



Modelling and Simulation of Photovoltaic Powered Converter System

R. Malathi

ASSOCIATE PROFESSOR, DEPARTMENT OF EEE, SCSVMV UNIVERSITY

ABSTRACT

In the area of renewable energies solar energy is abundantly available natural source of energy. Photovoltaic cells convert solar energy in the form of sun rays directly into electricity . PV cells are connected together to utilize the solar energy as a renewable form of energy at required irradiation to obtain the desired voltage . The PV cells are formed as PV arrays for the desired voltage level and PV panels connected with converters forms the Photovoltaic system.

This paper deals with modelling and simulation of Photovoltaic (PV) system under standard test conditions. Photovoltaic system with DC-DC boost converter and single phase Voltage Source Inverter (VSI) are carried out using MATLAB/Simulink.

Key Words: Photovoltaic(PV) System, DC-DC Boost Converter, Voltage Source Inverter (VSI),

1. INTRODUCTION

PV modules generate low output voltage, the maximum power point voltage range is from 15V to 40V (IEEE trans P.E safety enhanced high step up converter vol.27, No.4 April/2012) and two output voltage of PV panels depends on temperature changes and solar changes in solar insolation. The low DC output voltage of PV modules has to be stepped up to the voltage level of application.

This chapter depicts the comparison of DC-DC Boost converter with single phase VSI . Modelling and simulation of Photovoltaic system with DC-DC boost converter and single phase Voltage Source Inverter (VSI) are carried out using MATLAB/Simulink.

2. MODELING OF PHOTOVOLTAIC MODULE

As solar intensity in tropical region is uncertain the energy available from PV module also fluctuating. This demands the need for dynamic models of all the sub systems involved which are responsive to the changes in the solar intensity and wind velocity, to have an intensify understanding of the entire system.

In this paper, dynamic model of PV module is developed. The developed dynamic models are simulated using MATLAB/SIMULINK environment. The performances of the developed model are presented.

2.1 MATHEMATICAL MODEL OF PV CELL/MODULE

The most well used model for a PV cell is the single-diode model its equivalent circuits are presented in Figure 2.1(Townsend, 1989)¹⁰⁵, (Ulleberg and Morner, 1997)¹⁰⁶. Due to the large value of shunt resistance R_{sh} it is generally neglected shown in Figure 3.1 (a) Hence, the five parameter model shown in Figure 2.1 (a) can therefore be reduced into the four parameter model as shown in Figure 2.1 (b). This reduced four parameter model is employed in this study.

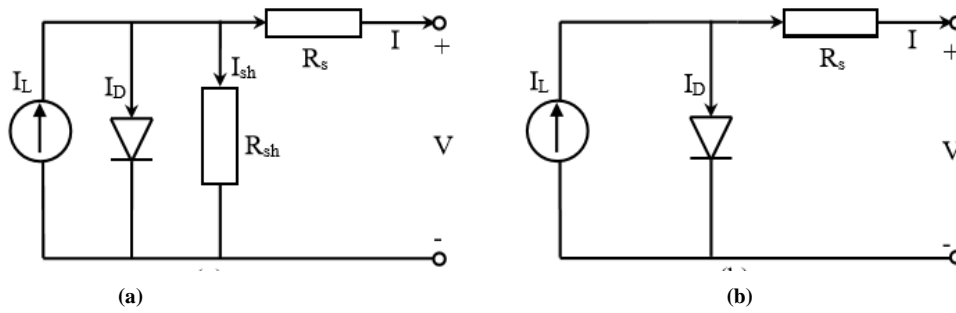


Figure 2.1 Single diode equivalent circuit model of PV cell

(a) Model with five parameters (b) Model with four parameters

The relationship between the PV cell output voltage (V) and the PV cell current (I) can be expressed as,

$$I = I_L - I_D = I_L - I_0 \left[\exp\left(\frac{V+IR_s}{\alpha}\right) - 1 \right] \quad (2.1)$$

where I_L is the light generated current in amperes,

I_0 is the reverse saturation current of the diode in amperes,

I is the load current in amperes,

V is the PV cell output voltage in volts,

R_s is the series resistance in ohms,

α is the thermal voltage timing completion factor and is also known as curve fitting parameter.

