlinear current-voltage characteristics, with a distinct maximum power point (MPP) depending on factors such as solar irradiance and operating temperature. Maximum Power Point Tracker (MPPT) using boost converter generally used to extract the maximum power for grid connected standalone photovoltaic systems. This paper presents the performance analysis of DC/DC boost converter used in PV systems as MPPT. Detailed system is designed and developed in Matlab/Simulink. Simulation is performed with 100W STF PV module considering different irradiance levels.

Keywords: Photovoltaic(PV)Systems; DC/DC Boost Converters; PWM; Maximum Power Point Tracking.

1. INTRODUCTION

In today society, human race around the world are always hungry for energy. This form of energy known as electricity is supply to industrial plants, commercial offices, and residential buildings. Unfortunately, this large amount of electricity is heavily relied on non-renewable fossil fuels such as coal, oil and natural gas to generate, which are constantly decreasing and eventually will run out. It is important to look for alternative energy solution to reduce our dependency on non-renewable fossil fuels and at the same time ensuring plenty of energy in future.

Among other renewable sources solar energy have good prospects for both isolated load and grid interconnection, system must be optimized to it specific location in order to maximize it usage and providing constant and reliable electricity to the consumer. Solar cell has nonlinear I-V characteristics. The knee point of the curve is the optimum operating point of a solar cell where it generates maximum power. To operate the solar cell at this point it is necessary to match the PV source to the load so that the operating point of PV module coincides with maximum power point. But practically load may be fluctuated. Again the MPP of the solar cell varies with solar irradiances and weather conditions. So to track the MPP at different irradiances Maximum Power Point Trackers (MPPT) is used. MPPT usually composed of a DC/DC converter and a control algorithm to adjust the duty cycle of DC/DC. MPPT using different DC/DC converter has been proposed [1-9]. But detailed performance analysis of the DC/DC boost converter on the basis of ripples content on the PV and load side, stability, tracking speed. Efficiency calculation for grid connected photovoltaic system is needed. In this research DC/DC boost converter is designed with optimized parameters so that the minimum ripple content in the current in both PV and load side.

2. SOLAR PV ARRAY

2.1 Equivalent Circuit of Solar Cell

An ideal solar cell can be modeled by a light generated current (the generated photocurrent when the sunlight hits the solar panel) source and a diode connected in anti-parallel. The diode represents the p-n transition area of the solar cell. In practice a shunt resistance Rsh, arising from the leakage of current through the cell, or at the edges, or between contacts of different polarity and a series resistance Rs, arising from the emitter region and from contacts. The equivalent circuit of a solar cell is shown in Fig. 01.
2.2 Equation of PV Module

PV cells are interconnected in a parallel-series configuration to form PV arrays. The basic equation [10] that describes the current output of PV module \( I_{PV} \) of the single-diode model presented in Fig. 01 is given by

\[
I = N_p I_{ph} - N_p I_0 \left[ \exp \left( \frac{e(V+IR)}{nRTS} \right) - 1 \right] - \frac{N_S(V+IR_S)}{R_{sh}}
\]  

(1)

Where \( N_p \) and \( N_S \) are the number of parallel and series connections of cells, respectively, in the given photovoltaic Module (\( N_p = 4 \) and \( N_S = 9 \))

2.3 Effect of Irradiance

The effect of the irradiance on the current-voltage (I-V) and power-voltage (P-V) characteristics of a solar PV panel under different irradiance is best depicted in Fig. 02 and Fig. 03 respectively. From these figures it is clear that as the irradiance increases, both the short circuit current and open circuit voltage increases. As a consequence the maximum power point (MPP) increases.

![Fig. 02 I-V characteristics of solar PV array at different irradiances](image1)

![Fig. 03 P-V characteristics of solar PV array at different irradiances](image2)

3. PV MODULE WITH MAXIMUM POWER POINT TRACKER (MPPT)

To track the maximum operating point for certain irradiance and weather conditions a DC/DC converter inserted between PV array and load. The operating point of solar PV array is forced to the peak point by continuously adjusting the duty cycle of the semiconductor switch of DC/DC converter. PV system with maximum power point tracking circuit is shown in Fig. 04.
2.1 MPPT Algorithm

According to the control strategy [11] for seeking the maximum power point, there are two categories of MPPT methods: direct or true seeking and indirect or quasi seeking of maximum power point. The methods, either the direct or indirect, vary in complexity, sensors required, tracking efficiency, convergence speed, cost, range of effectiveness, implementation hardware, and in other respects. Among the methods, Perturb and Observe (P & O) is the most commonly used MPPT method due to ease of implementation and low cost [12-16]. The flowchart of P & O algorithm is shown in Fig. 05. In this method PV array voltage and current are measured, then perturb the operating point by small amount and observe the resulting change in power as clearly explained in Fig. 06.

