A Matlab /Simulink based Comparative Study of Solar PV Array with Different Types of Power Electronic Converters

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Abstract: In this paper, the modelling and simulation work has been carried out in Matlab/ Simulink software environment for a solar energy based source (PV array) with the coupling of different power electronic converters. The P-V, I-V curves have been obtained at varying irradiation levels and temperature for solar PV array. Further this solar PV array output is fed to the different power electronic converters as Boost, Buck-Boost and Cuk converters with different control strategies for controlling the output voltage from PV array. The analysis of different results has been carried out in this paper and specifying the best suited power electronic converter for controlling the output voltage with a suitable control strategy for the different applications of solar energy based system.

Keywords: Solar PV module, PV array, DC-DC boost, cuk, buck-boost converter, Duty ratio.

1. INTRODUCTION

Power converter is an indispensable interface for the conversion of non-conventional energy sources into useful and regulated electrical ac or dc form. Power converter is a weak link and its efficiency determines the utilization of the source and controls the power output. Its cost, volume, and weight are the deciding factors for the overall cost and volume of the installation system. Therefore, the design and development of low cost, high-efficient and small size power conversion systems is still an attention of researchers. The electrical energy output from the solar PV array depends on solar insolation level and temperature [1]. Electrical energy intern depends on the conversion characteristics of photovoltaic cells. To extract maximum power from PV source a power electronic converter is connected between the PV source and the drive system.

The present paper consists of the analysis of PV array with the coupling of DC-DC boost, cuk, buck-boost converter. These converters convert the variable solar power output to the constant power output by controlling the duty ratio of the converters. This constant and controlled output is needed in many PV applications such as; Solar water pumping, solar air conditioning etc. All the results are obtained in the environment of Matlab/Simulink software.

Proposed model:

The proposed model (*refer to fig.1*) consists of PV array and different power electronic converters for the purpose of obtaining the smooth and controlled output voltage waveform by controlling the duty ratio of the converter for the purpose of different solar power applications.

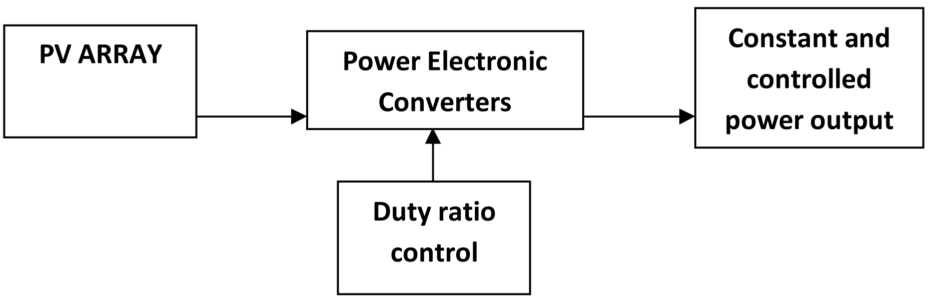

Fig. 1 Proposed model for controlled output from PV array

System Design and Modeling:

PV Array: PV Arrays are built up with combined series and parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model as shown in Fig.2.

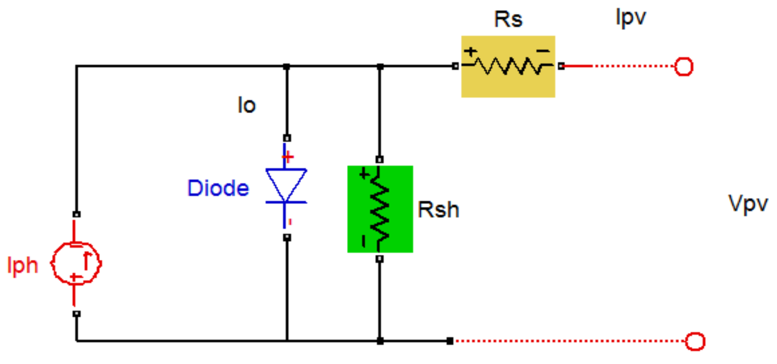

Fig. 2 Simplified equivalent circuit model of PV cell

A photovoltaic array (PVA system) is an interconnection of modules .The power produced by a single module is hardly ever enough for commercial use, so modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current.

