

Performance analysis of DC-DC boost converters based on PV system

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Abstract. This paper presents the simulation of PV system using Multisim and compare the simulation results with the parameters of the actual solar cell, to analyze the errors. For further study, we prove that a DC-DC boost converter can achieve balance and we can figure out the upper and lower limit value of current through the inductance. The study presents the bypass function of capacitance C_1 in the boosted circuit. The boost converter is relevant to the efficiency of PV system. The duty cycle D can be adjusted automatically to control the value of the input voltage for tracking maximum power point of a solar cell.

Introduction

The demand for electrical energy is increasing around the world and it has motivated the scientists to study the new renewable energy sources. PV energy is popular and it is becoming a real economical renewable source of energy since it offers many advantages such as incurring no fuel costs, a clean source of energy, requiring little maintenance, and no noise emissions [1].

Scientists devote themselves to the research of the new renewable energy. In this field, the development of computing technologies also provides lots of convenience [1]. It presents us to software simulation, which reduces the cost of a real laboratory to a small laboratory in our PC that allows us to simulate a real phenomenon and gives results that are close to the real ones. There are lots of software to choose from such as MULTISIM, MATLAB...

In this paper, we take advantage of the computing technologies to do some simulations of PV system, which is convenient and reliable.

PV system model

Figure 1 shows the Simulink model of PV system. As shown in the model, the whole PV array is composed of three PV modules in series and each component contains six photovoltaic cells. In the study, each component is replaced with voltage-controlled current source to simulate the system. Furthermore, adjustable voltage source represents the intensity of sunlight.

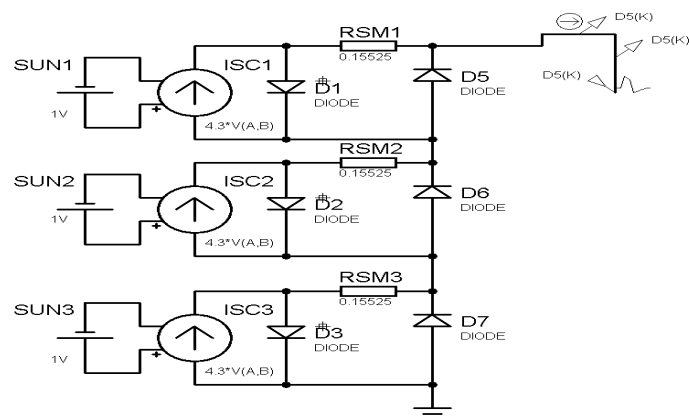


Figure 1. Simulink model of PV system

Simulation circuit of PV modules

Figure 2 shows the simulation circuit of PV modules, where the mathematical equation and PV panel parameters are represented. Figure 3 shows the V-I and P-V characteristics of a typical 40W PV cell. This result is obtained from the circuit as shown in Figure 2.

