

Comparison of electrical output quantity of photovoltaic module through boost converter in MATLAB-simulink environment

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Available online at: www.isca.in, www.isca.me

Received 8th April 2017, revised 9th June 2017, accepted 24th June 2017

Abstract

Solar PV module is a conversion technology in which solar power is converted to direct current (DC) electricity and boost converter is a device which is use for enhance the DC voltage and current amplitude. Converter based solar PV module, requires two weather data, radiation and temperature in the form of input variables and the output can be voltage, current, or power. In this paper, stepwise process of mathematical modelling of converter based solar PV module are described, in which weather data (Irradiance and temperature) has been used as input and comparison of output between PV Module and Boost Converter has been performed that how the generated power of PV Module is increased by using Boost Converter. All the simulation work has been performed in MATLAB/Simulink environment.

Keywords: PV Module, Boost Converter, Irradiance, Temperature, Power, MATLAB/Simulink.

Introduction

In the field of renewable energy, solar energy is most trifling, utilizable non-conventional energy; occur liberally in our environment that leads to the photovoltaic (PV) effects. Photovoltaic word is a combination of photo and voltaic. 'Photo' that means light and 'Voltaic' that tends to create electrical energy. Therefore the PV module produces the electricity directly from sunlight¹. Photovoltaic provides the user with the ability to produce power in a quiet, clean and consistent way. For environment reference PV module is connected to boost converter. Therefore converter based PV solar modules are steadily interesting to admissible in our community.

They are usually allowed for standalone or grid related applications. It has become god's gift for the rural community for which electricity had become a dreamy thing². The mathematical modeling of Converter based PV Module has been continuously rebuilt so that the investigator can improve its understanding of functionality. In this paper, stepwise process of converter based PV module simulation is described by using mathematical equations, which are generated from their schematic diagrams. For the purpose of simulation, Simulink toolbar from MATLAB has been used extensively. Almost all the components, and blocks were used which are available in Simulink toolbar.

Mathematical modelling and presentation of PV module

The schematic diagram of equivalent circuit of solar cell and module are shown below³:

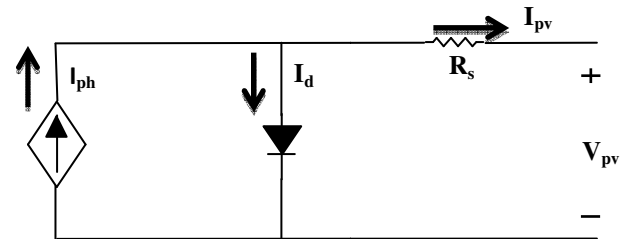


Figure-1: The equivalent circuit of solar module.

Where: I_{ph} = photo current, I_d = diode current, I_{pv} = photovoltaic output current, R_s = series resistance, and V_{pv} = photovoltaic output voltage of solar module. After analyse the above circuit, following equations (1)-(4) and (5)-(8) are obtained, which are help to simulate the different blocks of PV Module³.

Photocurrent of PV Module:

$$I_{ph} = \frac{G}{G_r} [I_{scr} + K_i \cdot (T_{ak} - T_{rk})] \quad (1)$$

Reverse saturation current of PV Module:

$$I_{or} = \frac{I_{scr}}{[\exp(\frac{V_{oc}}{a_r}) - 1]} \quad (2)$$

Saturation current of PV Module:

$$I_o = I_{or} \cdot \left[\frac{T_{ak}}{T_{rk}} \right]^3 \cdot \exp\left[\frac{q \cdot E_g}{A \cdot k} \left(\frac{1}{T_{rk}} - \frac{1}{T_{ak}} \right) \right] \quad (3)$$

Output photovoltaic current of PV Module:

$$I_{pv} = I_{ph} - I_o \cdot \left[\exp\left(\frac{V_{pv} + I_{pv} \cdot R_s}{a} \right) \right] \quad (4)$$

Where: G = Irradiance (W/m^2), G_r = Reference Irradiance ($= 1000 \text{ W/m}^2$), I_{or} = Reverse saturation current, I_{scr} = Short-circuited current, I_o = Saturation current, K_i = Temperature coefficient ($= 0.0017 \text{ A/K}$).

