Implementing A Single Switch DC/DC Converter for A Solar Battery Powered Pump System

Arun. R  
PG Scholar  
Department of Electrical & Electronics Engineering  
KIT-Kalaignarkarunanidhi Institute of Technology, Coimbatore-641 402

A. Tamilpandian  
Assistant Professor  
Department of Electrical & Electronics Engineering  
KIT-Kalaignarkarunanidhi Institute of Technology, Coimbatore-641 402

Udhayakumar. M  
Lecturer  
Department of Electrical & Electronics Engineering  
Nachimuthu Polytechnic college, Pollachi- 642 003

T. Vignesh  
Assistant Professor  
Department of Electrical & Electronics Engineering  
Jay Shriram Group of Institutions, Tiruppur-638 660

Abstract

The DC converter used in this paper is a single-switch non-isolated dc/dc converter for a standalone solar battery powered pump system. The converter is formed by the amalgamation of buck converter, with a buck boost converter. As a result of this integration, it reduces repeated power processing and may achieve improved conversion efficiency. The main objective is to perform multiple tasks like maximum-power-point tracking (MPPT), battery charging, and driving the pump at constant flow rate with a single switch to reduce the switching loss. The result is then compared with the real time model.

Keywords: MPPT, DC/DC converter, pump system, constant flow rate

I. INTRODUCTION

The need for renewable energy sources is on the rise because of the acute energy crisis in the world today. India plans to produce 20 Gigawatts Solar power by the year 2020, whereas we have only realized less in our potential. Solar energy is a vital untapped resource in a tropical country like ours. The main hindrance for the penetration and reach of solar PV systems is their low efficiency and high capital cost. Among the various applications of photovoltaic technology, a stand-alone photovoltaic (PV)-battery-powered pump system can be utilized in many areas such as urban street watering, rural farm irrigation, and fish farms. The stored energy can be used to maintain the system operation when shading happens to the PV panel, to provide the system with use time flexibility and load controllability, and can also be applied to provide energy for other loads and applications.

To fulfill the requirement of tracking the maximum power point (MPP) of a PV array, charging/discharging the battery, and controlling the loads, the conventional design uses a cascaded converter approach. The power dissipated in individual components of these cascaded converters, however, accumulates when energy is transmitted from one stage to another since the power is repeatedly processed. Moreover, a high number of power switches usually indicates high converter cost and physical size.

In order to simplify the converter circuitry, much research has been done on combining the cascaded power stages together to form a single-stage converter. The number of active switches like MOSFETs is reduced by sharing a single switch for different current paths. This single-switch converter (SSC) technology is well developed in ac/dc and inverter domains.

II. LITERATURE REVIEW

The conventional two-stage converter design for the PV-battery-powered pump system. The front stage buck converter is used to track the MPP of the PV module by changing the input impedance of the converter. The battery voltage here is lower than the PV source input voltage. The second stage buck-boost converter is used to regulate the output voltage in order to maintain a desired flow rate of the pump. Two active switches S1 and S2 are controlled separately. The method for developing single-stage converters in is used here to combine active switches S1 and S2. The operation of the two converters would not be affected if both of the MOSFETs are moved to the return paths of the circuit. By doing this, S1 and S2 share a common node, i.e., the drain of S1 and the source of S2. The operation remains identical if S1 and S2 turn ON/OFF synchronously. Hence, S1 and S2 can be replaced by a synchronous switch. Diodes D2 and D3 are added to provide current paths when the current through the original switches S1 and S2 are different. Thus, the proposed converter is derived, as shown in Fig. 1.
III. PROPOSED CONVERTER

A. Converter design:

The proposed single-stage single-switch converter, shown in Fig. 1, is derived through the integration of a buck converter into a buck-boost converter. It consists of an input inductor $L_1$ for charging the battery and MPPT, a rechargeable battery $V_B$ to balance the input and output power, a capacitor $C_1$ to absorb the ac current ripple of the battery, an output inductor $L_2$ to supply the load, which is a dc pump in this application, a power switch $S$, four diodes (D1 to D4), and an output capacitor $C_2$. $i_{BC}$ denotes the total current flowing out of the battery and capacitor $C_1$. The battery charging or discharging current contributes to the dc component of $i_{BC}$, whereas the ac component of $i_{BC}$ goes into the capacitor $C_1$. Switch $S$ provides current paths for both the battery and the PV source during the ON period and also to realize reduced repeated power processing. Diodes D1 and D3 provide the current paths of negative $i_{BC}$ during different operation periods while diode D2 serves as a path for positive $i_{BC}$. Diode D4 links the energy to the load from inductor $L_2$.

