International Journal of Advanced Technology in Engineering and Science
Vol. No.4, Issue No. 09, September 2016
www.ijates.com
ijates
ISSN 2348 - 7550

ANALYSIS OF STAND-ALONE PHOTOVOLTAIC SYSTEM WITH BOOST CONVERTER

Gaddam. Ramya Krishna[1], Yogesh Y Pundlik[2]

ABSTRACT

Use of renewable energy and in particular solar energy has brought significant attention over the past decades. Photovoltaic (PV) power generation projects are implemented in very large number in many countries. Many research works are carried out to analyze and validate the performance of PV modules. Implementation of experimental set up for PV based power system with DC-DC converter to validate the performance of the system is not always possible due to practical constraints. Software based simulation model helps to analyze the performance of PV and a common circuit based model which could be used for validating any commercial PV module will be more helpful. Simulation of mathematical model for Photovoltaic (PV) module and DC-DC boost converter is presented in this paper. The model presented in this paper can be used as a generalized PV module to analyze the performance of any commercially available PV modules. I-V characteristics and P-V characteristics of PV module under different temperature and irradiation level can be obtained using the model. The design of DC-DC boost converter is also discussed in detail. Simulation of DC-DC converter is performed and the results are obtained from constant DC supply fed converter and PV fed converter.

Key Words — DC-DC Boost converter, MATLAB/Simulink, Modeling, Photovoltaic, Simulation, Solar power.

I. INTRODUCTION

Photovoltaic (PV) modules are used to generate electricity from light. When sunlight falls on the PV modules, it converts sun light into DC electricity. Apart from the advantages of renewable energy sources, the PV based power generation has few more added advantages. The PV based system has no wear and tear which results in less maintenance. The PV based systems are employed in stand- alone applications such as street lighting, water pumping and also accommodated in grid connected systems.

A circuit based system model of PV modules helps to analyze the performance of commercial PV modules.

Modeling of photovoltaic modules or arrays is presented in various papers. Simple circuit based PV models are proposed in [1-2]. The methods of adjusting I-V characteristics of the model using Artificial Intelligence is presented in [3-4]. The model of PV module based on the circuit model and its mathematical equation using basic blocks is developed in MATLAB/Simulink [5]. Matlab program based PV module is presented in [6].

The MATLAB/Simulink based model of PV module is presented in this paper. The model presented in [5] is further enhanced by creating a subsystem and dialog box based on [7]. The dialog box allows the user to enter the important input parameters required for analysis. This model can be used as a common system to analyze the performance of any commercial PV modules by entering the required parameters.

This paper also focuses on design of DC-DC boost converter and integration of DC-DC boost converter with PV Module. DC-DC Boost converter is designed and simulated using MATLAB. The input and output of the converter are obtained from simulation under open loop condition with constant DC input supply. Further, the outputs are taken from the converter by feeding the output of PV module as input to it.

II. CIRCUIT MODEL OF PV MODULE

The voltage and current generated by a single PV cell is very low. So, solar cells are interconnected in a series-parallel combination to achieve the desired power. Desired voltage is generated by connecting the solar cells in series and the desired current is generated by connecting the cells in parallel. The series connection of cells known as PV modules usually has 28, 36 or 54 cells in it and array is the parallel connection of modules.

The equivalent circuit of an ideal PV cell consists of a current source and a diode connected in anti-parallel with it[7- 9]. A general model of the solar cell is the combination of current source (I_{pv}) connected in anti-parallel to a diode 'D', series resistance (R_{se}) and parallel resistance (R_p). Fig.1 shows the general model of solar cell.

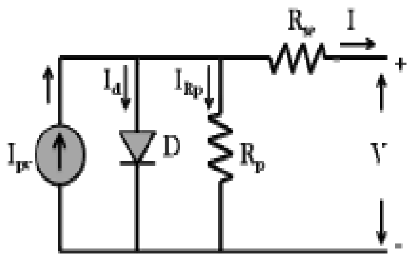


Fig.1 General model of solar cell

The PV system has non linear I-V and P-V characteristics. The two main factors which affect the output of PV system are temperature and irradiation level. The change of temperature and irradiation level results in change of voltage and current generated by PV system. The nominal operating condition of the solar module is 25^0C temperature, 1000 W/m^2 (G=1) irradiation at AM of 1.5.

I-V and P-V characteristics of PV cell are shown in Fig. 2. Open circuit voltage (V_{oc}) is the maximum voltage a cell can generate under open circuit condition at I=0 and the short circuit current (I_{SC}) is the current corresponds to short circuit at V=0. Through the operation, the PV cell generates maximum power at only one point and this point is called as Maximum Power Point (MPP). I_m, V_m and P_m in the graph are maximum current, maximum voltage and the maximum power of the solar cell respectively.