$$T_{ak} = T_a + 273 \text{ (in Kelvin)} \quad (5)$$

$$T_a = \text{Operating temperature (in } ^\circ\text{C)}$$

$$T_{rk} = 25 + 273 \text{ (Reference temperature in Kelvin)} \quad (6)$$

$$V_{oc} = \text{Open circuited voltage}$$

$$A = \text{Ideality factor}$$

$$a_r = \frac{N_s \cdot A \cdot k \cdot T_{rk}}{q} \quad (= \text{Modified ideality factor with reference temperature}) \quad (7)$$

$$a = \frac{N_s \cdot A \cdot k \cdot T_{ak}}{q} \quad (= \text{Modified ideality factor with operating temperature}) \quad (8)$$

N_s = Number of PV cells connected in series, q = Charge of electron ($= 1.602 \times 10^{-19} \text{ C}$), $k = 1.3805 \times 10^{-23} \text{ J/K}$ (Boltzmann constant), E_g = Band-gap energy.

The following Table shown all the parameter, which is used in simulation of PV module.

Table-1: Parameter used in simulation of PV Module.

Description of parameter	Values
Short circuited current (I_{scr})	8.4 A
Open circuited voltage (V_{oc})	37 V
Number of series connected cell in module (N_s)	65
Number of parallel connected cell in module (N_p)	1
Ideality factor (A)	1.5
Band gap energy (E_g)	1.1 J
Series resistance (R_s)	0.1 Ω

Mathematical Modelling and presentation of Converter

Schematic diagram of converter have been shown in Figure-2⁴:

After analyse the Figure-2, following equations (9)-(10) are obtained, which are used for simulate a dc to dc boost converter⁵.

$$L \frac{dI_L}{dt} = -(1-s)V_c + V_{pv} \quad \text{Or} \quad I_L = \frac{1}{L} \int (-V_c + s \cdot V_c + V_{pv}) dt \quad (9)$$

$$\text{And} \quad C \frac{dV_c}{dt} = (1-s)I_L - \frac{V_c}{R} \quad \text{Or} \quad V_c = \frac{1}{C} \int (I_L - s \cdot I_L - \frac{V_c}{R}) dt \quad (10)$$

Where: I_L = Inductive current of converter, V_c = Capacitive voltage of converter, R = Resistance, L = Inductance, C = Capacitance, s = Switch topology ($= 0$ or 1).

The following table shown all the parameter, which used in simulation of boost converter:

Table-2: Parameter used in simulation of boost converter.

Description of parameter	Values
Resistance (R)	3 Ω
Inductance (L)	1.5mh
Capacitance (C)	250 μf
Duty cycle (D)	0.8

Stepwise process of simulation of converter based photovoltaic module

For the purpose of simulation, Simulink toolbar of MATLAB/Simulink environment has been used. The propose model, which has been used for the simulation is as described below; it clearly illustrate what all blocks are used.

