Design and Analysis of DC-DC Converters for Photovoltaic Systems

M. Anish John Paul[1] and C. Agees Kumar[2]
[1]Assistant Professor, Department of Electrical and Electronics Engineering,
Mar Ephraem College of Engineering and Technology, Marthandam, Tamil Nadu, India
[2]Professor, Department of Electrical and Electronics Engineering
Arunachala College of Engineering for Women, Vellichandai, Nagercoil, Tamil Nadu, India
E-Mail: anishjohnpaul@gmail.com, ageesofficials@gmail.com

*Abstract -*The solar energy conversion system is an alternative for conventional power generating system. The voltage which is available from solar array is variable and to obtain a stable voltage from solar panels, DC-DC converters are required for constant power production. A PV module is designed in MATLAB-SIMULINK using the S-function builder and controlled current source. The proposed PV module enables us to obtain its P-V and I-V characteristics at different temperature and radiations. This paper presents the design and simulation of DC-DC converters. In this paper, Boost converter, cascaded Buck Boost and Cuk converter are modelled in MATLAB and their results are compared.
Keywords: Photovoltaic Module, Boost Converter, Buck Boost, Cuk Converter

I. INTRODUCTION

The importance of solar energy for future energy supply has been growing vigorously with the growing concerns about the price and availability of fossil fuels. Solar energy is a never-ending renewable energy source. The photovoltaic systems convert the solar energy to the electricity. The maintenance cost is less for PV cell and its life span is more than 20 years. The basic PV system consists of PV panels, electric converter. The block diagram of the basic PV system is shown in fig. 1.
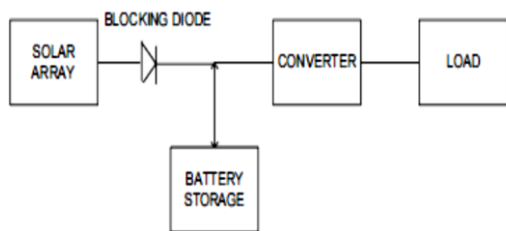

Fig.1 Basic photovoltaic system with connected load

The output power from the PV module or array depends upon the irradiance and temperature which are constantly varying. It is necessary to enhance the efficiency of a PV system, irrespective of irradiance and temperature. The PV system should contain some controller which is responsible for an optimization to extract maximum power from the panel. The major existing work done in this field is to find simple and efficient method to extract maximum power where analysis done with different irradiance and temperature. Several methods are proposed to extract maximum power and compared with their techniques performance are analysed by different authors. Recent works reflect the interest of designing of proper controller and extracting maximum power from the module through dc-dc converter. This paper presents design and simulation of four different types of dc-dc converters which are Boost, cascaded BuckBoost and Cuk, which are used in the PV system. The results of these converters are compared.

II. PV MODULE MODELLING

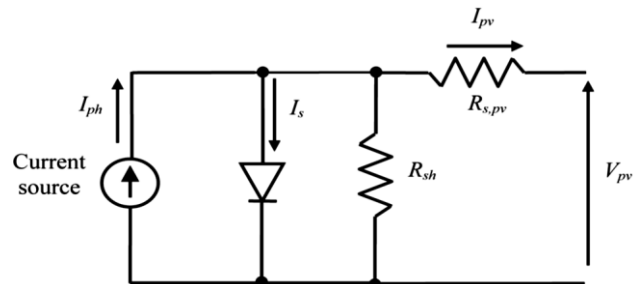*A. Equivalent Circuit of a Solar Cell:* A solar cell can be represented by an equivalent circuit shown in fig. 2.

Fig. 2 Equivalent circuit of a single solar cell

Where symbols in fig.2 are defined as follows:
I_{ph} - Photocurrent
I_s - Shunt current
I_{pv} - Output current
V_{pv} - Output voltage
R_{sh} - shunt resistance
R_{spv} - Series resistance.
The I-V equation of fig. 2 is given as

$$I = I_{ph} - I_0 \left\{ e^{\frac{q(V+R_S I)}{AKT}-1} \right\} - \frac{V+R_S I}{R_{sh}} \ (1)$$

where I_0 is the reverse saturation current of the diode, q is the electron charge (1.602×10^{-19}C), A is curve fitting factor and K is Boltzmann constant (1.38×10^{-23}J/K)