There are four unknown parameters (I_L , I_0 , R_s and α) in (2.1) that have to be determined before obtaining the V-I characteristics of the PV cell. Since four parameters are unknown in this model it is called as “Four Parameter Model”. Although the model shown in Figure 2.1(b) and the equation 2.1 look so simple, it is very difficult to obtain the four unknown parameters, because these parameters are functions of temperature, load current and/or solar intensity (Irradiation). The following section gives the detailed procedures for obtaining the four unknown parameters.

2.2 Determination of Light Current (I_L)

A method to calculate the light current I_L is proposed by Duffie & Beckman (John A. Duffie and William A. Beckman, 2013)⁴⁵ and according to them light current can be expressed as,

$$I_L = \frac{\phi}{\phi_{ref}} \left[I_{L,ref} + \mu_{L,SC}(T_c - T_{c,ref}) \right] \quad (2.2)$$

where ϕ at the irradiance of the geographical location (w/m^2)

ϕ_{ref} is the reference irradiance given by the manufacturer obtained in Standard Testing Condition (STC i.e. $1000 w/m^2$ is generally used)

$I_{L,ref}$ is the light current at the reference condition (also known as short circuit current, ISC, ref) (i.e. $1000 w/m^2$ and $25^\circ C$).

T_c is the PV cell temperature in degree centigrade.

2.3 Determination of Saturation Current (I_0)

According to (Townsend,1989)¹⁰⁵, saturation current (I_0) can be determined in terms of its own value at the reference condition. The expression for saturation current is expressed as,

$$I_0 = I_{0,ref} \left(\frac{T_c + 273}{T_{c,ref} + 273} \right)^3 \exp \left[\frac{e_{gap} N_s}{q \alpha_{ref}} \left(1 - \frac{T_c + 273}{T_{c,ref} + 273} \right) \right] \quad (2.3)$$

where $I_{0,ref}$ is the saturation current at the STC in amperes

e_{gap} is the band gap of the PV material (1.17eV for silicon materials)

N_s is the number of cell in series in a PV module.

q is the charge of an electron ($1.60217733 \times 10^{-19}$ Coulombs).

α_{ref} is the value of alpha at reference condition.

The saturation current at the reference condition can be determined as,

$$I_{0,ref} = I_{L,ref} \exp\left(-\frac{V_{oc,ref}}{\alpha_{ref}}\right) \quad (2.4)$$

where $V_{oc,ref}$ is the open circuit voltage of the PV module at STC.

The value of $V_{oc,ref}$ will be provided in the manufacturer's data sheet.

2.4 Determination of Thermal Voltage Timing Completion Factor

In order to calculate the thermal voltage timing completion factor (Curve fitting factor), it is necessary to determine its value under STC (Townsend,1989)¹⁰⁵. The value of α_{ref} is given by,

$$\alpha_{ref} = \frac{2V_{mp,ref} - V_{oc,ref}}{\frac{I_{sc,ref}}{I_{sc,ref} - I_{mp,ref}} + \ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right)} \quad (2.5)$$

where

$V_{mp,ref}$ is the voltage of PV module at maximum power point under STC (V). $I_{mp,ref}$ is the current of PV module at maximum power point under STC (A).

$I_{sc,ref}$ is the short circuit current of PV module at STC (A).

The thermal voltage timing completion factor (α) is the function of temperature, which is expressed as,

$$\alpha = \frac{T_c + 273}{T_{c,ref} + 273} \alpha_{ref} \quad (2.6)$$

2.5 Determination of Series Resistance (Rs)

Some manufacturers of the PV module provide the value of R_s in their data sheet. If it is not provided, the value of R_s can be calculated using the following expression (Ulleberg and Morner,1997)¹⁰⁶,

$$R_s = \frac{\alpha_{ref} \ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right) + V_{oc,ref} - V_{mp,ref}}{I_{mp,ref}} \quad (2.7)$$

2.6 Thermal Model of PV Cell

From the above expressions (2.1) -(2.7), it is very clear that the temperature plays a vital role in the PV module performance. Therefore, it is necessary to determine the thermal model of the PV module. A lumped thermal model proposed in (Ulleberg,1998)⁸⁴ is used in this study. The temperature of the PV module is affected by its ambient temperature, irradiation, PV module voltage and current. The dynamic equation for cell temperature is expressed as,

$$C_{PV} \frac{dT_c}{dt} = k_{in,PV} \phi - \frac{V \times I}{A_r} - k_{loss}(T_c - T_a) \quad (2.8)$$

where C_{PV} is the thermal capacitance of the PV module [J/ (OC.m2)]

$k_{in,PV}$ is the transmittance absorption product of the PV module.

k_{loss} is overall heat loss coefficient of the PV module [W/ (°C.m²)]

T_a is the ambient temperature in degree centigrade

A_r is the effective area of the PV module in m².

