Computer Simulation of MPPT Converter to Control PV Panel-Battery System

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Abstract:
This research intends to build and simulate a small renewable energy system consists of PV panel, lead-acid battery, and bidirectional DC-DC converter. Bidirectional Buck-Boost converter was used to regulating the voltage and current coming from the solar panels going to the battery and vice versa. It operates a Buck converter which charges the battery from the PV panel when State of charge (SOC) reaches less than 0.4. The battery needs 100 ms to charge from 12.2 V to 13 V with duty cycle 0.5 and 1 A. Also work as a Boost converter when SOC reaches 1 the battery was discharge for 100 ms and SOC decreases from 1 to 0.4.
A PSPICE PV panel model (consists of 20 solar cells, 12 V and 60 W maximum power at 25 °C with 1000 W/m² solar irradiation) has been used as a source of energy to the power circuit. The output of PV panel relates to Boost converter, which is the key for changing the PV’s terminal voltage to track the maximum power, it was rising a PV panel voltage from 10 V to 22 V for all variation of surface temperature from 300 K to 350 K at frequency 10 kHz and ΔVo = 1.1 V.

Keywords: PV system, DC-DC converter, Lead-acid battery, and PSPICE.

Introduction:
Solar energy is one of the most significant renewable energy sources that has attracted more attention in recent years. It has the highest abundance relative to other sources of energy. Solar energy is clean and emission-free as it generates no contaminants or by-products that are detrimental to nature. There are many fields of application for converting solar energy into electrical energy (1).

All the modern renewable energy systems like the photovoltaic system (PVS) should contain a storage element (battery) as an integral part. This system needs batteries to store and deliver overflowing energy to the load when the solar not obtainable. Lead-acid batteries (LABs) are the best types to use in PVS due to the Low cost compared with other batteries available in many designs and different sizes and having a long life (2).

It is necessary to excessive discharge, prevent battery overload, invert current flow at night, and safeguard the battery life of a PVS. When the battery is fully charged, the role of a converter is to disconnect the PV panel and keep the battery fully charged without damage.
(3). Using topologies of different DC-DC converters such as boost converter, buck converter, buck-boost converter, and other converters as power conditioning circuitry to supply sufficient current to efficiently for battery charging.

In this research, the stand-alone PV system will be described. A basic configuration of this system consists of a PV panel that converts direct current from sunlight, a battery bank, and its associated bidirectional converter that is a combination of a boost and buck converter, as shown in figure [1]. This converter could be worked in both ways of charging and discharging mode.

![Figure 1: PVS Block diagram](image)

**Design battery model**

A lead-acid battery model was created for the physical system. The battery model was conceived to accept current and ambient temperature inputs. The output was state of charge (SOC), voltage (Em), and cell temperature (Te). This model is the treatment of all battery parameters as the SOC, battery voltage, internal resistance, and temperature of the battery at a charge and discharge state.

The PV battery has two states one when charging (SOC 0→1) the other when discharging (SOC 1→0) so two circuits are built-in PSPICE as explained in the accepted paper in Al-Nahrain Journal of Science. Figure [2] explained some important results for this model.

![Figure 2: Model of the Lead-acid battery in PSPICE program.](image)
Photovoltaic panel

The PV panel model described by Harith M. Saeed (4,5) will be used to supply energy to the load. To accommodate the variables of this research some changes had to be taken like the no. of diodes and the value of Rs. Thus, the shape of the PV panel and its properties became as shown in figure [3]. The simulation model shows 12 V and 60 W maximum power at 25 °C with 1000 W/m² solar irradiation.

![Figure [3]: The created PSPICE panel](image)

Boost Converter

Boost converter shown in figure (4) will rise a PV panel voltage (6) from 10 V to 22V. Assuming I₀ = 4.4 A, fₛ = 10 KHz, ΔV₀ = 1.1 V.

Therefore,

\[ R = \frac{V_0}{P} \quad [1] \]

And the duty cycle from the equation below:

\[ D = 1 - \frac{V_{in}}{V_o} \quad [2] \]

The value of the capacitance is calculated from equation [3] (7):

\[ C = \frac{I_0 \cdot D}{f_s \Delta V_o} \quad [4] \]

The inductor shown in figure (8) works as a storage element is calculated from equation [5] (7):

\[ L_{min} = \frac{V_o \cdot T_s}{16 I_o} \quad [5] \]

A boost converter is used to keep track of the MPPT. This is achieved by recording the effect of the PV surface temperature on the positions of the MPP on the I-V curves.
Figure [4] clarified the complete boost converter circuit as simulated where Op-Amp. (U1) and Op-Amp. (U2) serves as MOSFET gate drive with the required D to drive M1. U1 is the error amplifier (compare the PV panel voltage with the max. voltage of the I-V curves for assigned temperature). U2 compares a saw-tooth signal to an error signal to produce a square wave.

![Boost Converter Circuit](image)

**Design and simulation bidirectional buck-boost converter**

Figure [5] shows the basic structure of the bidirectional DC-DC converter. This converter will be regulating the voltage and current coming from the solar panels going to the battery and vice versa (8).

