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Design And Simulation Of DC-DC Converter Topologies In Solar Photovoltaic System

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Abstract: *Photovoltaic (PV) is one alternative source of renewable energy. The output power from a PV system varies because it is highly dependent on the irradiance and temperature. Selection of the appropriate DC-DC converter is essential because it plays an important role in the overall performance of the PV system. Study of DC-DC converter topologies like boost, buck-boost, and Cuk is carried out in this paper. The performance of the simulation models have been compared by simulating them one by one in the MATLAB/Simulink platform. The boost converter gives less output power in comparison to other converters. The buck-boost and Cuk converters give almost 80% output power. The Cuk converter improves transient response and also gives less ripple in output power in comparison to the other converters.*
Keywords: *Photovoltaic systems, MATLAB/Simulink models, DC-DC converter topologies, renewable energy*

1. INTRODUCTION

Solar energy is clean, pollution free, no potential damage to the environment as compared to non-renewable energy like coal, wood, natural gasses, etc. The photovoltaic effect converts solar radiation into electrical energy in solar cells. PV arrays have the number of cells in series and parallel or a group of panels. PV systems have standalone and grid connected applications such as light sources, battery charging, solar water pumping stations, hybrid vehicles, military, and satellite systems [1]. The DC-DC converters are widely used as an interface between the PV panel and the load. The converter must be designed to directly connect to the PV panel and search the maximum power point (MPPT).

Over the last decades, many researchers have studied the DC-DC converters used in photovoltaic systems. There are many papers presented on converter topologies and their selection for the PV system based applications. A detailed review of converter topologies of both non-isolated and isolated DC-DC converters is presented by Venkatet. al [2]. The review provides a direction and reference point on the DC-DC converters for researchers and designers working in solar PV applications. The non-isolated DC-DC converter topologies are reviewed, compared, and discussed by Jeremy et.al [3]. The recent development of converters in terms of efficiency, steady-state oscillation, Number of components, voltage transfer, and tracking speed is well explained.

The selection of the appropriate DC-DC converter plays an important role in the overall performance of the PV system. Thus, in this paper detailed study of DC-DC converters topologies for PV system is carried out and then all topologies are trying to implement in MATLAB/Simulink.

2. PROBLEM FORMULATION AND METHODOLOGY

The circuit diagram of a solar cell consists of a current source, a diode, a series resistance and a parallel resistance as shown in Figure. 1. The antiparallel diode with the photo current source represents the theoretical model of an ideal PV cell. During the night or other times when it is dark outside, the solar cell remains passive and functions as a diode.

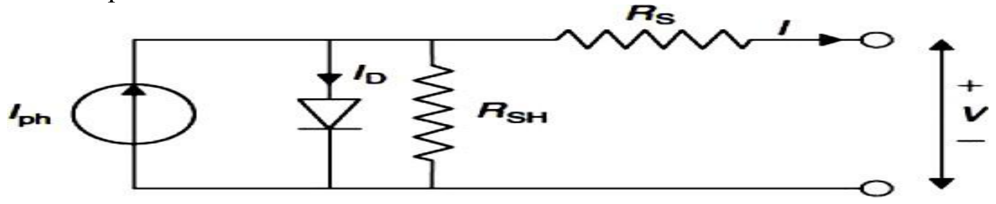


Figure 1: Circuit diagram of solar cell [4]

The mathematical model of the PV module has been developed based on mathematical equations in MATLAB/Simulink software. The following table shows the datasheet parameters of PV module DS-100 M which have been used for simulation.

Table 1: Specification of the DS-100 M PV module [5]

Model	**DS-100 M**
Maximum Power [W]	100
Open circuit voltage V_{oc}[V]	21.6
Short circuit current $I_{sc} \approx I_{pv}$[A]	6.11
Voltage at maximum power point V_{mp}[V]	18
Current at maximum power point I_{mp}[A]	5.55
Number of cell in series N_s	36
Number of cell in parallel N_p	1

The output current of this model, based on the Shockley diode equation, may be expressed as follows:

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + IR_s}{V_t a}\right) - 1\right] - \frac{(V + IR_s)}{R_p} \quad (1)$$

Where

I_{pv} : Photocurrent (A)

I_0 : Diode saturation current (A)

Thermal voltage of the array

$$V_t = N_s kT / q \quad (2)$$

N_s : Number of cells connected in series

q : Electron charge ($1.60217646 * 10^{-19}$C)

k : Boltzmann constant ($1.3806503 * 10^{-23}$J/K)

T : Module operating temperature (K)

a : Diode ideality constant

R_s : Series resistance(ohm) and

R_p : Parallel resistance (ohm)

Using these equations the mathematical model of PV panel at the Standard Test Conditions (STC) or reference Point which is 1000W/m^2 solar irradiation and 25^{o}C cell temperature has been developed [1].