3. DEVELOPMENT OF PV MODEL IN MATLAB/SIMULINK

As per the mathematical equations described above, dynamic model for PV module consisting of 72 cells in series is developed using MATLAB/SIMULINK. The block diagram of the PV module model is shown in Figure 3.1. The model takes solar irradiance ϕ and the ambient temperature T_a as input. Along with the input parameters, manufacturer's data is also used to determine the four unknown parameters (2.2) - (2.7). Then based on the equation (2.1), the output voltage of PV module is determined numerically. The thermal model equation (2.8) is used to determine the PV cell temperature. The output quantities of PV module (i.e. PV module voltage and load current) are fed back to take part in the dynamic calculations. Table 2.1 gives the parameters used in the simulation of a TATA BP solar power module (TP 180).

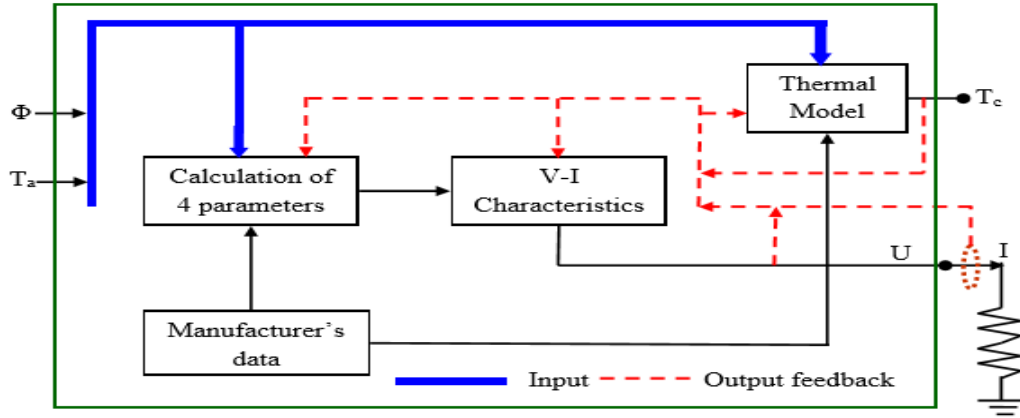


Figure 3.1 Block diagram of PV model developed in MATLAB/ SIMULINK

3.1 SIMULATION PERFORMANCE OF PV MODULE MODEL

The performance of the developed model is tested using MATLAB/SIMULINK. The irradiance is varied in steps by keeping the ambient temperature as constant at 25°C, the V-I characteristics of the PV module is plotted and is shown in Figure 3.2. It is clear from the Figure 2.3 that higher the irradiance, the larger the open circuit voltage (VOC) and the short circuit current (ISC). Figure 2.4 shows the Power Vs Voltage characteristics of the PV module for the same irradiance levels. For increase in irradiance the power delivered from the PV module also increases. Figures 2.3 and 2.4 also show the maximum power point (MPP), open circuit voltage, and the short circuit current.

Table 3.1 Parameters of PV module

Parameters	Values
Voltage at maximum power point (Vmp, ref)	35.8 V
Current at maximum power point (Imp, ref)	5.03 A
Open circuit voltage at STC (Voc, ref)	43.6 V
Short circuit current at STC (Isc, ref = IL, ref)	5.48 A
Reference Irradiance (ϕref)	1000 w/m ²
Reference cell temperature (Tc, ref)	25°C
Thermal capacitance (CPV)	5 X 10 ⁴ J/ (°C.m ²)
Area of the PV module (m ²)	1.25
Transmittance absorption product (kin, PV)	0.9
Heat loss coefficient (kloss)	30 W/ (°C.m ²)
Temperature coefficient (μ I, SC)	0.038
Module Power at STC	180 Watts