The mathematical equation for output current of ideal cell is [8-10].

$$I = I_{pv} - I_d \qquad (1)$$

where, I_{pv} is the light generated current which is directly proportional to the solar irradiation and I_d is the Shockley equation. The light generated current of the solar cell is mainly depends on the solar irradiation level and its working temperature, which is expressed as

$$I_{pv} = \left[I_{sc} + K_I\left(T_c - T_r\right)\right]\cdot G \qquad (2)$$

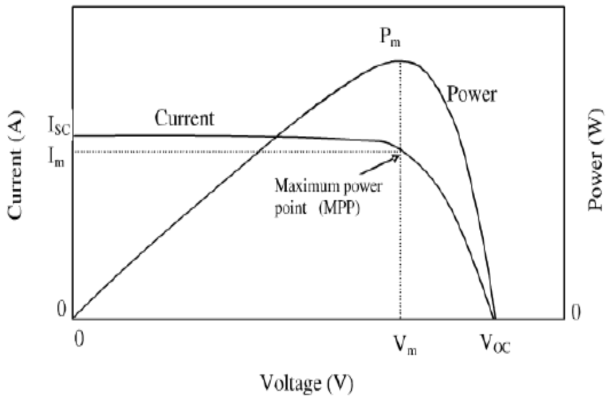


Fig.2 I-V and P-V characteristics of solar cell

where, I_{sc} is the short-circuit current of cell at 25°C temperature and G=1, K_I is the short-circuit current temperature co-efficient of cell, T_c and T_r are the operating temperature of cell and reference temperature respectively. The temperatures are in $_o$K. The Shockley equation can be expressed as

$$I_d = I_s \left\{ \exp\left(\frac{q}{AkT_c} \right) - 1 \right\} \quad (3)$$

where, I_s is the saturation or leakage current of the diode, q is the electron charge [1.60 x 10-19 $_o$C], k is the Boltzmann constant [1.38x10-23J/K], and A is the ideality factor of diode. The values of k and T_c should be taken into

account with same unit as either in $_oC$ or in $_oK$. The diode ideality factor *'A'* differs with respect to PV technology adopted [11]. Mono crystalline Si and the poly crystalline Si are most commonly used to technologies to produce PV

modules. The ideality factors of those PV technologies are 1.2 and 1.3 respectively. The ideality factor of other technologies is also listed in [11]. Based on the general model, the equation for the output current of solar cell can be defined as

$$I = I_{pv} - I_d - I_p \quad (4)$$

$$I = I_{pv} - I_s \left\{ \exp\left(\frac{q}{AkT_c N_s} V + IR_{se} \right) - 1 \right\} - \frac{V + IR_{se}}{R_p} \quad (5)$$

The value of parallel resistor *'R_p'* in equation (5) is extremely high and it is generally neglected for analysis of PV. The equivalent circuit of PV without R_p is the called as the simplified model. The appropriate model of solar cell [11] is shown in fig 3. Based on the appropriate model, the output current defined in equation (5) is re-written as

$$I = I_{pv} - I_s\left\{\exp\left(\frac{qV}{AkT_c} + IR_{se}\right) - 1\right\} \qquad (6)$$

The solar cells must be connected in series-parallel combination to obtain the desired output power. The mathematical equation for the PV array of the simplified model with (N_s) number of modules connected in series and (N_p) number of modules connected in parallel can be described as

$$I = I_{pv}N_p - I_sN_p\left\{\exp\left(\frac{qV}{AkT_cN_s} + \frac{IR_{se}}{N_p}\right) - 1\right\} \quad (7)$$

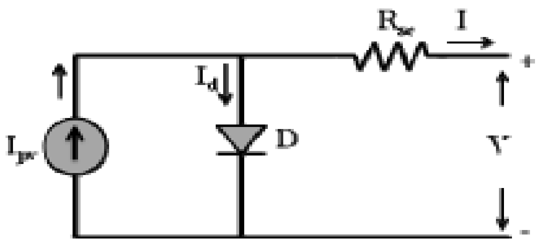


Fig.3 Appropriate model of solar cell

The diode saturation current of the cell varies with the cell temperature, which is expressed in [10] as,

$$I_s = I_{rs}\left(\frac{T_c}{T_r}\right)^3 \exp\left[\frac{qE_g}{A_k}\left(\frac{1}{T_c} - \frac{1}{T_r}\right)\right] \qquad (8)$$

where, I_{rs} is the reverse saturation current of a cell at a reference temperature and a solar irradiation, E_g is the band gap energy of the semiconductor used in the cell. E_g is approximately equal to 1.12 eV for the polycrystalline Si at 25 $_0$C [12-13]. Using equation (9), the reverse saturation current of a cell I_{rs} at reference temperature of 25$_0$C can be calculated.