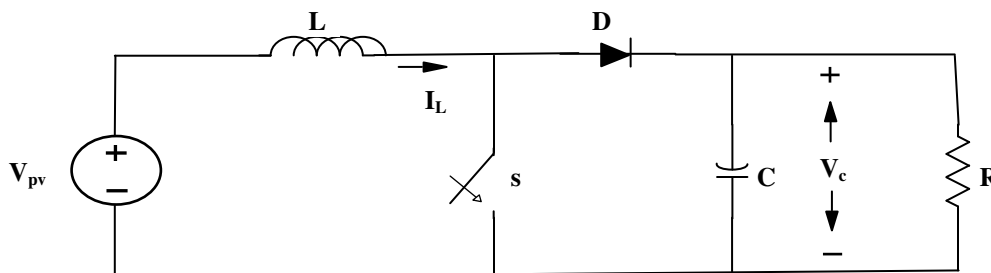


Figure-2: dc to dc boost converter

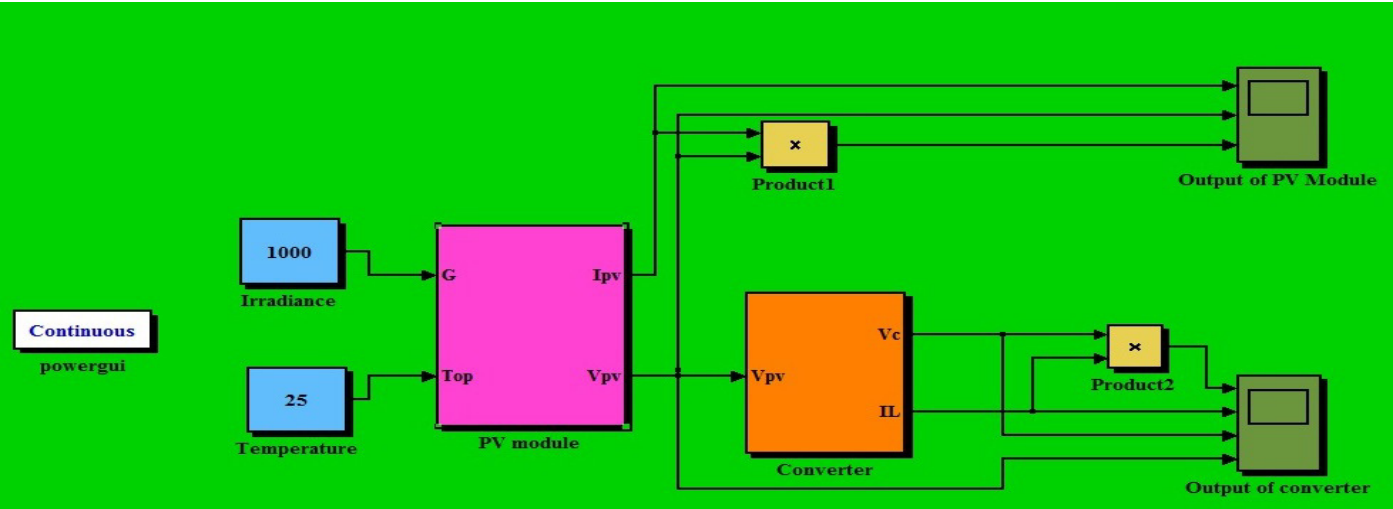
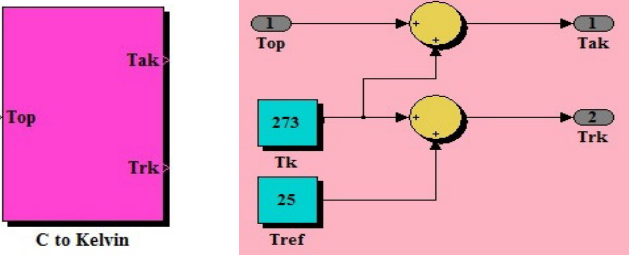


Figure-3: Optimized model of converter based PV Module.

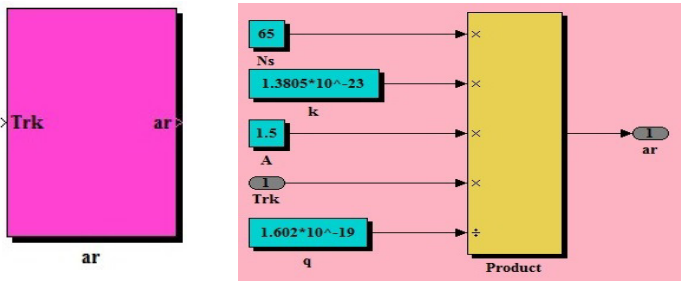
The entire step of simulation for above modal are describe as follows, where implementation of each steps are shown in wright side of the figure and their equivalent subsystem are shown in left side of the figure.

Step-1: The following Figure-4 is used to obtain the operating temperature, in which conversion of degree Celsius into Kelvin has been occurring. For simulation work, equation (5) and (6) are used.



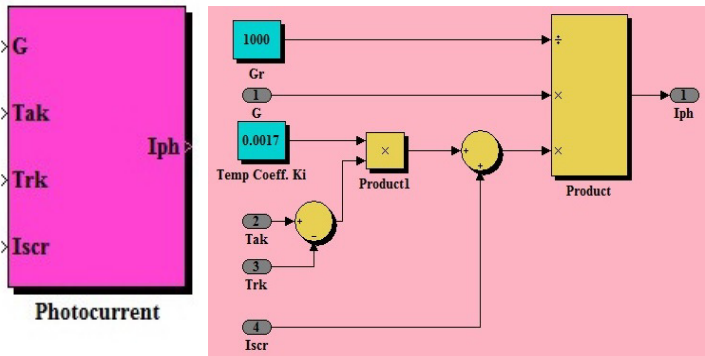
a. Subsystem 1 b. Connection diagram of subsystem 1
Figure-4: Implementation of degree Celsius to Kelvin conversion.