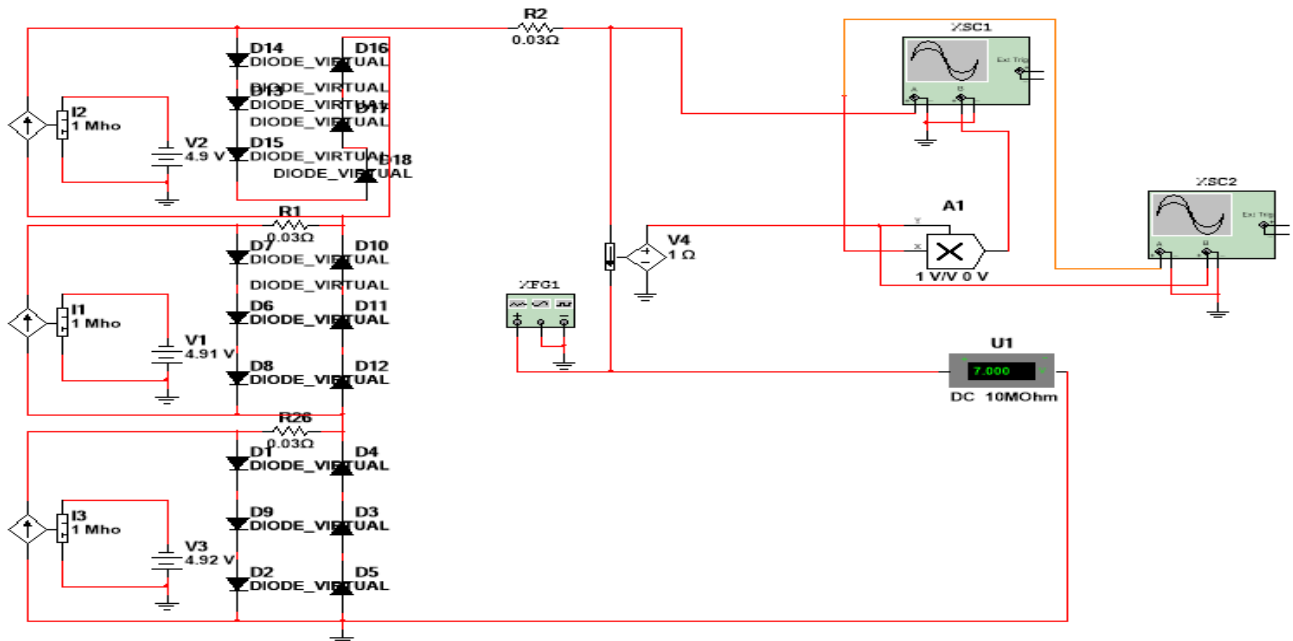


Figure 2. Simulation circuit of PV module

In Figure 2, the PV system is replaced by the three voltage-controlled current sources, which is adjustable and represents the intensity of the sunlight. In the simulation circuit, the voltage and the power can be calculated. The oscilloscopes show the V-I and P-V characteristics as Figure 3 [2].

(xsc1: P-V characteristic; xsc2: V-I characteristic)

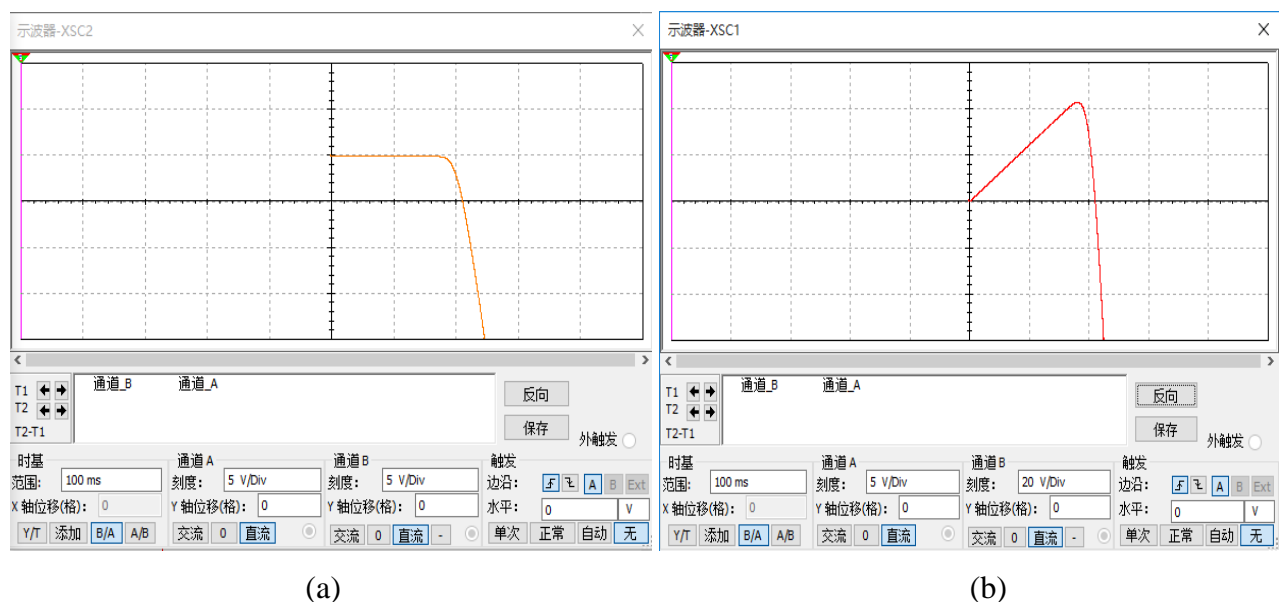


Figure 3. V-I and P-V characteristics of a typical 40W PV cell; (a). V-I (b). P-V

As illustrated in Figure 3, the voltage is constant and then decreases with the increase of the current. The power increases with the increase of the voltage and reaches a peak, which is the maximum power point. In this state, the cell solar can achieve the maximum power output.