The PV module can be made modeled by the following equations [2, 3]:

Module photo-current:

$$I_{ph} = [I_{sc} + K_i(T_{ak} - T_{rk})]*(\beta/1000) \quad \ldots\ldots\ldots (1)$$

Module reverse saturation current:

$$I_{rs} = I_{sc} / [e^{(q*V_{oc} / N_s kAT_{ak})} - 1] \quad \ldots\ldots\ldots (2)$$

Module saturation current is temperature dependent and is given by:

$$I_o = I_{rs}[\frac{T_{ak}}{T_{rk}}]^3 * [e^{q*E_{go}*\frac{1}{Bk}\{\frac{1}{T_{rk}} - \frac{1}{T_{ak}}\}}] \quad \ldots\ldots\ldots (3)$$

PV Module output current:

$$I_{pv} = N_p * I_{ph} - N_p * I_o[e^{q*\{\frac{V_{pv} + I_{pv}*R_s}{N_s kAT_{ak}}\}} - 1] \quad \ldots\ldots\ldots (4)$$

A photovoltaic system simulation model is developed in Matlab/ Simulink software environment using basic circuit equations of the photovoltaic solar cells including the effects of insulation and temperature changes as shown in Fig. 3. This block contains the sub models that are connected to build the final model. Figures are not going to be explained in full detail.

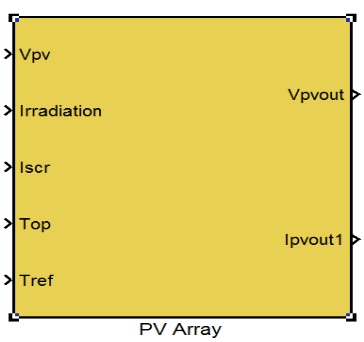

Fig. 3 Matlab/ Simulink model of PV Array

In this paper, the PV array can be formed by connecting several series and parallel modules. The specifications of solar PVA are shown below (refer to table. 1).

Table.1 Specifications of solar PVA

Design Voltage (V)	Number of series connected modules	Number of parallel connected modules
120 V	8	8

Power Electronic Converter: Large numbers of dc-dc power electronic converter circuits are known that can increase or decrease the magnitude of the dc voltage and/or invert its polarity [4].

Boost- Converter: A basic dc-dc *boost* converter circuit is shown in Fig.4 *below*, along with its respective conversion ratio M (D) = 1/ (1-D). This converter produces an output voltage *V* that is higher in magnitude than the input voltage.

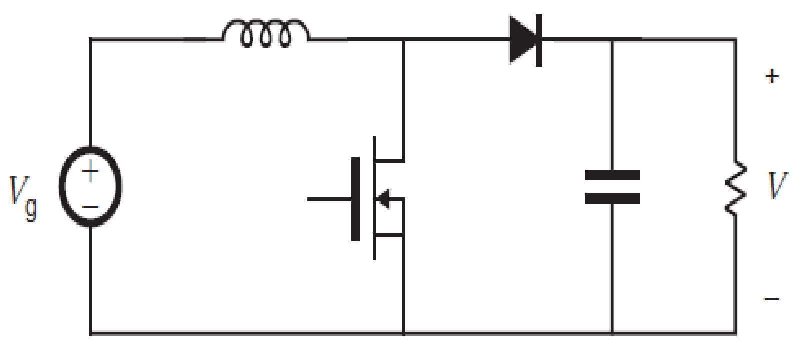

Fig. 4 Boost converter circuit

The relation of output voltage to input voltage in boost converter is as follows:

$$\frac{V}{Vg} = 1/(1-D) \quad \ldots\ldots \quad (5)$$

Buck-Boost Converter: Dc-dc buck-boost converter is shown below in fig.5. The output to input conversion ratio is *M* (*D*) = - *D*/(1 – *D*). This converter inverts the polarity of the voltage, and can either increase or decrease the voltage magnitude [5].