Step 2:- The following Figure-5 is used to obtain the reference ideality factor, which is implemented by using equation (7).



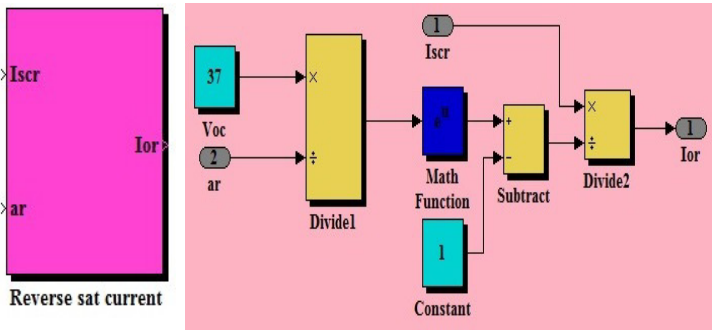
a. Subsystem 2 b. Connection diagram of subsystem 2
Figure-5: Implementation of reference modified ideality factor.

Step 3:- The following Figure-6 is used to obtain the photocurrent, which is implemented by using equation (1).



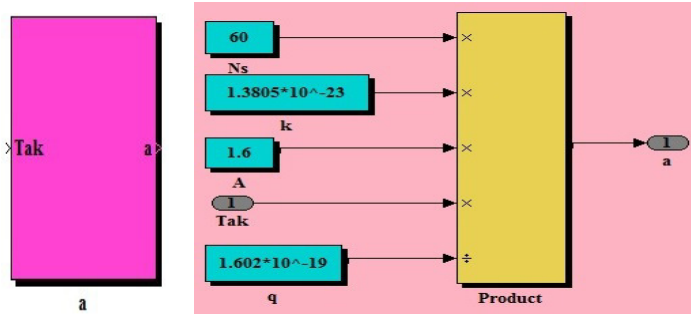
a. Subsystem 3 b. Connection diagram of subsystem 3
Figure-6: Detailed Implementation of PV Module photocurrent.

Step 4:- The following Figure-7 is used to obtain reverse saturation current, which is implemented by using equation (2).



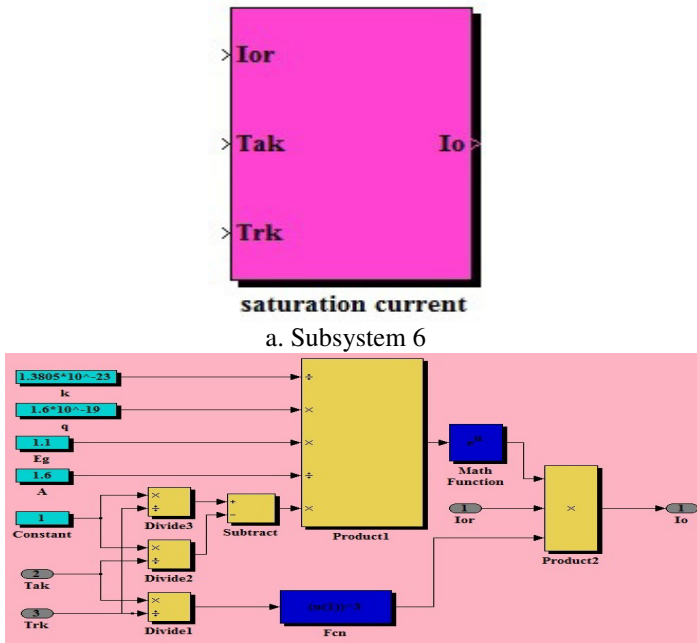
a. Subsystem 4 b. Connection diagram of subsystem 4
Figure-7: Implementation of Reverse saturation current.

Step-5: The following Figure-8 is used to obtain modified ideality factor, which is implemented by using equation (8).



