

Design and SIMSCAPE Simulation of Non-Isolated DC-DC Boost Converter for Maximum Power Tracking in Solar PV System

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Abstract

The use of fossil fuel results exaggerated global warming that attracting various interest to the green energy sources recently. As compare to fossil fuels solar power is everlasting supply of energy whereas fossil fuels and traditional sources of power are restricted. Currently solar power or solar photovoltaic's (PV) gaining a lot of attention of the researchers and market players of this field. The sole downside of the solar PV (SPV) system is its high cost of capital, which can be stipendiary by increasing its power output. Maximum power point tracking (MPPT) is that the optimum answer to extract maximum SPV generated power.

MPPT is nothing but the tracking of maximum available power of an SPV system by means of the DC-DC converter. DC-DC converters play very important role in case of MPPT. In this paper design of a non isolate DC-DC boost converter is presented for solar module of 20 Watt for tracking maximum power. Testing is done is MATLAB/SIMSCAPE environment and results show that designed converter is able to track maximum power output. Comparative results were presented for MPPT and without MPPT operation.

Keywords: Boost Converter, DC-DC converters, MPPT, Solar PV. MATLAB, SIMSCAPE.

Introduction

The DC/DC converters are widely utilized in regulated switch mode DC power supplies. The input of those converters is an unregulated DC voltage, that is obtained by PV array and thus it will be fluctuated because of changes in radiation and temperature.

In these converters the average DC output voltage should be controlled to be equated to the specified value though the input voltage is changing. From the energy point of view, output voltage regulation within the DC/DC convertor is achieved by perpetually adjusting the amount of energy absorbed from the supply which injected into the load, which is in turn controlled by the relative durations of the absorption and injection intervals¹. In this paper a basic circuit of DC-DC buck-boost converter has been designed

which is tested in MATLAB SIMSCAPE library. The advantage of SIMSCAPE is that it provides better realistic modeling of physical component so that the physical modeling can easily be implemented on hardware¹⁻⁵.

Modeling of PV system

The output of PV cell is a function of photon current that can be also determined by load current depending upon the solar insolation in its operation, see equation^{2,6-9}.

$$I_{pv} = I_{ph} - I_{s1} \left[\exp \left\{ \frac{V_{pv} + I_{pv} R_s}{N \times V_T} \right\} - 1 \right] - I_{s2} \left[\exp \left\{ \frac{V_{pv} + I_{pv} R_s}{N_2 \times V_T} \right\} - 1 \right] - \frac{V_{pv} + I_{pv} R_s}{R_{sh}} \quad (1)$$

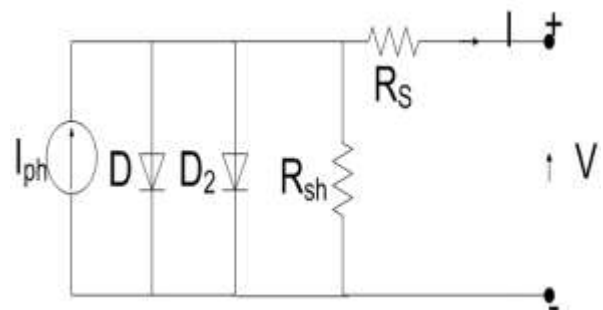


Fig. 1: Equivalent circuit of a two-diode model of a PV cell¹⁻².

where I_{ph} is the solar induced or photon generated current:

$$I_{ph} = I_{ph0} \frac{I_r}{I_{r0}} \quad (2)$$

I_r is the irradiance (light intensity or insolation) in W/m^2 reaching on the cell; I_{ph0} is the measured solar-generated current for the standard irradiance I_{r0} ; I_{s1} is the saturation current of the first diode; I_{s2} is the saturation current of the other diode; V_T is the thermal voltage; $V_T = kT/q$; k is the Boltzmann constant; T is the solar cell operating temperature; q is the elementary charge on an electron; N is the quality factor (diode emission coefficient) of the first diode; N_2 is the quality factor (diode emission coefficient) of the other diode; V_{pv} is the voltage across the solar cell's terminal.

The PV panel's output is also depends on solar insolation and temperature. A solar cell modeled on the basis of two diode model has been given in MATLAB in SIMSCAPE library. Solar cell given in MATLAB library is used for modeling and simulation. Fig. 2 shows the solar cell available in MATLAB SIMSCAPE library⁶.