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q}{AkT_{c(n)}N_s}V_{oc}\right) - 1} \qquad (9)$$

III. DC-DC BOOST CONVERTER MODELING

DC-DC converters are used in PV systems to regulate the voltage generated by the PV modules. DC-DC boost converters are used in grid connected applications to step up the module voltage. The circuit diagram of DC-DC boost converter is shown in fig 4.

International Journal of Advanced Technology in Engineering and Science
Vol. No.4, Issue No. 09, September 2016
www.ijates.com
ijates
ISSN 2348 - 7550

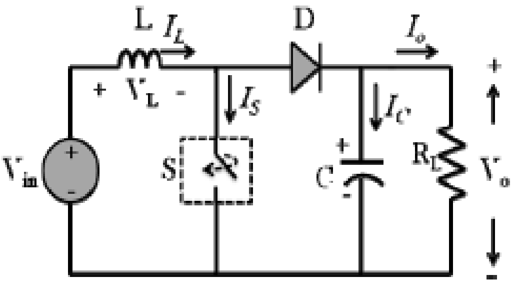


Fig.4 DC-DC Boost converter

The DC-DC boost converter circuit consists of Inductor (L), Diode (D), Capacitor (C), load resistor (R_L), the control switch (S). These components are connected in such a way with the input voltage source (V_{in}) so as to step up the voltage. The output voltage of the boost converter depends on the duty cycle of the control switch. So, the output voltage can be varied by varying the ON time of the switch. Thus, for the duty cycle "D" the average output voltage can be calculated using

$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)} \qquad (10)$$

where V_{in}, V_o are the input and output voltage of the converter respectively and D is the duty cycle of the control switch. In an ideal circuit, the output power of the converter is equal to input power which yields.

$$P_o = P_{in} \Rightarrow V_o I_o = V_{in} I_{in} \qquad (11)$$

The inductor value and the capacitor value are calculated using the formulas given in [14]

3.1. Selection of Inductor:

The inductor value of the Boost converter are calculated using

$$L = \frac{V_{in}}{(f_s \Delta I_L)} D \qquad (12)$$

Where f_s is the switching frequency and ΔI_L is the input current ripple. Current ripple factor (CRF) is the ratio between input current ripple and output current. For good estimation of inductor value CRF should bound within 30%. i.e.,

$$\frac{\Delta I_L}{I_o} = 0.3 \qquad (13)$$

The current rating of inductor should be always higher than that of the maximum output current.

ijates
ISSN 2348 - 7550

3.2 Selection of Capacitor

The capacitor value can be obtained from

$$C = \frac{I_{out}}{(f_s \Delta V_o)} D \qquad (14)$$

Where ΔV_o is the output voltage ripple which is usually considered as 5% of output voltage which yields

$$\frac{\Delta V_o}{V_o} = 5\% \qquad (15)$$

The DC-DC boost converter is designed for $V_{in} = 16V$, $V_{out} = 24V$, $I_{out} = 2.5A$, and the switching frequency f_s is considered as 20kHz. Using these values the components values are calculated as follows L=355μH, C=35μF and R_L=10Ω.

IV. SIMULATION RESULTS AND DISCUSSION

4.1. Simulation of PV Module

The complete model of the PV module simulated using MATLAB/Simulink is shown in fig 5.The subsystem of the complete model, the subsystem for light generated current (I_{pv}), saturation current (I_s) and Shockley Equation (I_d). The model is developed based on Equation (7).