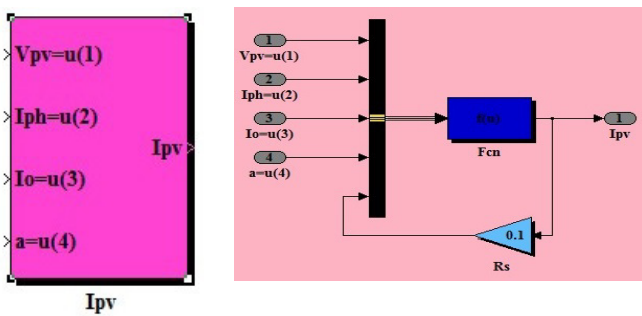
a. Subsystem 5 b. Connection diagram of subsystem 5.
Figure-8: Implementation of modified ideality factor.

Step 6:- The following Figure-9 is used to obtain saturation current, which is implemented by using equation (3).



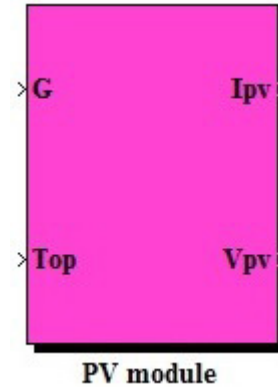
a. Subsystem 6
Figure-9: Detailed implementation of Saturation current.

Step-7: The Figure-10 is used to obtain output photovoltaic current, which is implemented by using equation (4).

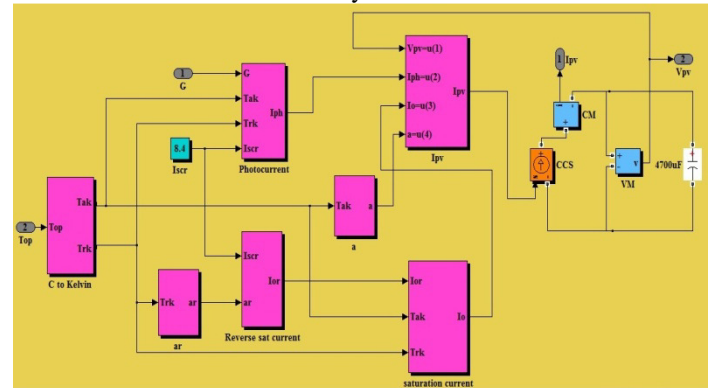


a. Subsystem 7 b. Connection diagram of subsystem 7.
Figure-10: Implementation of Output photovoltaic current.

Step-8: The following Figure-11 is specified all the required connections of above described subsystem.

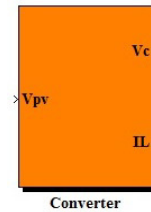


a. Subsystem 8

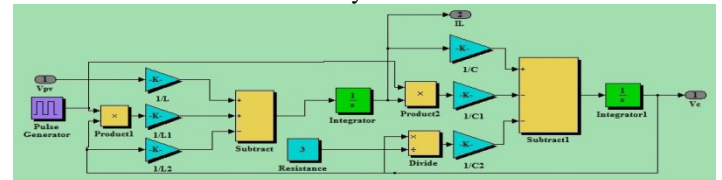


b. Connection diagram of subsystem 8.
Figure-11: Implementation of PV Module.

Step 9:- The following Figure- 12 is used to implement a boost converter by using equation (9) and (10).



a. Subsystem 9



b. Connection diagram of subsystem 9
Figure-12: Implementation of Boost converter.

Results and discussion

A proposed model of converter based PV Module is able to provide, very close results as compare to real solar panel.

In simulated solar PV Module, there are two weather data of irradiance and operating temperature of 1000 W/m^2 and 25°C respectively has been used as inputs and outputs obtain of current, voltage and power. Further output voltage of PV Module has been used as input for the boost converter and obtain other output data of current, voltage, and power. In the following Figure-(13)-(15), all the behaviour of outputs are described.

As seen in Figure-13, output behaviour of current for both PV Module and converter are described. In PV Module; initially current value is 8.4A, after few second it suddenly decreased with approximately zero ampere due to diode configuration of

PV Module (after few second diode behaves opened switch due to reverse biasing). In converter; initially current is increase with 0 to 276.70A, after that it is pulsating between 276.70A to 284.42A.

As seen in Figure-14, output behaviour of voltage for both PV Module and converter are described. In PV Module; initially voltage is linearly increase with 0 to 36.4V, after that it behaves as constant with 36.4V due to diode configuration of PV Module (after few second diode behaves opened switch due to reverse biasing). In converter; initially voltage is increase with 0 to 90.65V, after that it is pulsating between 90.65V to 263.36V.