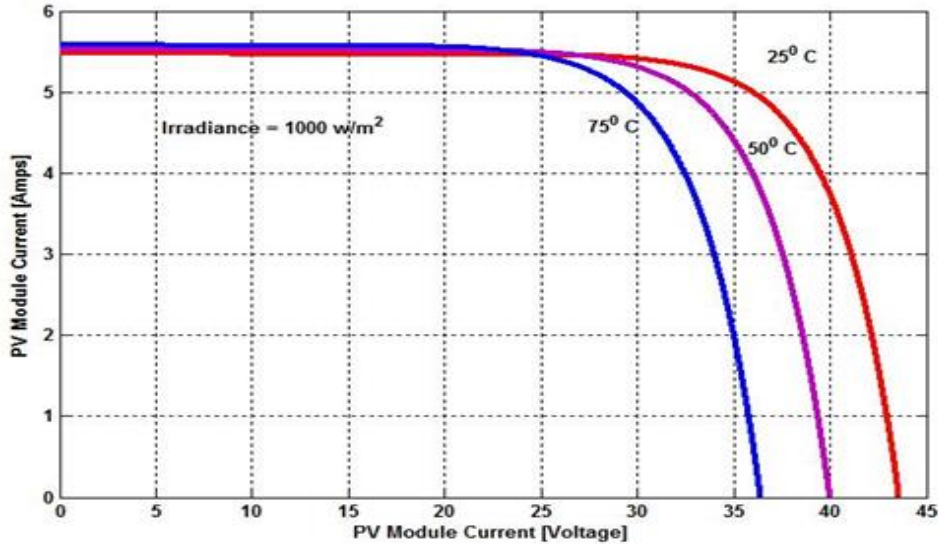


Figure 3.2 V-I Characteristics of the TS 180 under different cell temperatures and constant irradiance ($\phi = 1000 \text{ w/m}^2$)

3.2 DC-DC Boost Converter

The conventional boost converter is shown in Fig.3.3 it consists of a DC input voltage source V_{in} , a large inductor L is in series with source voltage, power semiconductor switch S, diode D, filter capacitance C and the load resistance R. When the switch S is ON, the current through the inductor L, increases. The diode D is in the OFF state at that time inductor stores energy during the ON period of the switch S. when the switch S is turned OFF, the energy stored in the inductor is released through the diode D, to the output RC circuit.

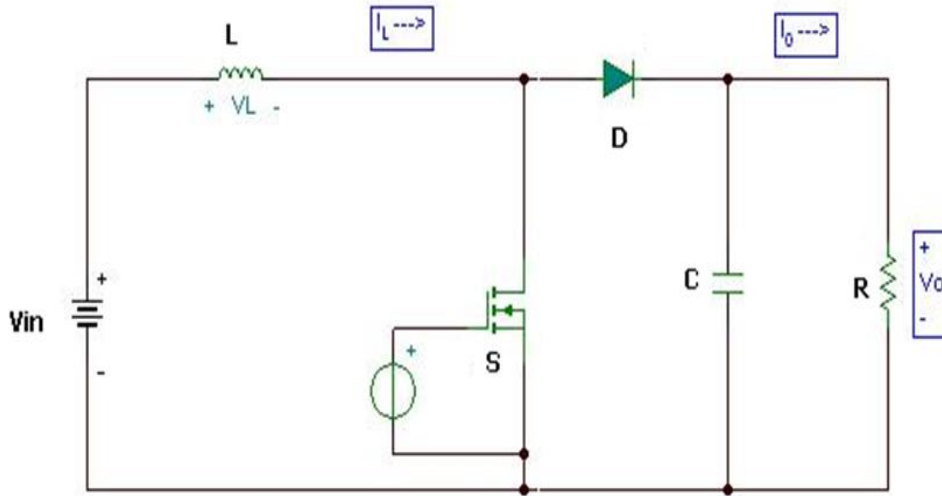


FIG 3 CONVENTIONAL BOOST CONVERTER

Figure.3.3 PV Powered Boost Converter System

3.3 SIMULATION OF PV SYSTEM

3.3.1 Simulation Results of Boost Converter

The simulation circuit of photovoltaic powered conventional boost converter with single phase inverter is developed and simulated in Matlab/Simulink. The simulation parameters are given in Table 3.1.