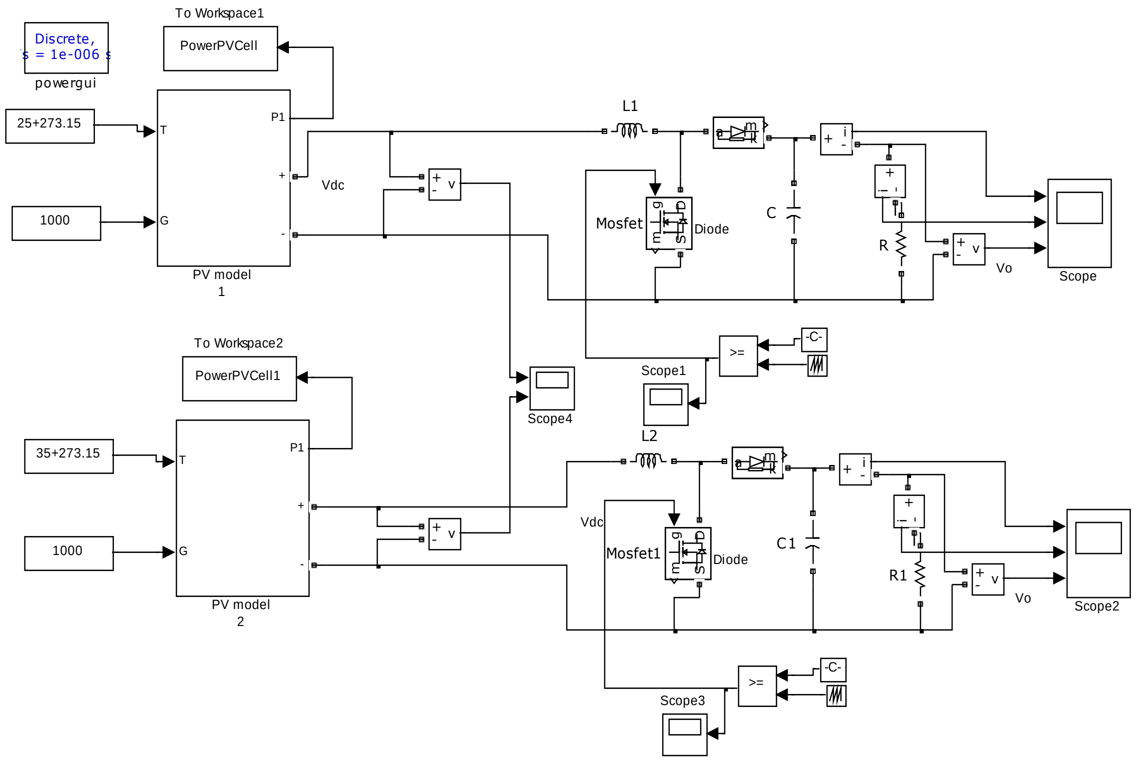


Fig. 5 Simulink Model of DC-DC Boost Converter

PV module is chosen for validating the model. The maximum output power is 60W. The important parameters required for simulating the model are taken from the manufacturer datasheet [15].

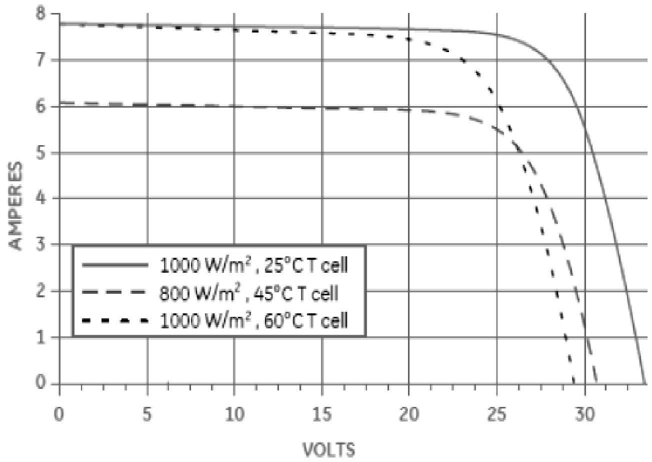
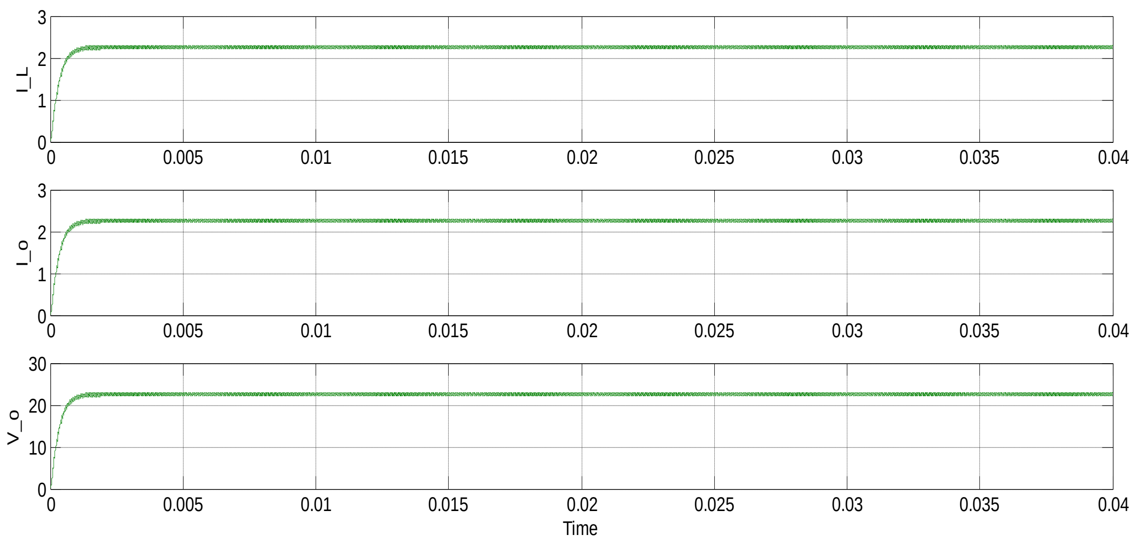