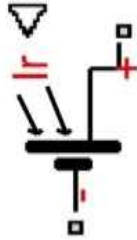


Fig. 2: Solar cell in MATLAB’s SIMSCAPE library.

The solar PV array used for testing is 20W panel and parameters used are specified in table 1 below:

**Table 1
Parameters of Solar Module.**

Performance at standard test conditions, STC: 1000 W/m ² , 25 °C.	
Nominal Power P _{MPP} of module	20 W
Short Circuit current I _{sc} of module	0.6 A
Open Circuit Voltage V _{oc} of module	44 V
Number of series connected cell in module	36*2
V _{MPP} of module	35.98
I _{MPP} of module	0.0557

Solar cell is simulated on the basis of short circuit current and the open circuit voltage, 5 parameters. Solar cell parameters used for simulation are given in table 2.

**Table 2
Solar Cell Modelling on the basis of 5 Parameters used in Simulation.**

Parameters	Value
Short Circuit current I _{sc} of cell	0.6 A
Open Circuit Voltage V _{oc} of cell	0.6 V
I ₀ of cell	1000 W/m ²
N of cell	1.5
R _s of cell	0.001 Ω
Number of series connected cell in module	36*2

The value of first diode’s quality factor (N) is taken as 1.5 and series resistance R_s is taken as 0.001 Ω. Beside these 5 parameters, temperature dependence parameters taken for simulation are given in table 3.

**Table 3
Temperature Dependence Parameters used in Simulation.**

Parameters	Value
First order temperature coefficient for I _{ph} , T _{IPH1}	0.0001 1/K
Energy gap, EG	1.11 eV
Temperature exponent for I _s , T _{XIS1}	3
Temperature exponent for R _s , T _{RS1}	0
Standard temperature, T	25°C
Device measurement temperature, T _{meas}	25°C

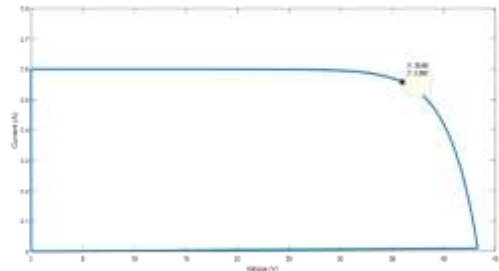


Fig. 3: I-V characteristic of solar module at 1000 W/m² insolation and 25°C temperature

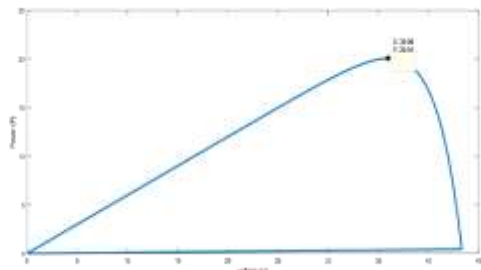


Fig. 4: P-V characteristic of solar module at 1000 W/m² insolation and 25°C temperature

On the basis of parameters given in table 2 and 3 simulation results obtained are shown in table 4. Current vs. voltage (I-V) characteristic obtained is shown in fig. 3 and power vs. voltage (P-V) characteristic is shown in fig. 4 at standard test conditions, STC: 1000 W/m², 25 °C.

DC-DC Boost Converter

Boost converter also known as voltage step up converter is used to obtain higher output voltage from lower input voltage. The boost converter topology is shown in Fig. 5. Fig. 5 presents the operating principle of boost converter. When the switch S₁ is turned on by the pulse of PWM, current flows through the inductor (L) and energy is stored in it. When switch is turned off, energy stored in the inductor

in the form of magnetic field provides an induced voltage across the inductor that adds to the input voltage. The input voltage and voltage across the inductor are in series and collectively charge the output capacitor (C_{out}) to a voltage higher than input voltage¹¹⁻²⁵.