TABLE 3.1 Simulation Parameters

SL.NO	PARAMETRES	VALUES
1.	Inductance(L)	10mH
2.	Capacitor(C)	2200 μ F

3.	Filter Capacitor	1000 μ F
4.	Frequency	50Hz
5.	V _{in}	48V
6.	Duty ratio	0.6

The simulation performance of the circuit is presented. Simulation circuit of PV module is shown in Fig.3.4

Simulation circuit of PV powered boost converter is shown in Fig. 3.5. The solar output voltage is 48V and is shown in Fig. 3.6. Switching pulses for the converter switch S1 is presented in Fig.3.7. Boost converter output voltage is presented in Fig.3.8

Simulation circuit of boost converter with single phase voltage source inverter is shown in the Fig .2.9 . The switching pulses for the inverter switches M1 and M3 are given in Fig .3.10 . The output voltage of single phase VSI is presented in Fig .3.11.and the output voltage is 54 volts.

Fig .3.12 shows the output current of VSI and it is 1.8A

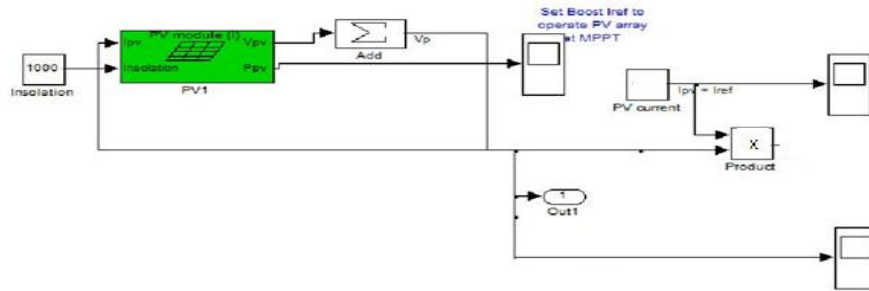


Figure 3.4 Measurement of Solar Power

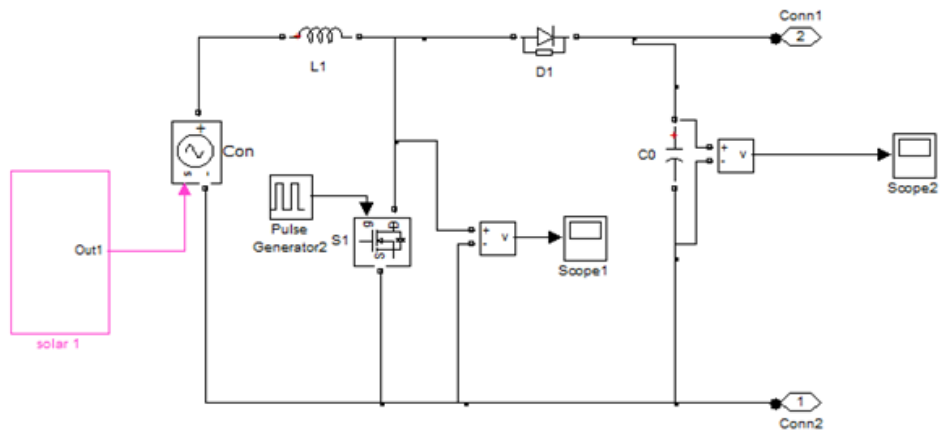


Figure 3.5 Boost converter

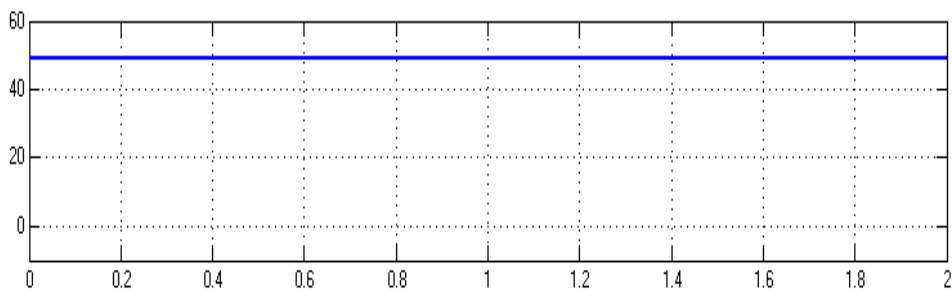


Figure 3.6 Output voltage of solar

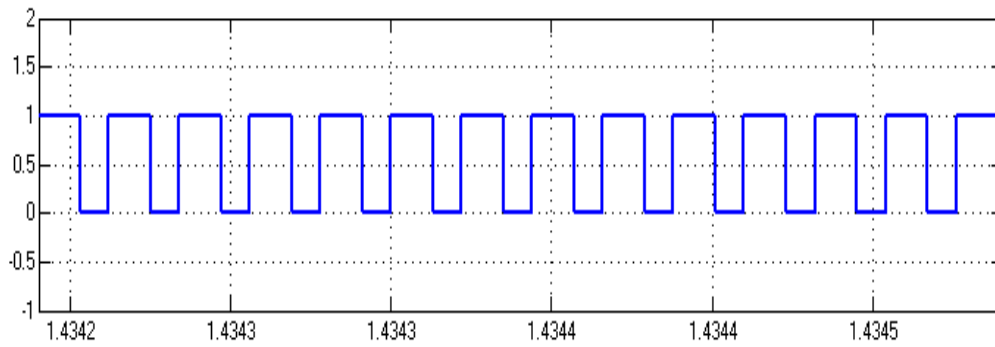


Figure 3.7 Switching pulse for boost converter S1

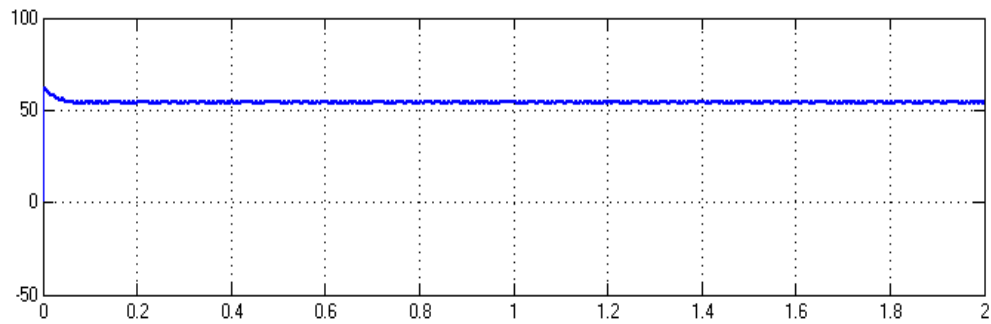


Figure 3.8 Output voltage of boost converter

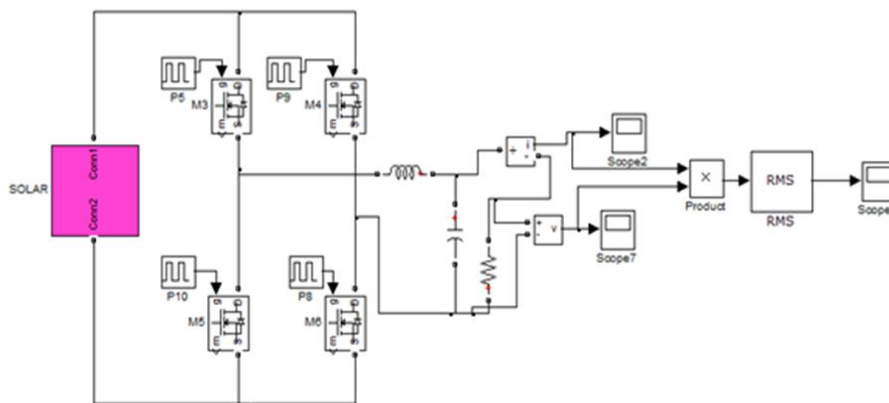


Figure 3.9 Boost converter with single phase Voltage Source Inverter (VSI)