B. Modes of operation

Since the constant voltage control method is used for MPPT in this design, the PV input voltage is controlled to operate within a range by adjusting the switching frequency. To simplify the analysis of the operation of the converter in the steady-state high frequency domain, both the PV module and battery are assumed to be constant dc voltage sources within a switching period, under the assumption that the input capacitor is large enough to hold the PV source voltage when the switch is OFF. The capacitance of $C_2$ is large enough so that the output voltage ripple is negligible and the output can be treated as a constant dc voltage source as well. All the semiconductor devices are assumed to be ideal. The input buck inductor $L_1$ works in discontinuous conduction mode (DCM), whereas the output buck-boost inductor $L_2$ operates in continuous conduction mode (CCM). To explain the working principle of the converter, the circuit operation stages and current flowing paths in one switching period are shown in Fig. 2. During the steady state, the converter shows four distinctive operation modes.

1) Mode 1 ($T_0 - T_1$):

In Fig. 2(a), the operation stage when switch $S$ is ON is illustrated. During this stage, diodes D1, D3, and D4 are reverse biased, and diode D2 is forward biased. The input inductor $L_1$ is charged up by the PV source $V_{in}$. 

![Fig. 1: Proposed converter model](image1)

![Fig. 2(a): Mode 1 Current flow circuit](image2)
2) Mode 2 (T1 − T2):
This mode happens when the inductor current iL1 is larger than iL2 when the switch S is ON, as shown in Fig. 2(b). The extra energy from PV source Vin charges the battery and the capacitor C1, and hence, iBC is reversed. Diode D3 provides the path for the negative iBC while diode D2 is reverse biased.

![Fig. 2(b): Mode 2 Current flow circuit](image)

3) Mode 3 (T2 − T3):
Mode 3 starts when switch S is turned OFF. The operation stage is illustrated in Fig. 2(c). Diodes D2 and D3 are reverse biased, and inductor L1 discharges its stored energy to the battery and capacitor C1 through diode D1. Inductor L2 begins to release its stored energy in previous stages to the output capacitor C2 and the pump load through diode D4.

![Fig. 2(c): Mode 3 Current flow circuit](image)

4) Mode 4 (T3 − T4):
During this period, switch S is OFF, and the input inductor L1 is reset. The operation stage is illustrated in Fig. 2(d). Inductor L2 continues to discharge its stored energy to the output capacitor C2 and the pump load through diode D4 until the next switching period.

![Fig. 2(d): Mode 4 Current flow circuit](image)
IV. BATTERY- MODES OF OPERATION

In the proposed design, the battery serves two functions:
It maintains a steady dc-link voltage and balances the energy difference between PV generation and load changes. The charging/discharging of the battery is determined by the PV input power and load output power. The mode of operation of battery is shown in Fig. 3.

1) Mode A: This situation happens when the pump is not connected while the PV module is working normally. The second half of the converter is disabled, and only the buck stage works to track the MPP. The battery is charged by the PV input source.

   If the pump does not have an ON/OFF switch, a relay/switch can be inserted between C2 and L2.

2) Mode B: This situation happens when the pump operates with power smaller than the maximum power of the PV panel. The extra energy from the PV input will charge the battery. That means that the average value of iBC in Fig. 3 is negative.

3) Mode C: This situation happens when the maximum power from the PV module is not enough to supply the pump load. This usually happens when the PV cells are shaded or under cloudy weather. The battery complements the PV energy to the load in this case. The battery discharges its energy, and the average value of iBC in Fig. 3 is positive.

4) Mode D: This situation happens when the maximum power of the PV input matches the load power. There will be no current flowing into the battery. The average value of iBC is zero.

5) Mode E: This situation happens when no power can be provided from the PV input, usually during nighttime. In this case, the front buck stage of the converter is disabled, and only the buck-boost stage is working. All the energy for the pump is provided by the battery. The average value of iBC in Fig. 3 is positive. If the PV panel does not have protection circuitry, a diode can be added after the PV panel to prevent the reverse current flowing into the PV panel.