The simulation results are simulated in the ideal state. But in practice V-I and P-V characteristics are affected by some factors. So it is a way to evaluate the solar cell sold on the market. Table 1 shows the errors of the parameters between the Simulink system and the solar cell on the market. (Solar Module Type: SMF-20, Made by DongGuan Singfo Solar).

Table 1. the errors of the parameters between the Simulink system and the solar cell

Parameter	Simulative value	True value	Error
Open circuit voltage(V_{oc})	10.8V	10.8V	0%
Short circuit current(I_{sc})	4.9A	4.9A	0%
Voltage at Pmax(V_{MPP})	9V	9V	0%
Current at Pmax(I_{MPP})	4.46A	4.46A	0%
Maximum power(P_{max})	42W	40W	5%

As shown in the table 1, there is some difference between the simulative value and true value. The most important is to improve the solar cell and reduce the impact of some factors.

Equilibrium of DC-DC boost converter

In the field of electronics, DC-DC booster converters are so popular among the scientists. It plays the important role of booster. Figure 4 shows the schematic diagram of the DC-DC boost converter. In this paper, the value of electric current through the inductance L_1 will be deduced and we will prove that the boost converter can achieve balance. In other words, the upper and lower limit value of current through the inductance is constant.

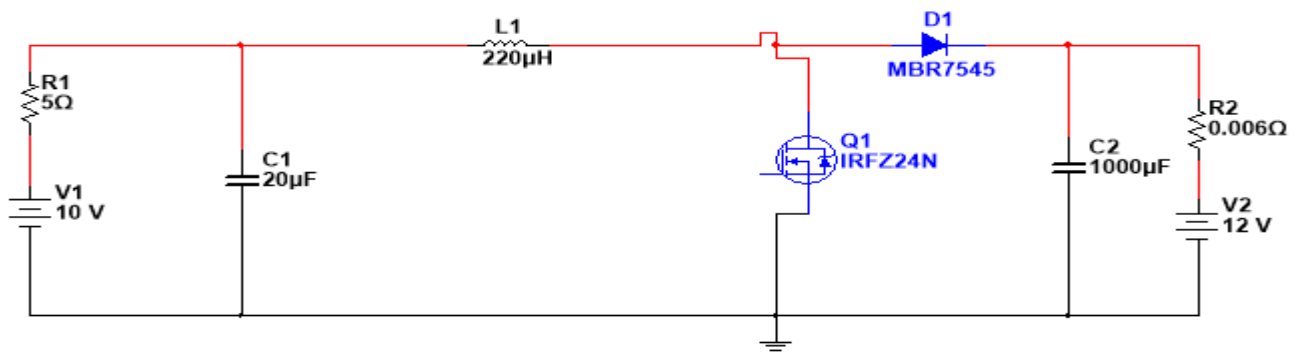


Figure 4. The schematic diagram of the DC-DC boost convert.

In this paper, we prove that the boost converter can achieve balance throughout the method of hypothesis. We firstly assume that the boost converter can achieve balance so that we can work out the upper and lower limit value of electric current through the inductance in theory. So we can work out the value of the current to prove the boost converter can achieve balance. Figure 5 shows the simulation curve of the current through the inductance.