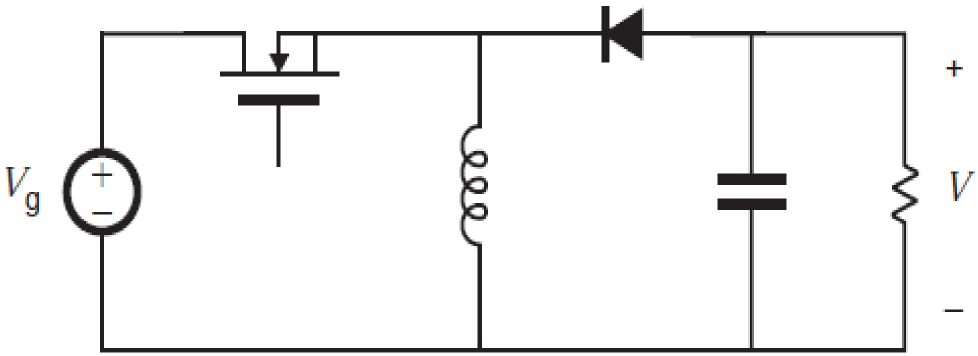

Fig. 5 Buck-Boost converter circuit

The relation of output voltage to input voltage in buck-boost converter is as follows:

$$\frac{V}{Vg} = -D/(1-D) \quad \ldots\ldots \quad (6)$$

Cuk Converter: Dc-dc cuk converter is shown below in fig.6. The conversion ratio *M* (*D*) is identical to that of the buck-boost converter. Hence, this converter also inverts the voltage polarity, while either increasing or decreasing the voltage magnitude.

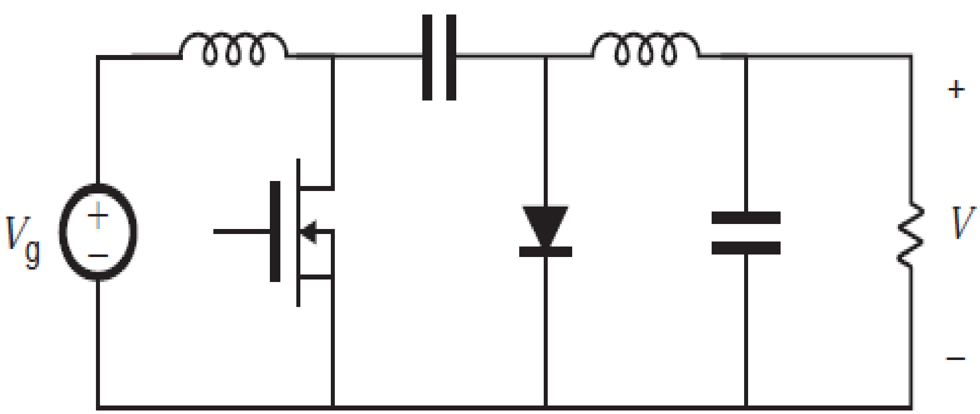

Fig. 6 Cuk converter circuit

2. RESULTS AND DISCUSSION

Fig.7 below shows the Matlab/ simulink based model of PVA with boost converter to enhance the voltage level.