Fig. 6(a). Typical I-V Characteristics of GEPVp-200-M Module under various conditions.

The typical I-V characteristics of GEPVp-200-M Module at T_c=25$_0$C and G= 1000 W/m$_2$, T_c=45$_0$C and G= 800 W/m$_2$ and at T_c=60$_0$C, G= 1000 W/m$_2$ presented in the data sheet. The model is simulated for the same condition and the results generated. The simulation results shown in Fig. 7 are well matched the graph provided in datasheet. Hence, the proposed model can be used as common platform to analyze the performance of any PV Module.

4.2. Simulation of DC-DC Boost Converter

The boost converter is simulated using MATLAB/Simulink. The results obtained from the Boost converter are presented. The open loop simulation performed with the input voltage of 16V for the duty cycle D=0.33. Fig.8 shows the simulation circuit of designed boost converter



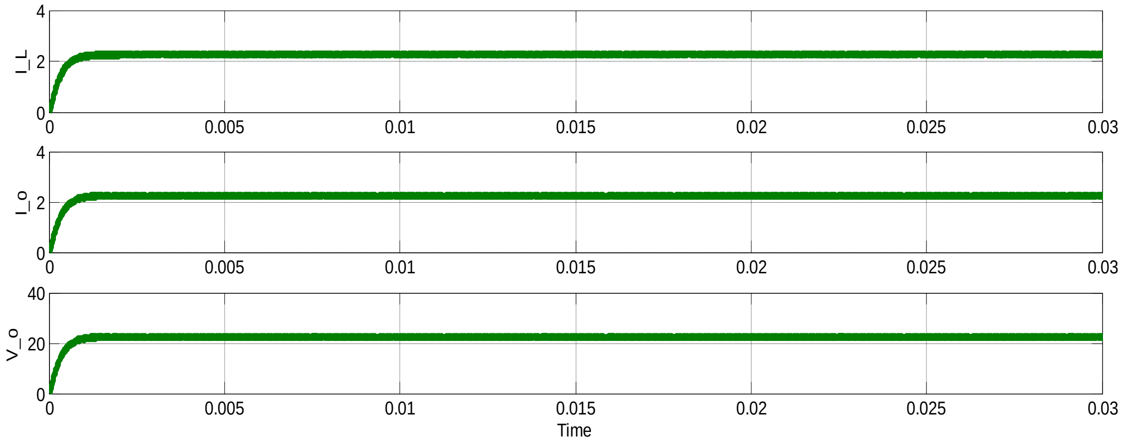


Fig. 7(a) Simulation results for I_L, Io and Vo of DC-DC Boost Converter

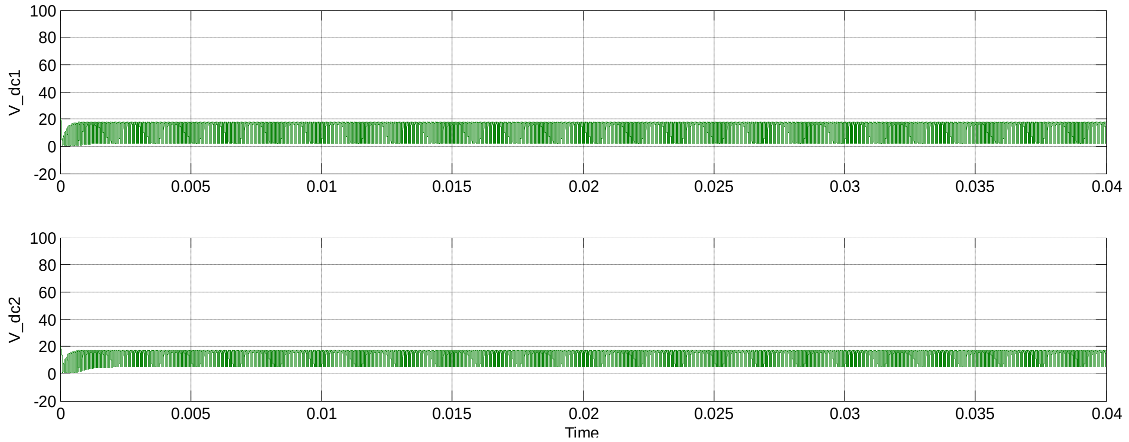


Fig.7(b).Simulation results for Vdc1 and Vdc2 of DC-DC Boost Converter

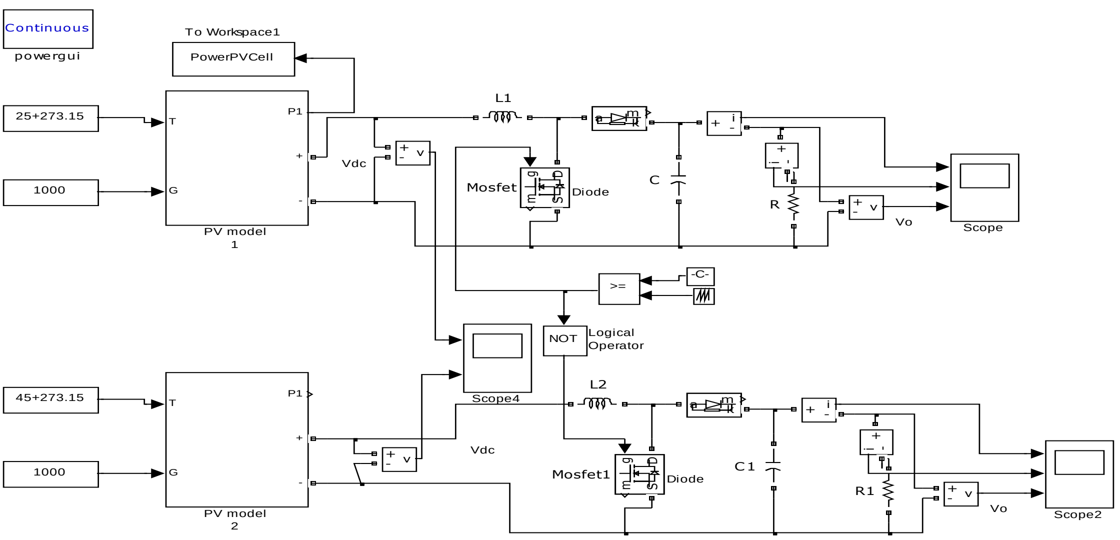
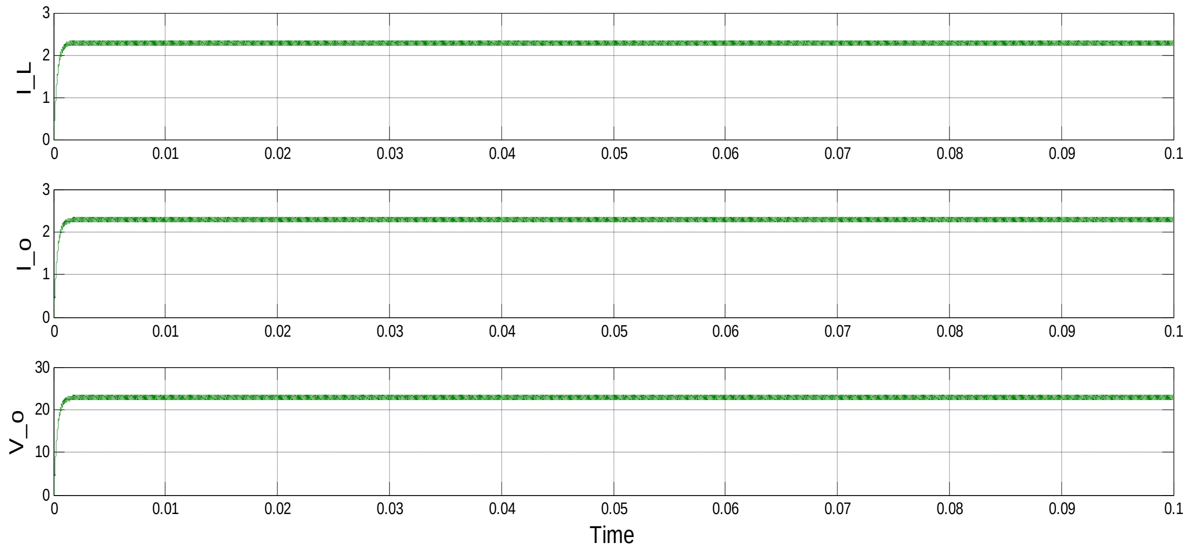


Fig.8 Simulation model for PV fed DC-DC Boost converter

International Journal of Advanced Technology in Engineering and Science
Vol. No.4, Issue No. 09, September 2016
www.ijates.com
ijates
ISSN 2348 - 7550

Fig.7(a) shows the waveform of input voltage of boost converter. The output voltage and output current of the boost converter at constant input voltage are presented in Fig.7(b) The output voltage and current approaches the desired values.