![Bidirectional Buck-Boost Converter Circuit](image)

Depending on the equations below (9)
\[
L_{\text{min}} = \frac{V_o \cdot D (1 - D)}{f_s \cdot \Delta I} \quad \text{--- [6]}
\]
\[
L_{\text{max}} = \frac{V_{\text{in}} \cdot D}{f_s \cdot \Delta I} \quad \text{--- [7]}
\]

If \( D = 50\% \), then \( L_{\text{min}} = L_{\text{max}} \).

C1 & C2 (output and input filter capacitance) values are found from these equations (10):

\[
C1 = \frac{\Delta I_L}{8 \Delta V_0 f_s} \quad \text{--- [8]}
\]
\[
C2 = \frac{I_0 \cdot D}{\Delta V_0 f_s} \quad \text{--- [9]}
\]

The values of the inductor \( L \) and the capacitance of C1 & C2 are calculated, assuming: \( V_o = 12 \text{ Volt}, V_{\text{in}} = 22 \text{ Volt}, D = 0.5, f_s = 1 \text{ KHz}, I_0 = 1A, \Delta I_L = 0.24 \text{ A} \) and \( \Delta V_0 = 0.6 \text{ Volt} \)

So, the inductance value \( L_1 \) is calculated according to the equation. \[6\] (21mH), capacitor C1 (50 μF) and C2 (666 μF).

**Pulse width modulation (PWM)**

This unit is shown in figure [6] which generates the signal for driving the converter’s switching devices. The U1A (uA741) error amplifier senses the error output resulting from the difference between the real voltage (SOC) and a reference voltage (0.4). The error amplifier output signal is compared with the saw-tooth signal that properties (\( T_{\text{period}} = 1\text{ms}, V_{\text{peak}} = 9\text{V} \)) to produce the square wave with the necessary duty ratio for driving the converter switching device. To activate one of the two sources (PV panel & lead-acid battery) the logical circuit shown in figure [6] (Sources Control Circuit) was built. In this circuit when SOC less than 0.4 then the PV panel is active (charge mode) while when SOC greater than 0.4 the battery is active (discharge mode).

**Figure [6]: Total circuit of PVS**

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\[
L_{\text{min}} = \frac{V_o \cdot D (1 - D)}{f_s \cdot \Delta I} \quad \text{--- [6]}
\]
\[
L_{\text{max}} = \frac{V_{\text{in}} \cdot D}{f_s \cdot \Delta I} \quad \text{--- [7]}
\]
The complete PVS results:

The whole PV system (PVS) shown in figure [6] for charging mode and discharging mode will be simulated.

Buck operation during the charging mode

The bidirectional buck-boost converter circuit shown in Figure [6] with \(V_{in} = 22 \text{ Volt}, D = 0.5, \text{ and } V_o = 12 \text{ Volt}\) was simulated to check the buck operation, where the power flows from left to right. The battery is charged via the bidirectional converter in this mode. The battery is charged by constant current, constant voltage methods. This procedure and simulation results are shown in the below figures.

The curve in figure [7] shows that the waveform of the gate-source voltage for both transistors in the bidirectional converter. This figure clearly shows that the second transistor does not work, but the first transistor connects the battery with the PV panel to charge it.

![Figure 7: The gate to source voltage for M1 & M2 – buck mode.](image)

The input voltage (PV) and the bidirectional converter output voltage waveforms are shown in figures [8] and [9] respectively.

![Figure 8: The converter input voltage (PV panel) VS Time Buck mode.](image)

![Figure 9: The converter output voltage VS Time Buck mode.](image)
Figures [10] and [11] display the battery output voltage and SOC respectively during buck mode. The battery needs 100 ms to charge from 12.2 Volt to 13 Volt.

![Battery voltage function of time](image1.png)

**Figure [10]:** Battery voltage function of time
Buck mode.

![State of charge function of time](image2.png)

**Figure [11]:** State of charge function of time
Buck mode.

**Boost operation during the discharging mode**

The bidirectional converter circuit at the discharge mode shown in figure [6] was simulated to verify boost operation.

The battery is discharged into this mode through the bidirectional converter. The battery is discharged by methods of constant voltage and constant current. Figures below show the results of this simulation.

Figure [12] displays the waveform of gate-source voltage for both transistor M1 & M2 where M2 is conducted to discharge the battery.

![The gate to source voltage for M1 & M2 – boost mode](image3.png)

**Figure [12]:** The gate to source voltage for M1 & M2 – boost mode
The input voltage (battery voltage) and the output voltage of the bidirectional converter waveforms are shown respectively in figures [13] & [14].

Figure [13]: The converter input voltage (Battery Voltage) Vs Time - Boost mode

Figure [14]: The converter output voltage vs Time Boost mode

Figures [15] and [16] show the battery voltage and SOC during boost mode, respectively. The battery was discharged for 100 ms and SOC decreases from 1 to 0.4.

Figure [15]: Battery voltage function of time – boost mode

Figure [16]: SOC Vs. Time – Boost mode

Finally, the behaviour of the battery model for different PV surface temperature are shown in figure [17] and [18].
Conclusions

From the present study, the following points could be concluded:

1. The battery model of lead-acid and PV are defined in the PSPICE library so, it could be used for most renewable energy systems applications.
2. The bidirectional converter works on buck and boost mode, so it is suitable to charge and discharge battery using a suitable control circuit. The operation of the bidirectional converter and power flow was verified by the PSPICE program.

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