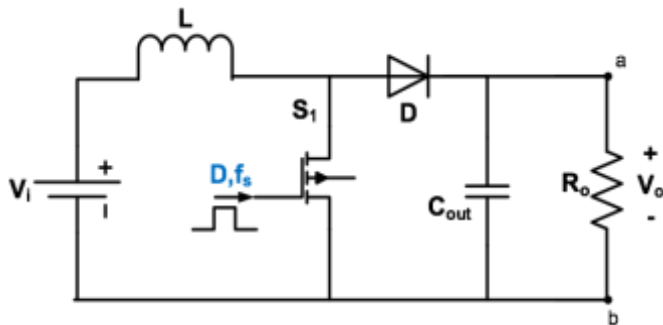


Fig. 5: Topology of boost converter⁹

Design Specific for MPPT operation^{6,9}:

Impedance seen from solar PV (Z_{source}).

$$Z_{source} = \frac{V_i}{I_i}$$

$$V_i = (1 - D)V_o \text{ and } I_i = \frac{I_o}{(1-D)},$$

$$Z_{source} = \frac{V_o}{I_o}(1 - D)^2 = Z_o(1 - D)^2$$

$$D = 1 - \sqrt{\frac{Z_{source}}{Z_o}}$$

For transferring maximum power $Z_{source}=Z_{MPP}$

where $Z_{MPP} = \frac{V_{MPP}}{I_{MPP}}$

Thus $D = 1 - \sqrt{\frac{Z_{MPP}}{Z_o}}$

(3)

From equation (3) duty cycle corresponding to MPP can be obtained, for $0 \leq D \leq 1$ load impedance must be:

$$Z_o \geq Z_{MPP}$$

(4)

Inductor value can give as:

$$L = \frac{V_i \times D}{\Delta I_L \times f_s} \tag{5}$$

Results and Discussion

Table 4 gives an assortment of equations of designing parameters for boost converter with relative example.

To verify the response of the converters, simulations are conducted in Simscape library of MATLAB which is closer to the practical design. N-channel MOSFET is used for switching purpose and controlling of it is done by means of voltage controlled PWM generator. The MATLAB simulation in SIMSCAPE is presented in the fig 6.

Table 4
Design parameters for boost converter

Condition for load Impedance	Duty cycle (D)	Switching frequency (f_s)	load current (I_l)	Ripple current (ΔI_l)	Inductor (L)	Capacitor (C_{out})
$Z_o \geq Z_{MPP}$	$D = 1 - \sqrt{\frac{Z_{MPP}}{Z_o}}$	10 KHz	$\frac{V_o}{Z_o} = \frac{V_i}{Z_o(1 - D)}$	$\Delta I_L = 0.1 \times I_L$	$L = \frac{V_i \times D}{\Delta I_L \times f_s}$	$= \frac{C}{Z_o \times f_s \times 0.01}$
$Z_o = 500\Omega$	64.05%	10 KHz	0.199 A	0.0199	0.1158 H	0.00001281 F

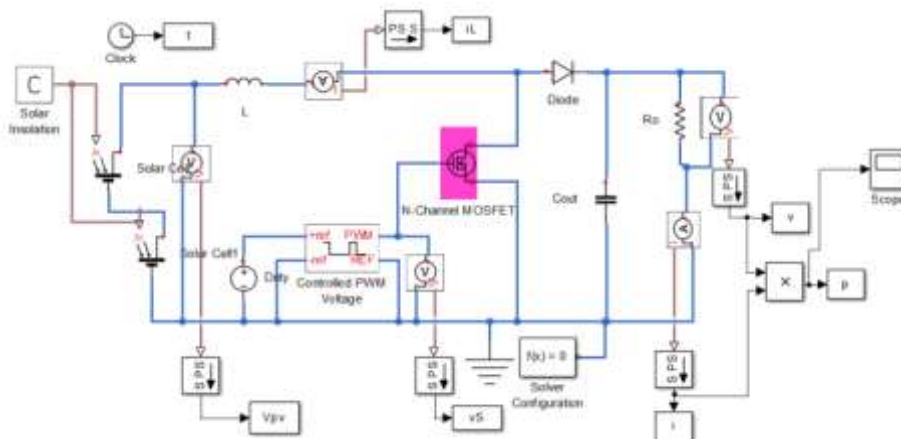


Fig. 6: MATLAB simulation of proposed system in SIMSCAPE environment

All the library component used for simulation are obtained by the SIMSCAPE library of MATLAB, the advantage of using SIMSCAPE library over the Simulink library is, the component used in the SIMSCAPE library are deals with the physical signals with proper unit whereas the Simulink library uses the signal which are unit less. In other words the components of SIMSCAPE library are more realistic or practical hence the hardware implementation may be easy in case of physical modeling. The left hand side (LHS) of Fig. 6 shows the simulation of solar PV array, the middle section shows the simulation of buck boost converter and the right

hand side (RHS) section shows the load and measuring components.