The DC-DC boost converter is fed by the PV Module. The input voltage of boost converter shown in fig 9(a) is the output of PV module. The output voltage and current waveforms obtained from the PV fed boost converter are depicted in Fig.9(b).



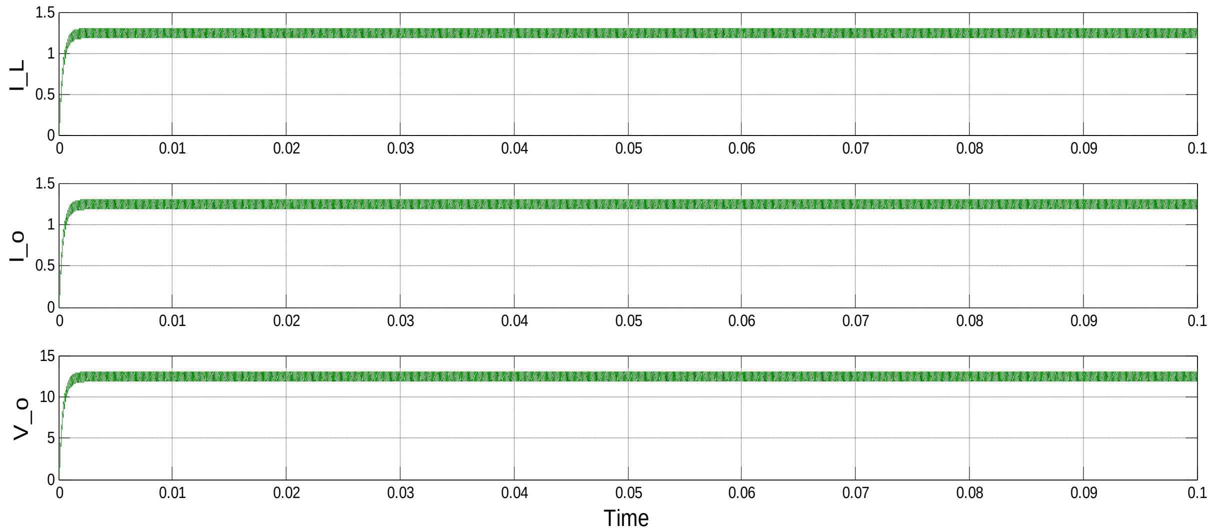


Fig. 9(a) Simulation results for PV fed DC-DC Boost converter I_L, Io and Vo of PV fed converter

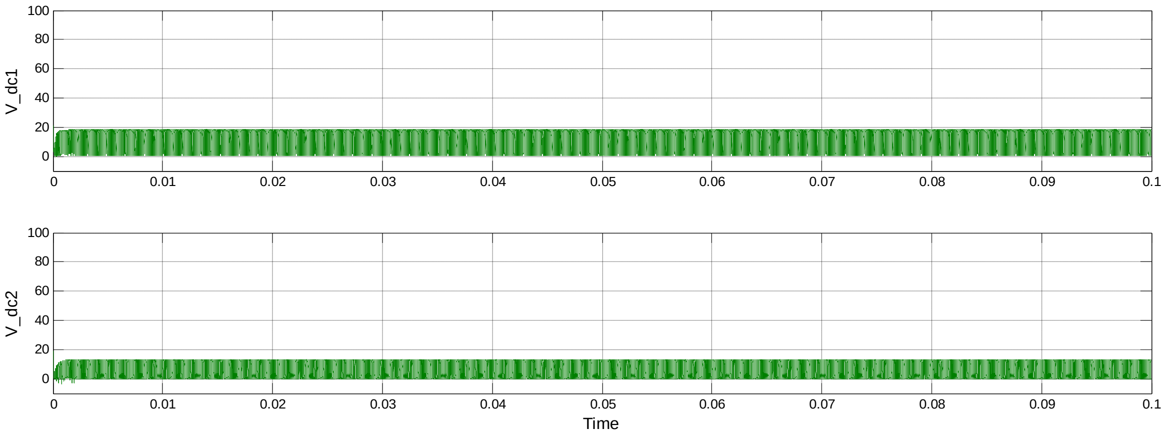


Fig. 9(b). Simulation results for Vdc1 and Vdc2 of PV fed converter

The model is simulated under constant cell temperature of Tc=25^{o}C and different irradiation level and the output of the PV module model is fed into the converter. The irradiation level has changes from 1 to 0.75 at t=0.015 and at t=0.030 the irradiation decreased from 0.75 to 0.5 as shown in Fig. 15. The voltage and current of the boost converter under these conditions is presented in Fig. 16. The boost converter is simulated for the fixed duty cycle of 0.3.