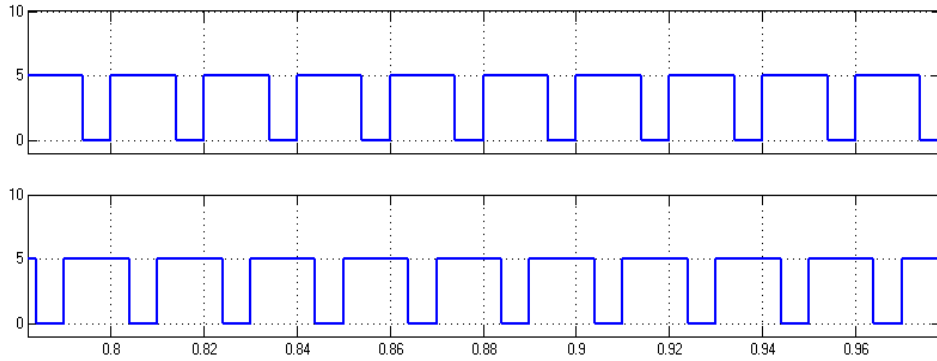


Figure 3.10 Switching pulses for Voltage Source Inverter (VSI)

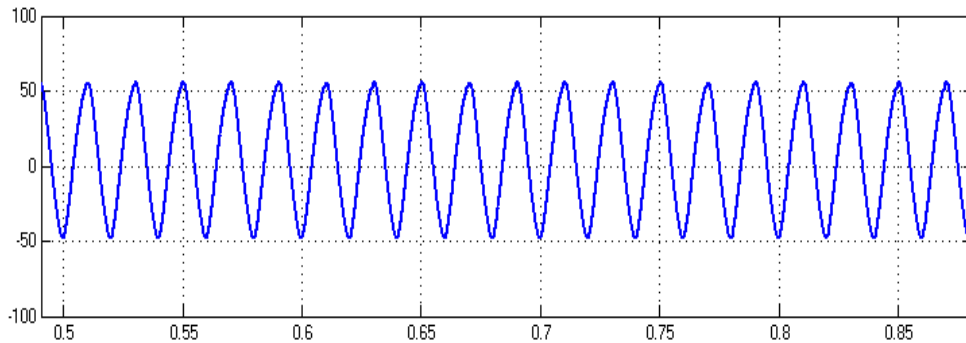


Figure 3.11 Output voltage of inverter

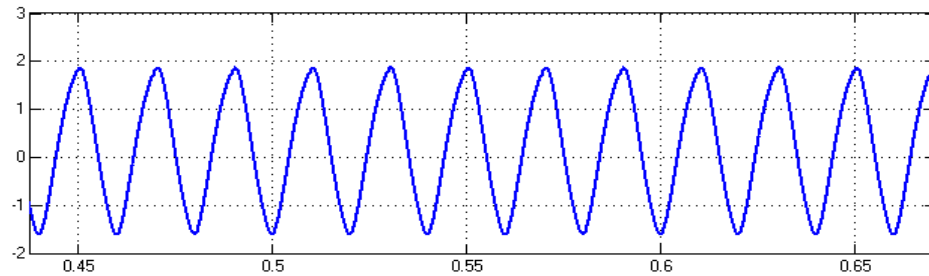


Figure 3.12 Output current of inverter

3.3.2 Simulation Results of PV System

PV Voltage (V)	DC-DC Converter output voltage(V)	VSI Output Voltage Vo(v)	VSI Output Current Io(A)
48	60	54	1.8

4. Conclusion

The simulation circuit of photovoltaic powered conventional boost converter with single phase inverter is developed and simulated in Matlab/Simulink. The simulation performance of the circuit is presented. The solar output voltage is 48V . Boost converter output voltage is 60 V.

This voltage is given as input voltage for single phase VSI. The VSI circuit is simulated and the output voltage of VSI is 54 Volts.

5.References

1. Ulleberg, O & Morner, "TRNSYS simulation models for solar-hydrogen systems", Solar Energy, vol. 59, no. 4-6, pp. 271-279,1997.
2. Qun Zhao and Fred C. Lee, "High-Efficiency, High Step-Up DC-DC Converters", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 18, NO. 1, pp. 65-73, JANUARY 2003.
3. Townsend, TU, "A Method for Estimating the Long-Term Performance of Direct-Coupled Photovoltaic Systems", 1989

-
4. Marcelo Gradella Villalva, Jonas Rafael Gazoli, Ernesto Ruppert Filho, "modeling and circuit-based simulation of photovoltaic arrays", 10th Brazilian Power Electronics Conference (COBEP), 2009.
 5. Hongmei Li, Xiao Ye, "Sliding-Mode PID Control of DC-DC Converter, 2010 5th IEEE Conference on Industrial Electronics and Applications", pp 730-734, 2010