Fig. 7 shows the simulation model of same solar PV array with the same load without DC-DC buck boost converter.

Simulation results without converter: Fig.8 shows the PV array results with only load without DC-DC boost converter from result it is clear we get the output power of 3.5 Watts which is not maximum at STC (1000 W/m² and 25 °C). For the same condition we get the output voltage of 42.9 V shown in fig. 9.

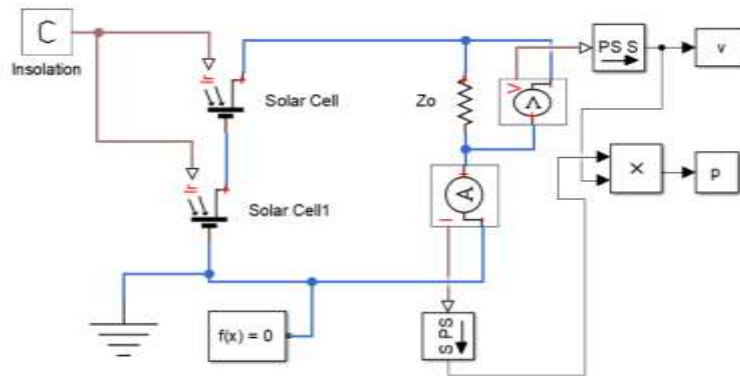


Fig. 7: MATLAB simulation of proposed system in SIMSCAPE environment without DC-DC converter

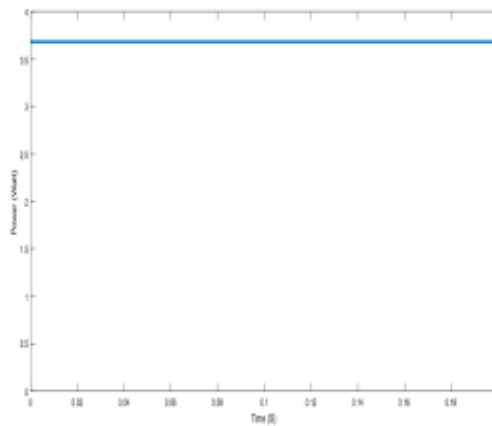


Fig. 8: PV array's output power without DC-DC boost converter

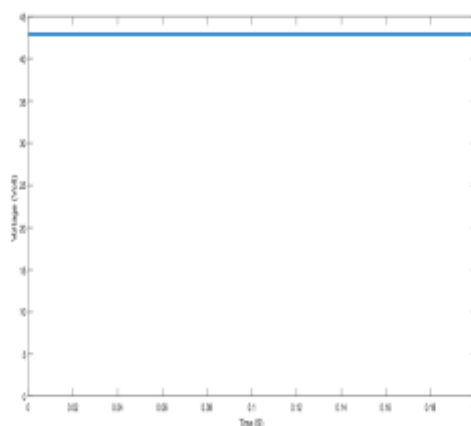


Fig. 9: PV array's terminal voltage without DC-DC buck boost converter

Simulation results with DC-DC boost converter: The simulation model of proposed system is presented in fig. 6. The results obtained by the simulation are discussed in this section. The power output after DC-DC buck boost converter is shown in Fig. 10, the power output is now 20 W which is nothing but the maximum power of the solar PV array at STC. The terminal voltage of the solar PV array before DC-DC boost converter is shown in fig. 11, the terminal voltage is equal to the voltage corresponding to the maximum power point that is V_{MPP} .