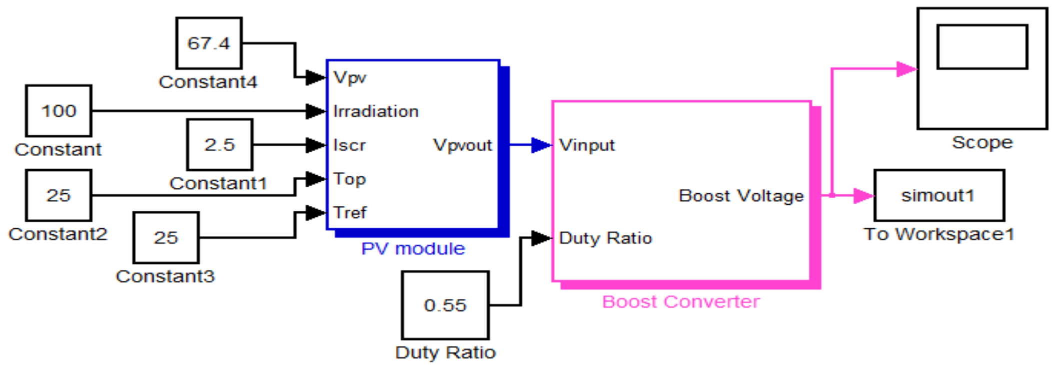

Fig. 7 A matlab/ simulink model of PV array with boost converter

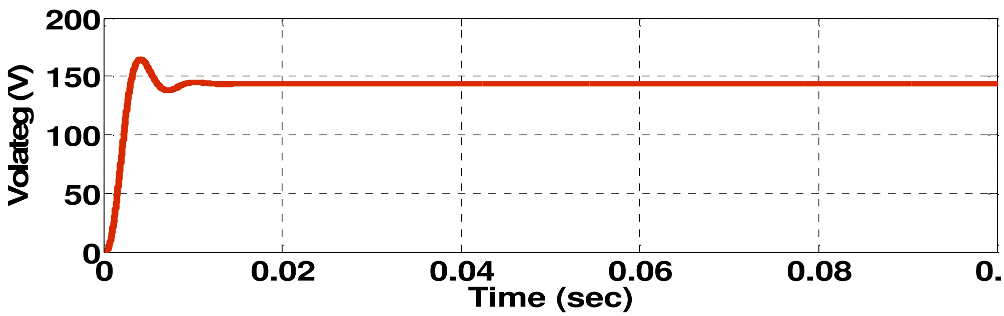

Fig. 8 Boost converter output voltage waveform

From the above fig.8 it is clear that the voltage level of solar PV array is boosted up from 120 V to 150 V with low transients in the waveform. The transients die out in1/10th of the simulation time period i.e.; in 0.01 sec when the simulation run time is kept at t=0.1sec.

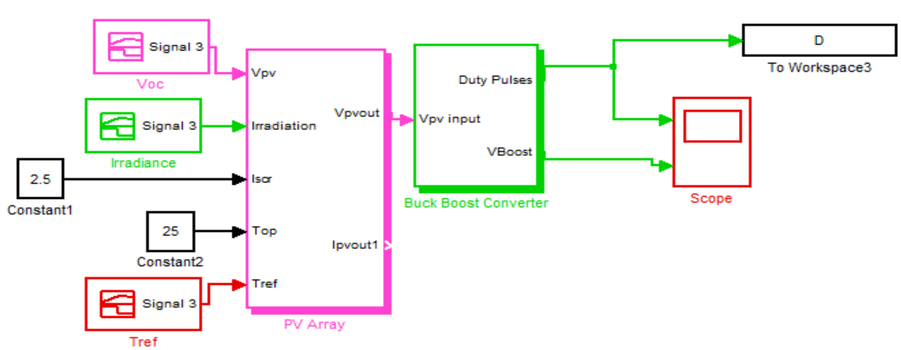

Fig. 9 A matlab/ simulink model of PV array with Buck-Boost converter

Fig.9 above shows the Matlab/ simulink based model of PVA with buck-boost converter to enhance the voltage level with the help of SPWM technique.