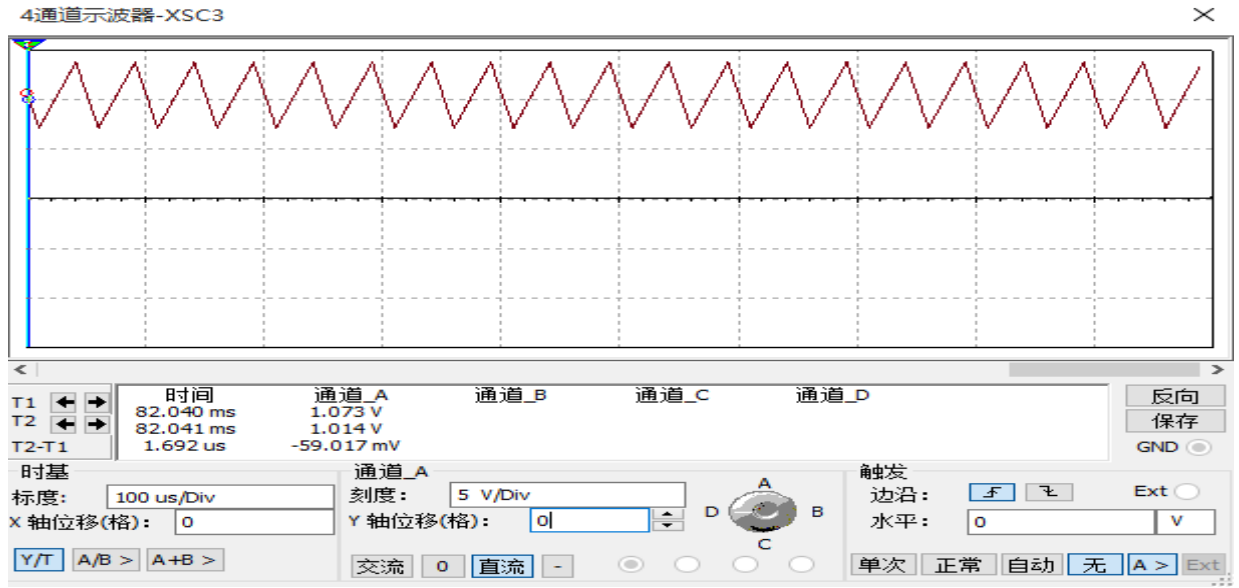


Figure 5. The simulation curve of the current through the inductance

In Figure 5, the waveform of the current through the inductance is triangle. We suppose the upper limit value as I_2 and the lower limit value as I_1 . The current flows periodically as the curve.

In the boosted circuit, the equivalent circuit is shown as Figure 6(a) when the MOSFET turns on and other part of the circuit is short. The conducting time of the MOSFET is t_1 . The equivalent circuit is shown as Figure 6(b) when the MOSFET turns off. The turn-off time is t_2 [3].

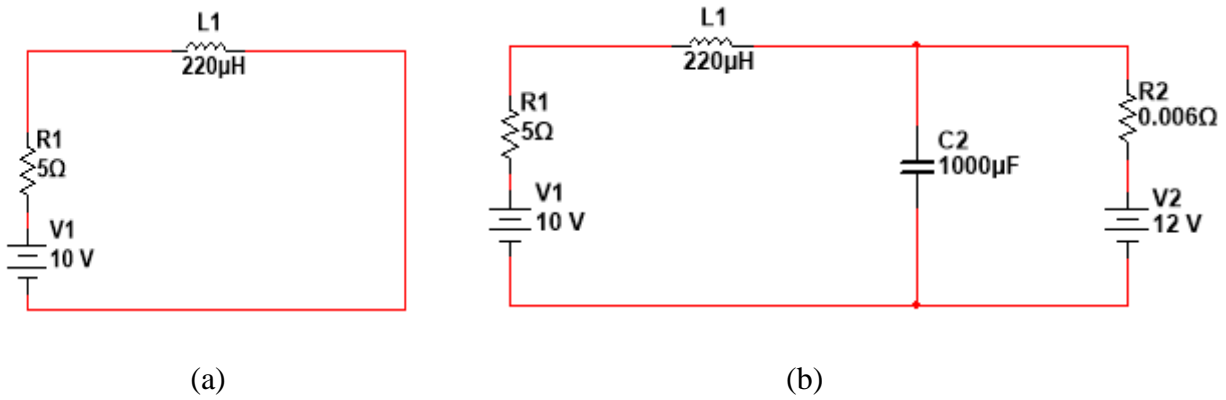


Figure 6. Equivalent circuit when the MOSFET turns on and off; (a). on (b). Off

As illustrated in Figure 6 (a), the inductance is charging and the current through it can be calculated by the three-factor method as follows:

$$i_L = 0 + (I_1 - 0)e^{\frac{-t}{\tau}}. \quad (1)$$

When the charge is over, the the upper limit value I_2 can be calculated as follows:

$$I_2 = I_1 e^{\frac{-t_1}{\tau}}. \quad (2)$$

As illustrated in Figure 6 (b), the inductance is discharging and the current through it can be calculated as follows:

$$i_L = \frac{U_s}{R} + (I_2 - \frac{U_s}{R}) e^{\frac{t-t_1}{\tau}}. \quad (3)$$