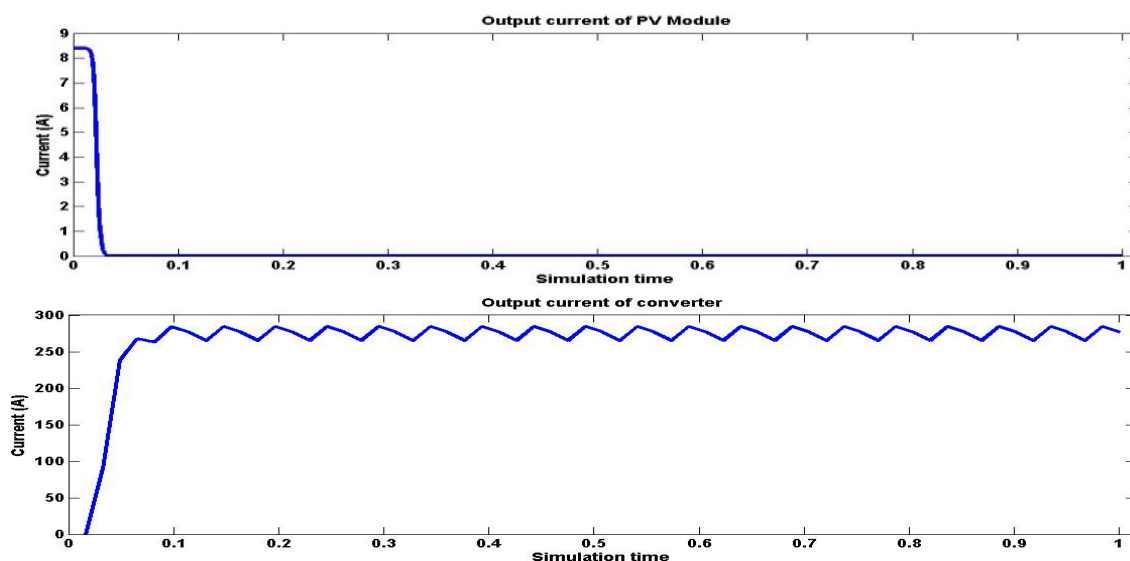


Figure-13: Comparison between output current of PV Module and Converter.

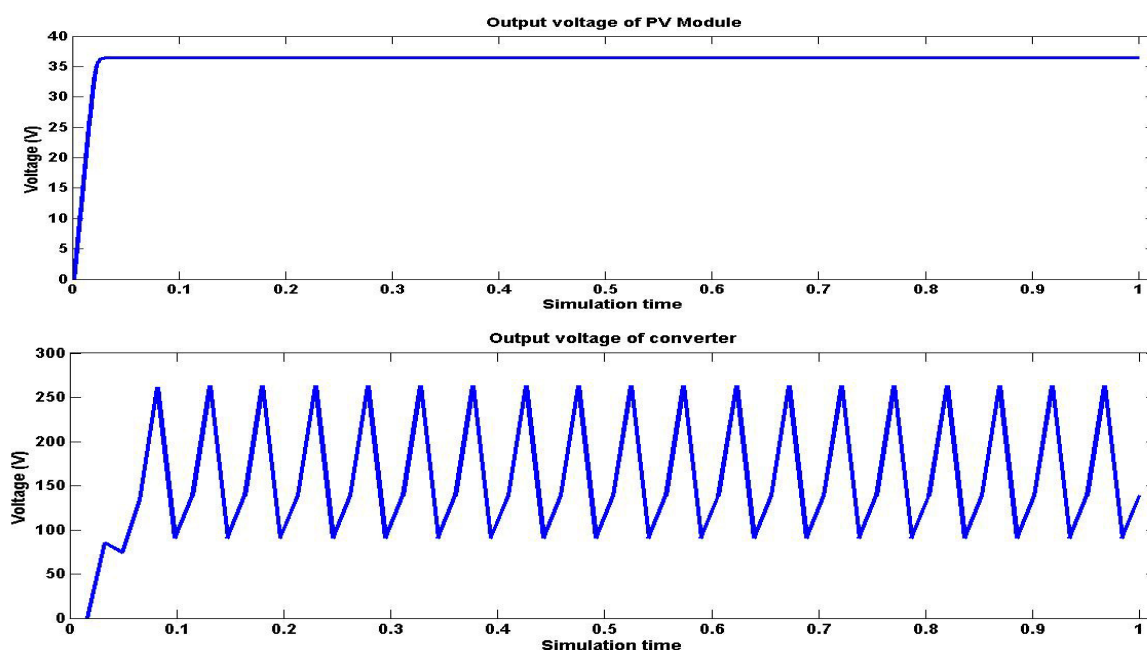


Figure-14: Comparison between output voltage of PV Module and Converter.