If the power increases due to each perturbation then the next perturbation will be in the same direction. If the power decreases then next perturbation will be in the opposite direction. This process is repeated until MPP is reached at \( \frac{dp}{dv} = 0 \). The system may oscillate around MPP if the insolation and temperature changes rapidly. The Simulink model for P & O MPPT algorithm is shown in Fig. 07.
4. SIMULATION AND RESULTS

The specifications of PV module [17] and optimized ratings of boost converter is presented in Table 1. Throughout the entire simulation only the change in solar irradiances are consider but temperature is assumed 25°C. The complete model of the proposed system in Matlab/simulink environment is given in Fig. 08. Fig. 09 and Fig. 10 illustrates the starting and steady state maximum power point tracking performance of the boost converter with two different irradiances.

**Table 1.** Specification of PV modules and converter ratings

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
<th>Parameters</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Maximum power, $P_M$</td>
<td>100W</td>
<td>Short-circuit current temp. coefficient</td>
<td>6.928 mA/ °C</td>
</tr>
<tr>
<td>Open circuit voltage, $V_{oc}$</td>
<td>21.5 V</td>
<td>Open-circuit volt. temp. coefficient</td>
<td>0.068 V/°C</td>
</tr>
<tr>
<td>Short circuit current, $I_{sc}$</td>
<td>6.22A</td>
<td>Maximum power temp. coefficient</td>
<td>(0.5±0.05) %/°C</td>
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<tr>
<td>Volt. at max. power, $V_M$</td>
<td>17.5V</td>
<td>Module size</td>
<td>36 Cells (4×9)</td>
</tr>
<tr>
<td>Current at max. power, $I_M$</td>
<td>5.72A</td>
<td>Inductor, $L_1$</td>
<td>660μH</td>
</tr>
<tr>
<td>Fill factor, FF</td>
<td>0.75</td>
<td>Capacitor, $C_1$</td>
<td>700μF</td>
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<tr>
<td>NOCT</td>
<td>47±2°C</td>
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It is clear that the extracted power initially undergoes a transient oscillation and has some delay before reaching the MPP. At irradiances 900 W/m² and 1000 W/m², the extracted power is 87.16 W and 96.5 W respectively and MPPT efficiency is 97.26% 96.4% respectively.

The MPPT, converter and system efficiencies are summarized in Table 2. Ripple content in input current, input power, output current and output voltage are presented in Fig. 11, Fig. 12, Fig. 13, and Fig. 14 respectively. The average value of input current, output current and output voltage is 5.2 A, 1.878 A and 46.63 V respectively and peak to peak ripple in input current, input power, output current, output power and output voltage are 0.85 A, 7.2 W, 0.013 A, 0.62 W and 0.33 V respectively.

**Table 2.** The key measurements at different irradiance levels for Boost Converter

<table>
<thead>
<tr>
<th>Irradiance G(W/m²)</th>
<th>P_M (W)</th>
<th>P_IN (W)</th>
<th>P_O (W)</th>
<th>MPPT Eff. η_M (%)</th>
<th>Convert-er Eff. η_C(%)</th>
<th>Overall Eff. η_O (%)</th>
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<tr>
<td>1000</td>
<td>100.1</td>
<td>96.5</td>
<td>88.1</td>
<td>96.4</td>
<td>91.3</td>
<td>88.01</td>
</tr>
<tr>
<td>900</td>
<td>89.62</td>
<td>87.16</td>
<td>81.35</td>
<td>97.25</td>
<td>93.33</td>
<td>90.78</td>
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<tr>
<td>850</td>
<td>84.38</td>
<td>81.77</td>
<td>76.11</td>
<td>96.91</td>
<td>93.07</td>
<td>90.19</td>
</tr>
<tr>
<td>750</td>
<td>73.90</td>
<td>71.44</td>
<td>66.07</td>
<td>96.67</td>
<td>92.49</td>
<td>89.41</td>
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<tr>
<td></td>
<td>700</td>
<td>68.67</td>
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<td>60.63</td>
<td>97.13</td>
<td>91.85</td>
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<tr>
<td>650</td>
<td>63.44</td>
<td>61.23</td>
<td>56.03</td>
<td>96.55</td>
<td>91.48</td>
<td>88.32</td>
</tr>
<tr>
<td>550</td>
<td>53.01</td>
<td>51.36</td>
<td>47.44</td>
<td>96.89</td>
<td>92.36</td>
<td>89.49</td>
</tr>
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**Fig. 11** Input current ripple of Boost converter

**Fig. 12** Input Power ripple of Boost converter.

**Fig. 13** Output current ripple of Boost converter

**Fig. 14** Output voltage ripple of Boost converter

5. **Conclusion**

Detail analysis of the performance of DC/DC boost converter for grid connected photovoltaic system is presented in this paper. The efficiency of MPPT, converter and overall system are calculated at different irradiances. Designed DC/DC boost converter has low input and output current ripple. So the size of the filter is greatly reduced. Due to the minimization of the ripples content on the current the power output of the converter is satisfactory. Designed MPPT algorithm can easily track the MPP accurately during both starting condition and sudden irradiance change. Thus the performance of the MPPT system is satisfactory. Thus for grid connected photovoltaic systems performance of MPPT using boost converter has been found satisfactory. In future hardware implementation of the boost converter with MPPT has been done.

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