When the discharge is over, the the upper limit value I_2 can be calculated as follows:

$$I_1 = \frac{U_s}{R} + (I_2 - \frac{U_s}{R}) e^{-\frac{t_2}{\tau}}. \quad (4)$$

According to the formula (3.2)(3.4), we use equations to work out the value of the current I_1 & I_2 .

$$I_1 = \frac{U_s(1 - 2e^{-\frac{t_1}{\tau}} + e^{-\frac{2t_1}{\tau}} + e^{-\frac{t_2}{\tau}}) - 12e^{-\frac{t_2}{\tau}}}{R(1 - e^{-\frac{t_2}{\tau}} + e^{-\frac{2t_2}{\tau}})}. \quad (5)$$

$$I_2 = \frac{U_s(1 - e^{-\frac{t_1}{\tau}} + e^{-\frac{T}{\tau}}) - 12e^{-\frac{T}{\tau}}}{R(1 - e^{-\frac{t_2}{\tau}} + e^{-\frac{2t_2}{\tau}})}. \quad (6)$$

(U_s represents the total electrodynamic force, R represents the total resistance)

The upper and lower limit value of electric current through the induction can be worked out. According to Figure 5, the current changes periodically as the figure. So we can say the DC-DC boost converter can achieve balance[4].

Bypass function of the capacitance C_1

As illustrated in Figure 4, we will discuss the function of the capacitance C_1 by the usage of the Fourier series in this paper. Throughout the simulation and observation, we found the capacitance C_1 has an impact on the booster circuit. The current waveform through the inductance L_1 is triangular as shown in Figure 5. Through the circuit, the current flows into the power source V_1 and the capacitance C_1 . By Fourier series expansion of the current, it can be seen as the summation of lots of low current including the fundamental wave, first harmonic, second harmonics and so on. It conforms to the Fourier series formula as follows:

$$f(t) = a_0 + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)] \quad (7)$$

When the value of n is small, the frequency of harmonic is low and the impedance is $R_1 = 1\Omega$ and $X_c = \frac{1}{2\pi fC}$ on the two branches. Because the value of the impedance X_c is infinite and much larger than that of the impedance R_1 , the branch with the capacitance can be seen as be off. So the current tends to flow into the power source in theory. When the frequency is high, the value of the impedance X_c is much lower. So the current tends to flow into the capacitance in theory.

According to the analysis above, the low harmonic and the fundamental wave tend to flow into the power source and the high tend to flow into the capacitance. Furthermore, we know the amplitude of the low harmonic is much smaller than that of the fundamental wave according to Fourier series formula, so the current through the power source tends to be thought as direct current. In other words, the capacitance C_1 filters out high frequency components and plays the role of the bypass. The capacitance C_1 is called bypass capacitor.

Maximum Power Point Tracking (MPPT)

The output power of PV cell is changed by environmental factors, such as illumination and temperature. Since the characteristic curve of a solar cell exhibits a nonlinear voltage-current

characteristic, a controller named maximum power point tracker (MPPT) is required to match the solar cell power to the environmental changes. The formula of the duty cycle is presented as follows:

$$U_0 = \frac{U_i}{1-D} \quad (8)$$

(U_i represents the input voltage, U_0 represents the output voltage, D represents the duty cycle).

In engineering, the duty cycle D can be adjusted automatically to control the value of the input voltage for tracking maximum power point of a solar cell. It has a positive impact on tracking maximum power point quickly and accurately.

Conclusion

In this paper, we prove that the boost circuit can achieve balance by Fourier series expansion of the current through the inductance L_1 . And the capacitance C_1 plays the role of the bypass. Moreover, we can learn more about the PV system by the simulation. The duty cycle D can be adjusted automatically to control the value of the input voltage for tracking maximum power point of a solar cell [5].

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