V. CONCLUSION

A circuit based system model of PV modules helps to analyze the performance of commercial PV modules. A general model of PV module is developed using comm. Only used blocks in the form of masked subsystem block. I-V and P-V characteristics outputs are generated for MSX 60 PV module under different irradiation and different temperature levels and the model is simulated for GEPVp-200-M Module under various conditions as presented in the data sheet. The results obtained from the simulation shows excellent matching with the characteristics graphs provided in the data sheet of the selected models. Thus, the model can be used to analyze the performance of any commercial PV module.

The DC-DC boost converter is also simulated and the results are obtained from the converter with constant DC input supply and by interconnecting the PV module with it. The results shows close match between the output of converter with constant DC input and the PV fed converter. The output voltage and current of the PV fed DC-DC boost converter obtained for change of irradiation levels at constant temperature is also presented.

REFERENCES

[1] J.A.Gow, C.D.Manning, " Development of photovoltaic array model for the use in power electronic simulation studies," IEE Proceedings Electric power applications, Vol. 146, No.2, March,1999.

[2] Jee-Hoon Jung, and S. Ahmed, "Model Construction of Single Crystalline Photovoltaic Panels for Real-time Simulation," IEEE Energy Conversion Congress & Expo, September 12-16, 2010, Atlanta, USA.

[3] T. F. Elshatter, M. T. Elhagry, E. M. Abou-Elzahab, and A. A. T. Elkousy, "Fuzzy modeling of photovoltaic panel equivalent circuit," in Proc. Conf. Record 28th IEEE Photovoltaic Spec. Conf., pp. 1656– 1659, 2000.

[4] M. Balzani and A. Reatti, "Neural network based model of a PV array for the optimum performance of PV system," in Proc. Ph.D. Res. Microelectron. Electron., vol. 2, pp. 123–126, 2005.

[5] S. Sheik Mohammed, "Modeling and Simulation of Photovoltaic module using MATLAB/Simulink" International Journal of Chemical and Environmental Engineering, 2011

[6] Francisco M. González-Longatt, "Model of Photovoltaic Module in Matlab™" 2do congreso iberoamericano de estudiantes de ingeniería eléctrica, electrónica y computación (ii cibelec 2005)

[7] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK" WCECS 2008, October 22 - 24, 2008, San Francisco, USA

[8] S. W. Angrist, , Direct Energy Conversion, Allyn and Bacon, Inc., 4th edition, 1982, pp. 177-227.

[9] O. Wasynczuk, "Modeling and dynamic performance of a line commutated photovoltaic inverter system," IEEE Transactions on Energy Conversion, vol. 4, no. 3, 1989, pp. 337-343.

[10] R. Messenger and J. Ventre, Photovoltaic Systems Engineering, CRC Press, 2000, pp.41-51.

[11] C. C. Hua and C. M. Shen, "Study of maximum power tracking techniques and control of dc-dc converters for photovoltaic power system," Proceedings of 29th annual IEEE Power Electronics Specialists Conference, vol. 1, 1998, pp. 86-93

[12] W. De Soto, S. A. Klein, and W. A. Beckman" Improvement and validation of a model for photovoltaic array performance" Solar Energy, 80(1):78–88, January 2006.

[13] GeoffWalker." Evaluating MPPT converter topologies using a Matlab PV model" Journal of Electrical & Electronics Engineering, Australia, 21(1), 2001.

[14] Brigitte Hauke, "Basic Calculation of a Boost Converter's Power Stage" Application Report , SLVA372B–November 2009– Revised July 2010

[15] Solarex MSX60/64 datasheet. Available online at: http://www.californiasolarcenter.org/newssh/pdfs/Solarex- MSX64.pdf

[16] GEPVp-200 PV Module Data sheet. Available online at: http://www.altestore.com/store/Solar-Panels/150-Watts-Up-Solar- Panels/GEPVp-200-200W-18V-Solar-Panel/p3843