B. PV Module Model in MATLAB Simulink: S-builder function block is used to form the PV module in MATLAB. Programming of PV is fed in the s-function builder block which is having three inputs (irradiation S, Temperature T and output voltage of PV V) and single output i.e. output current of PV module. The block diagram of PV module based on MA TLAB-SIMIULINK is shown in fig 3. The

output I_0 is given to controlled current source which is required for simulating the output current of the PV module. Controlled current source is having a bypass diode connected in parallel. A subsystem is created for convenience, which is consisting of all components shown in fig 3. In the subsystem block, + is the positive terminal of the PV module, - is the negative terminal of the PV module. The subsystem PV modules can be connected in series and parallel to form PV array and then it has been simulated in MATLAB-Simulink.
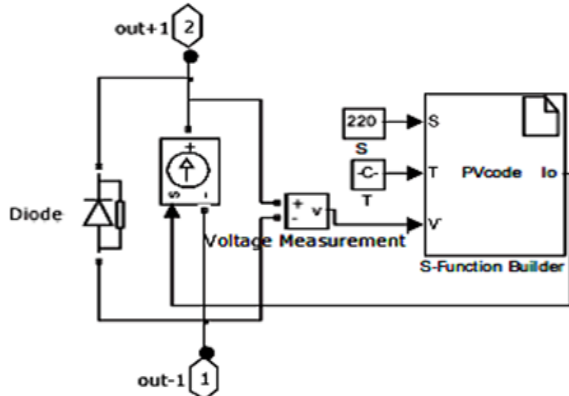

Fig. 3 Block diagram of PV module model in MATLAB-Simulink

III. DC-DC CONVERTERS

In PV system, the PV array can be connected to the load either directly or through a converter. In direct connection the power absorbed by the load will be smaller than the maximum power available at given irradiance and temperature for an operating point on the non-linear I-V characteristic of the PV array. A dc-dc converter can be connected between the PV array and load to make the PV array to operate around the maximum power point under varying solar radiations and temperatures. The dc-dc converter can increase or decrease the voltage of the PV system depending on the load requirements.

The various dc-dc converters commonly used with PV array for impedance matching are given below
1. Boost converter
2. Cascaded Buck Boost converter
3. Cuk converter
In this MOSFET is used as switching device.

A. Boost Converter: Boost converter is also known as step up converter as output of Boost converter is always greater than that of the input. It is a class of switched mode power supply (SMPS) containing at least two semiconductors (a diode and a switch) and at least one energy storage element, a capacitor C, inductor L, or the two in combination. Filters made of capacitors are normally added to the output of the converter to reduce output voltage ripple.Boost converter cannot emulate greater impedances than the impedance of the load. So it does not reach values near the open circuit voltage of the PV module. Fig. 4 shows the simulation diagram of the boost converter.
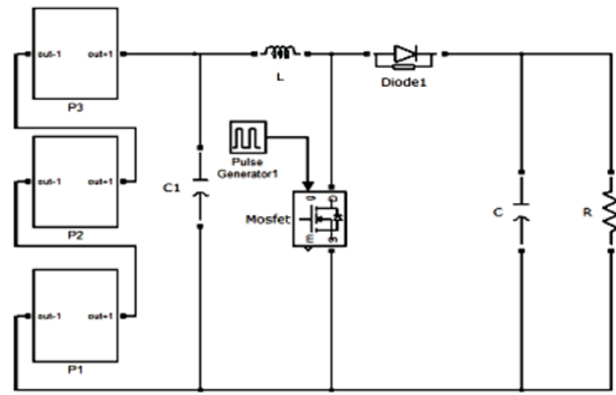

Fig. 4 Simulation diagram of Boost converter

The output voltage equation is given by

$$V_{out} = \frac{1}{1-D} * V_{in}$$

B. Cascaded Buck Boost Converter: The cascaded buck-boost converter can be formed by having buck converter as the first stage followed by boost converter. The buck-boost converter can sweep the whole range of the I-V curve in CCM (Continuous Current Mode) from open circuit voltage (Voc) to short circuit current (lsc). Buck-Boost converters are used in situations where array voltages and battery voltages are nearly matched. This converter provides to have either higher or lower output voltages compared to input voltages. The buck boost converter operates through inductive energy transfer. It has non- pulsating current characteristics.
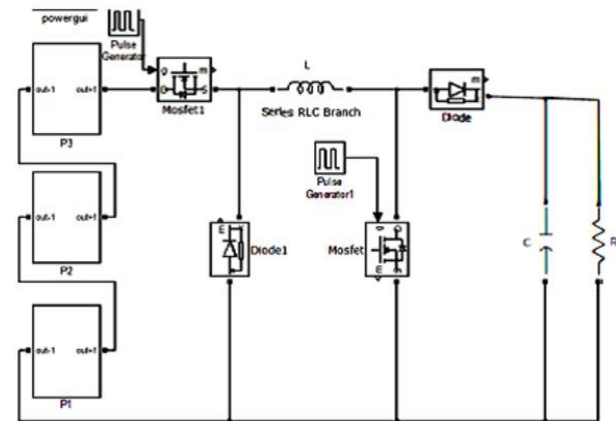