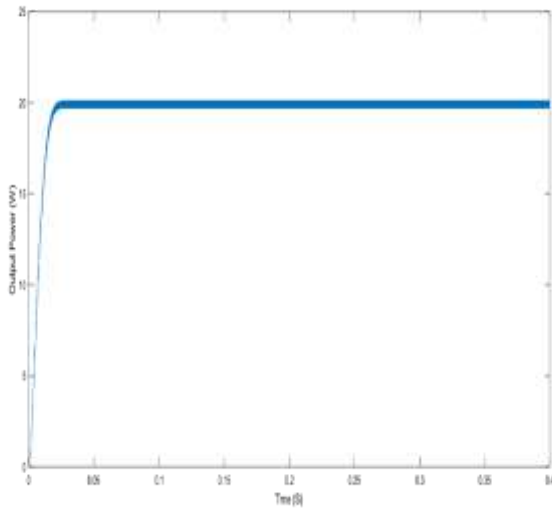


Fig. 10: PV array’s output power after DC-DC boost converter stage

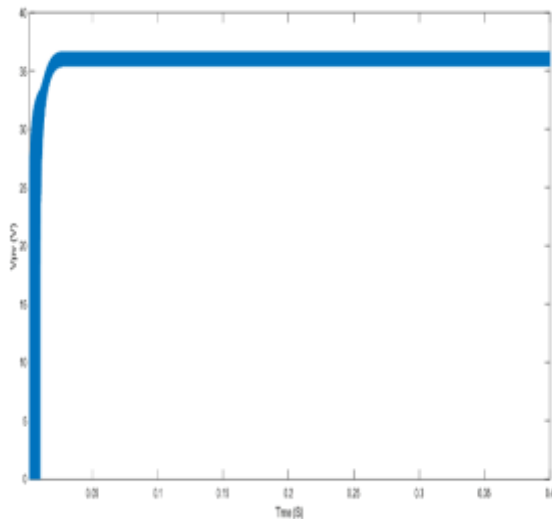


Fig. 11: PV array’s terminal voltage before DC-DC buck boost converter

The inductor current of the DC-DC buck boost converter shown in fig. 12, it shows that the designed converter operated in continuous conduction mode (CCM) as the value of inductor current not becomes zero at any instant of time. Fig. 13 shows the inductor current of duty cycle or zoomed across the X axis.

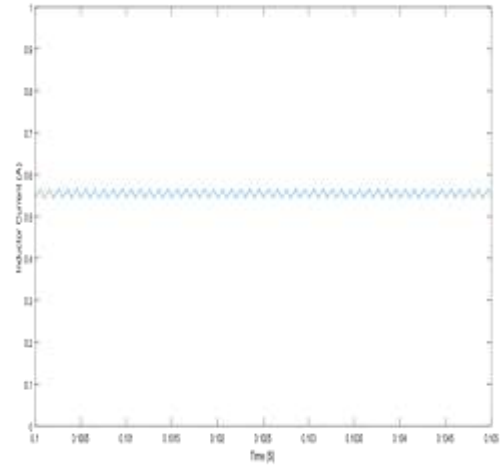


Fig. 12: Inductor current of the DC-DC buck boost converter

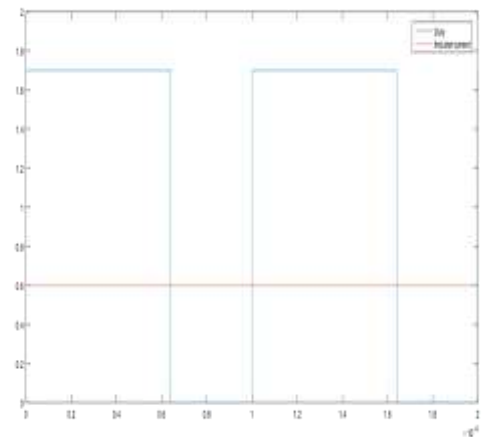


Fig. 13: Simulated response of inductor current and duty cycle.

Fig. 14 shows the output voltage of the DC-DC buck boost converter or the load voltage.

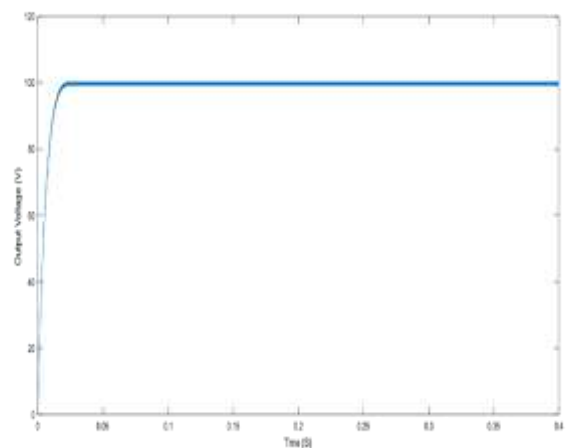


Fig. 14: Simulated response of load voltage.

Conclusion

This paper concerns with physical design and simulation of DC-DC boost converter to operate PV system in SIMSCAPE library of MATLAB for maximum power extraction. The input voltage is settled near to V_{MPP} where solar PV delivers maximum power.

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