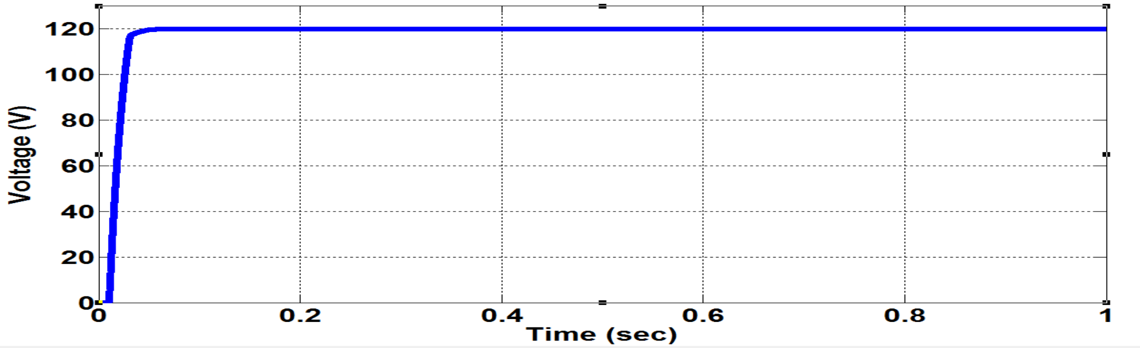

Fig. 10 Buck-Boost converter output voltage waveform

Fig. 10 above shows the voltage level is constantly maintained at 120 V of solar PV array with the help of DC-DC buck-boost converter. This converter doesn't incorporate any transients in the output voltage waveform. The simulation run time is kept at t=1sec for this model. The SPWM pulses are shown below (refer to fig.11) for both buck-boost and cuk converter.

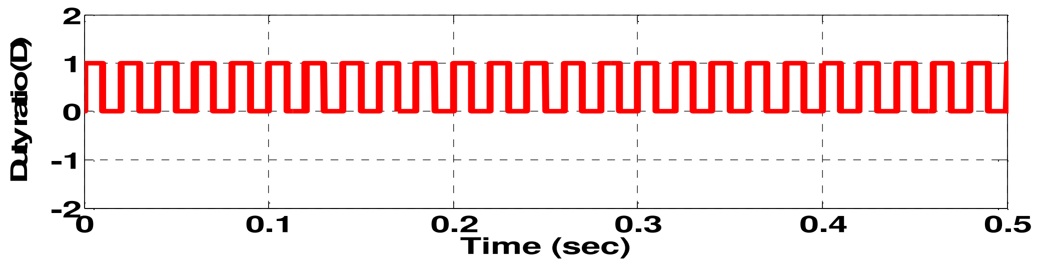

Fig. 11 SPWM pulses for the controlling of Buck-Boost and cuk converter

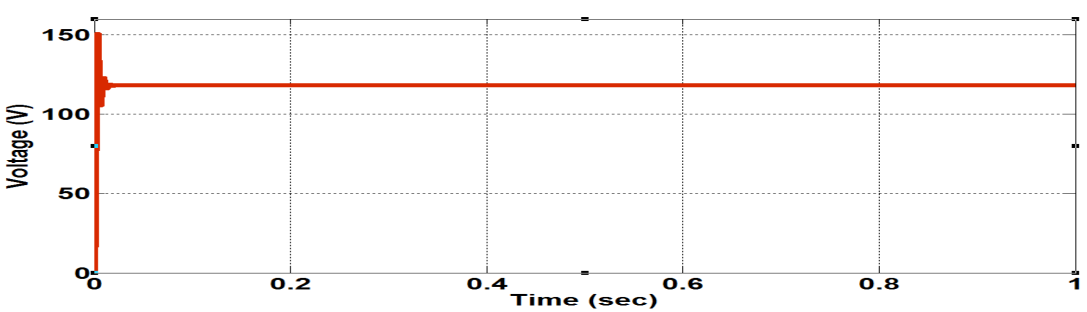

Fig. 12 Cuk converter output voltage waveform

Fig. 12 above shows the voltage level is constantly maintained at 120 V of solar PV array with the help of DC-DC cuk converter. This converter incorporates some transients of large magnitudes for a very short period nearly $1/10^{th}$ of the total simulation time. The simulation run time is kept at t=1sec for this model.

3. CONCLUSION

Continual increment in the energy demand leads to the better and efficient design and development of low cost, high-efficient and small size power conversion systems in solar based applications. The power electronic converters help in harnessing maximum output from the solar array by increasing the output voltage of solar array.

Present paper provides the matlab/ simulink software based analysis for different power electronic converters for obtaining more smooth and controlled output form solar array. It can be seen that, DC-DC buck-boost converter is the best suited converter for harnessing the maximum power from PV array, while the boost and cuk converters contains some large magnitude transients in the output voltage.

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