Fig. 5 Simulation diagram of cascaded buck boost converter

The output voltage equation for the buck boost converter is given by equation

$$V_{out} = \frac{D}{1-D} * V_{in}$$

C. Cuk Converter: Cuk converter is a dc-dc converter that has output voltage magnitude that is either greater than or less than the input voltage magnitude. The Cuk converter has low switching losses and the highest efficiency. It can provide better output current characteristics due to the inductor on the output stage. Fig.6 shows the simulation diagram of cuk converter.
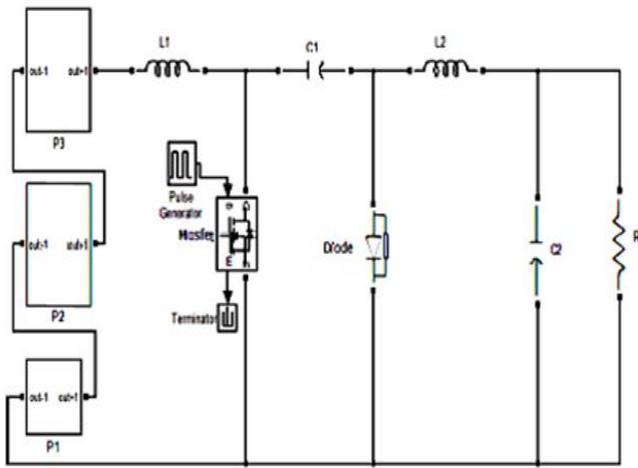
Fig. 6 Simulation diagram of Cuk converter

The relation between output and input voltage of cuk converter is given below.

$$V_{out} = \frac{-D}{1-D} * V_{in}$$

IV. SIMULATION RESULTS

A. Boost Converter: Fig. 7 shows the waveforms of input voltage V_{in}, output voltage V_{out}. Here the input voltage is fluctuating between 53- 60 volts. The output voltage is 78 volts.

B. Cascaded Buck Boost Converter: Fig.8 shows the simulation results for the buck-boost converter. V_{in} is the input voltage having value between 60 volts. The output voltage is given by $V_{out} = 68$ V. The output obtained is non-inverting.

C. Cuk Converter: The output obtained is inverted in case of the cukconverter that is negative. Therefore, voltage measurement block is connected with inverter to measure the output voltage. Fig.9. shows the simulation results for the Cuk converter. V_{in} is the input voltage having value between 40 volts. The output voltage is given by $V_{out} = 86$ V.
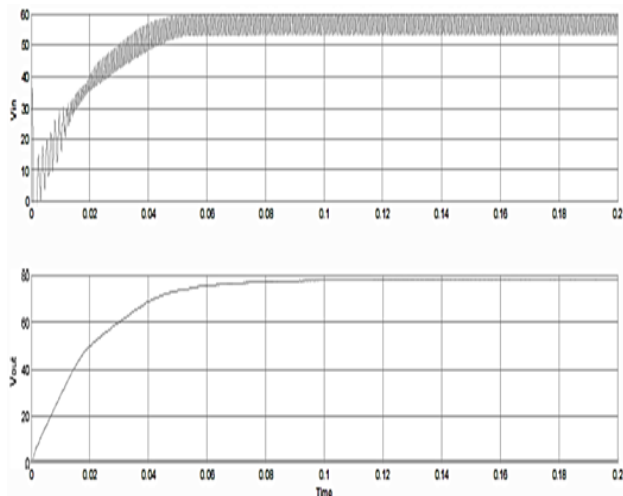

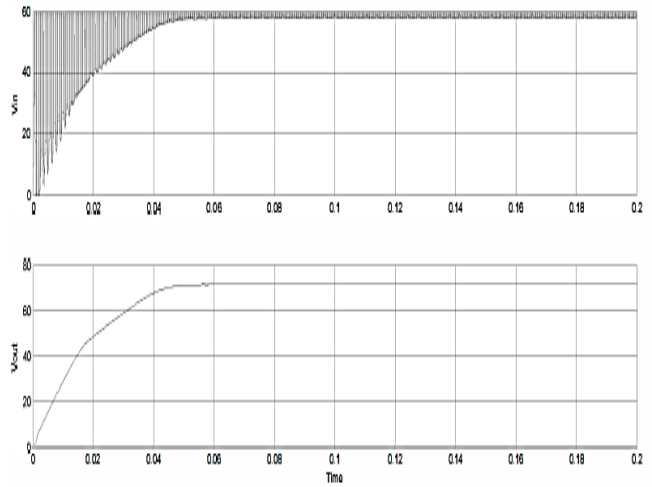Fig. 7 Simulation results of V_{in}, V_{out} for boost converter