V. PERTURB & OBSERVE ALGORITHM

Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the Voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn’t stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However, the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem, we can use incremental conductance method.
The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power $P$ is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If $P$ is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. Figure 4 shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure above, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of $P$ becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. The flowchart for the P&O algorithm is shown in fig.4.

Modeling of standalone PV system Solar panel
The entire system has been modeled on MATLAB and Simulink™. The inputs to the solar PV panel are temperature, solar irradiation, number of solar cells in series and number of rows of solar cells in parallel.

![Flow chart for P&O Algorithm](image-url)
VI. Simulation Model

The complete simulation circuit for the proposed strategy is shown in fig.6.

In this model the closed loop operation is achieved with the help of MPPT and the feedback error voltage, it is then compared with the carrier wave and then the triggering pulses are generated as shown in fig.7.
The generated pulses are fed to the single switch and then the desired operation is achieved.

The irradiation is taken to be varying as 1000, 500 and 100 Watt per sq. m., to reflect real life conditions and effectively show the use of an MPPT algorithm in field runs. It varies from 1000 Watt per sq. m. to 100 Watt per sq. m, which is close to the day and night values of solar irradiation received on the earth’s surface. The simulation is run for a total of 0.3 seconds, with the irradiation taking up a new value every 0.1 seconds and staying constant for the consequent 0.1 seconds.

Fig. 8(a): Irradiation signal 1000(Watt per sq. m. versus time) and corresponding battery operation.
The Fig. 8. Shows the variation in battery state of charge depends upon the irradiation level. Here we have taken 1000, 500 and 100 Watt per sq. m. Fig. 8(a), 8(b) & 8(c) shows the corresponding waveforms of 1000, 500 and 100 Watt per sq. m respectively.

VII. HARDWARE MODEL

In this system we have implemented two types of circuit that is DC/DC converter based solar battery powered pump system with single switch and DC/DC converter based solar battery powered pump system with multiple switches. There by we are comparing the results of both the results to avoid the losses due to the switches. Here we are proposing single switch for multiple operation but in the existing case, there will be more switches for each operation to control the entire process.
Table 1

DC/DC converter for a solar battery powered pump system with multiple switches readings.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>INPUT POWER (W)</th>
<th>POWER TAKEN BY BATTERY (W)</th>
<th>POWER TAKEN BY LOAD (W)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.5</td>
<td>5.1</td>
<td>4.4</td>
<td>90.4</td>
</tr>
<tr>
<td>2</td>
<td>9.1</td>
<td>4</td>
<td>4</td>
<td>92.3</td>
</tr>
<tr>
<td>3</td>
<td>6.2</td>
<td>3</td>
<td>2.7</td>
<td>91.9</td>
</tr>
</tbody>
</table>

Table 2

DC/DC converter for a solar battery powered pump system with Single switches readings.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>INPUT POWER (W)</th>
<th>POWER TAKEN BY BATTERY (W)</th>
<th>POWER TAKEN BY LOAD (W)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.8</td>
<td>4</td>
<td>4</td>
<td>95.4</td>
</tr>
<tr>
<td>2</td>
<td>6.0</td>
<td>4</td>
<td>3.7</td>
<td>96.25</td>
</tr>
<tr>
<td>3</td>
<td>6.3</td>
<td>3</td>
<td>2.9</td>
<td>95.2</td>
</tr>
</tbody>
</table>

As displayed in Table 1 and 2, single switch DC/DC converter has more efficiency compared to multi switch converter. Due to the less switching losses the overall efficiency of the system is improved.

VIII. CONCLUSION

This paper has presented a design of a single-stage single switch dc/dc converter for a PV-battery-powered water pump system with experimental verification. By using the variable frequency control, the main functions such as MPPT and driving the motor with specific speed can be realized with a reduced number of active switches and without sacrificing the overall efficiency as compared to the conventional two-stage design. The voltage stress problem of the dc-link capacitor in conventional single-stage converters is eliminated when a battery is used. Reduced repeated power processing is achieved automatically during the operation. It is shown that SSCs are capable of implementing practical PV-based applications. Another main drawback that limits the development of SSCs and bounds their power level to a low power range is the current stress in the converter where currents from multiple sources flow into the same switch simultaneously this may be rectified in future expansion of this paper.

REFERENCES

Implementing A Single Switch DC/DC Converter for A Solar Battery Powered Pump System
(IJSTE/ Volume 2 / Issue 12 / 031)