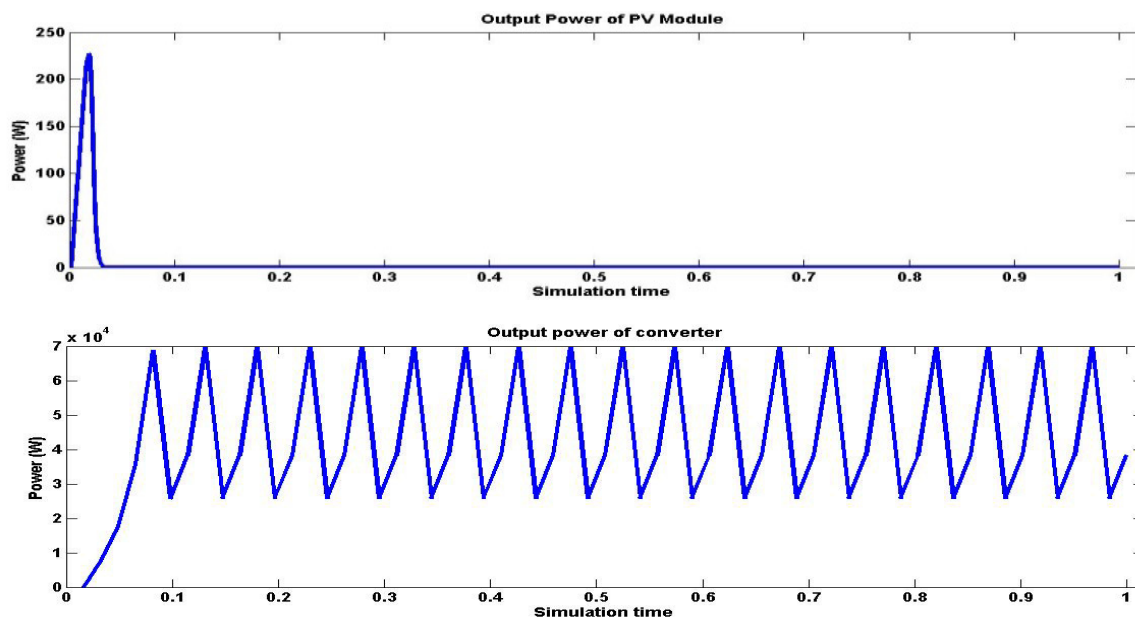


Figure-15: Comparison between output power of PV Module and Converter

As seen in Figure-15, output behaviour of power for both PV Module and converter are described. In PV Module; initially power is increase with 0 to 227.5W, after few second it suddenly decreased with approximately zero watt because current is become approximately zero ampere due to diode configuration of PV Module (after few second diode behaves opened switch due to reverse biasing).In converter; initially power is increase with 0 to 2.578×10^4 W, after that it is pulsating between 2.578×10^4 W to 6.979×10^4 W.

Conclusion

In this paper, mathematical modelling and step by step process of simulate to converter based PV Module is done. Entire implementation has been done in MATLAB/Simulink environment. All the parameters used in proposed model can be found in developer datasheets except the value of resistance, capacitance, inductance, and duty cycle, which are estimate analytically. Analysis and comparison of generated power of PV Module and converter is also successfully performed. Generated power of converter is in Kilowatts, which is very high as compare to generated power of PV Module. This enhanced power can be used in many high power demand application, grid application, stand-alone application etc.

The topics of future research related to solar PV Module are: i. PV generated Power forecasting. ii. Solar irradiance forecasting and load forecasting. iii. Improve the PV System, using mppt controller and power conditioning devices.

Acknowledgement

I would be very grateful to Mr Albert John Varghese, Asst. Professor, Department of Electrical Engineering, RCET, Bhilai, that he supported me in this work. I specially thank my friends and family for their help and thoughtful suggestions during my work.

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