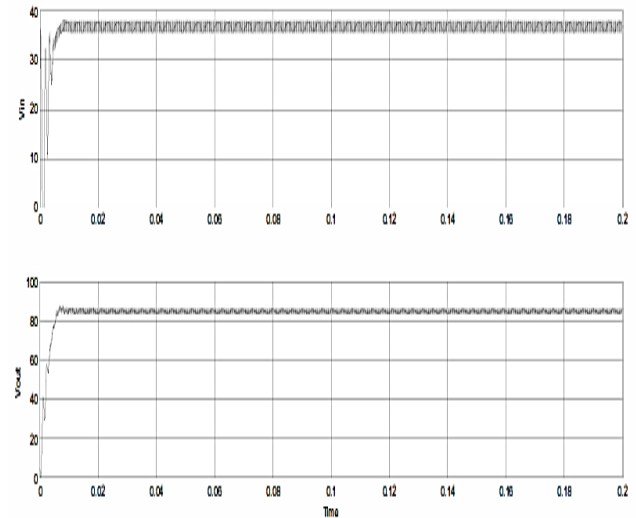Fig. 8 Simulation results of V_{in}, V_{out} for cascaded buck boost converter

Fig. 9 Simulation results of V_{in}, V_{out} for Cuk converter

V. CONCLUSION

This paper presents a PV module model in MATLAB which includes the s-function builder and controlled current source. In this paper, three types of dc-de converters are discussed. Out of the three converters except the boost converter, all three converters can function as a buck or boost converter both. In countries where the sun light available is less, there boost converter is preferable. However, regions where sunlight available is more, the converter has to perform both buck and boost functions as per requirements. All the above converters have their own advantages and drawbacks. The selection of the converter has to be done on the basis of the output voltage requirement, cost factor and type of application used.

REFERENCES

[1] Chetan Singh Solanki, *Solar photovoltaics – fundamentals, technologies and applications*, 2nd ed., New Delhi, India: PHI learning private ltd., 2011.

[2] Shridhar Sholapur, K. R Mohan, and T. R. Narsimhegowda, "Boost converter topology for PV system with perturb and observe MPPT algorithm",*IOSR Journal of Electrical and Electronics Engineering*, Vol. 9, No. 4,pp. 50-56, Jul - Aug. 2014.

[3] R Sriranjani, A. Shree Bharathi and S. Jayalalitha, "Design of Cuk Converter Powered by PV Array", *Research Journal of Applied Sciences, Engineering and Technology*, Vol. 6, No. 5, pp. 793-796, 2013.

[4] Kun Ding, Xin Gao Bian, Hai Hao Liu and Tao Peng, "A MATLAB Simulink- Based PV Module Model and Its Application Under Conditions of Non-uniform Irradiance", *IEEE Transactions on energy conversion*, Vol. 27, No. 4, Dec. 2012.

[5] A. I. Bratcu, I. Munteanu, S. Bacha, D. Picault, and B. Raison, "Cascaded DC-DC Converter Photovoltaic Systems: Power optimization Issues", *Industrial Electronics, IEEE Transactions*, Vol.58,No. 2, pp. 403-411,2011.

[6] S. Daison Stallon, K. Vinoth Kumar and S.Suresh Kumar, "High Efficient Module of Boost Converter in PV Module", *International Journal of Electrical and Computer Engineering*, Vol.2, No.6, pp.758-781, Dec. 2012.

[7] Sathish Kumar Kollimalla, and Mahesh Kumar Mishra, "Variable Perturbation Size Adaptive P&O MPPT Algorithm for Sudden Changes in Irradiance", *IEEE transactions on sustainable energy*,Vol.5,pp. 718-728, Jul. 2014.

[8] P. Manimekalai, R. Harikumar, and R. Aiswarya, "An Overview of Converters for Photo Voltaic Power Generating Systems", *in International Conference on Advances in Communication and Computing Technologies*, pp. 25-30, 2012.

[9] Eman Goma, Mohamed Orabi and El-Sayed Hasaneen Jaber Abu Qahouq, "Single-Output-Sensor On-Chip Integrated MPPT for PV Solar System Power Management", in *Applied Power Electronics Conference and Exposition-IEEE*, pp. 655-661, 2014.