2.1 Simulation Of Solar Pv Module In Matlab/Simulink

Mathematical modeling of the solar photovoltaic system is carried out in MATLAB software based on the Shockley diode equation as shown in Figure. 2. The datasheet parameters of DS -100 M PV module is selected for simulation as shown in Table 1.

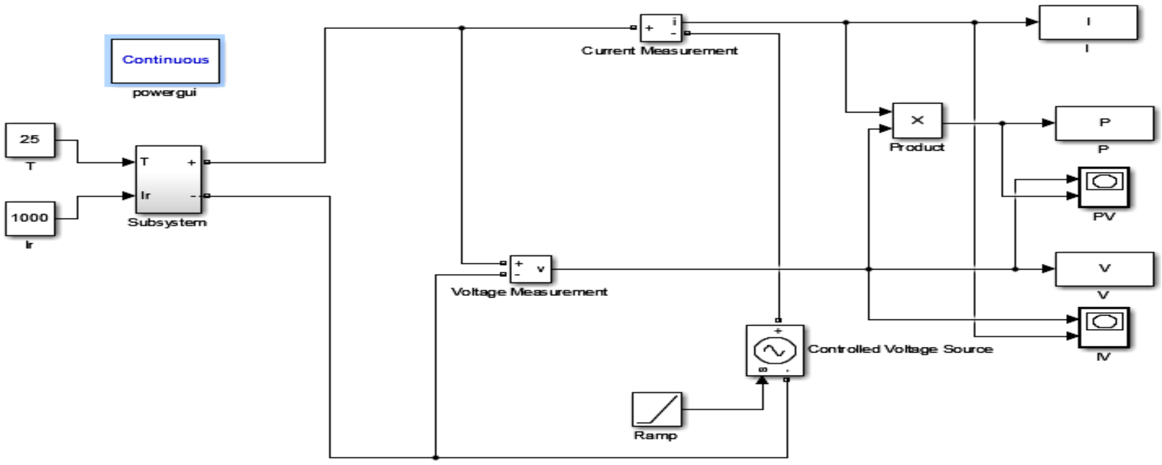
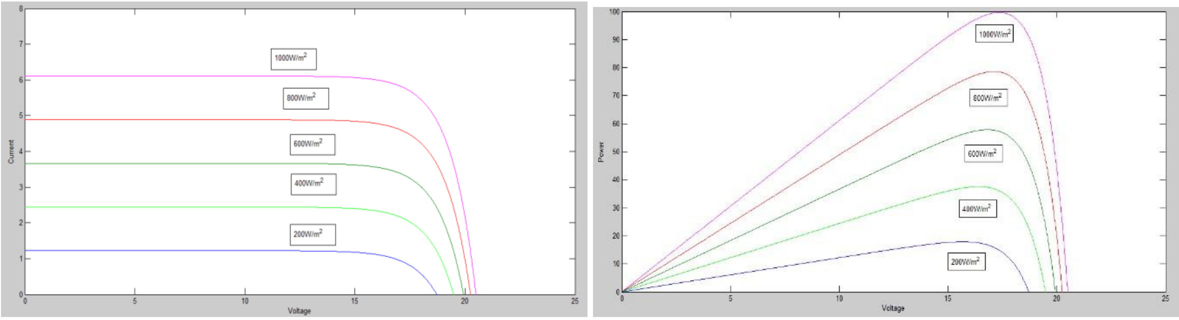


Figure 2: Simulation Model of Solar PV system



(a) (b)

Figure 3 (a): V-I characteristics (b) P-V characteristics of PV module

The V- I and P-V characteristics of the PV module obtained at different irradiance level is shown in Figure. 3. Then suitable DC-DC converter has been implemented for the given PV system.

3. Dc-Dc Converters

There are various DC-DC converter topologies are employed to regulate the input voltage in the solar PV system. They can be classified as Isolated DC-DC converters and Non-isolated DC-DC converters. Mainly used non-isolated DC-DC converters topologies are

1. Boost or step-up converter
2. Buck-boost converter
3. Ćuk converter etc.

3.1 Boost Or Step-Up Converter

It is also called the step-up converter as its output voltage is always greater than the input voltage. It consists of inductor L, controlled switch S, diode D, capacitor C, and resistive load R_L as shown in Figure. 4. In certain PV applications, the load side voltage magnitude needs to be a greater value in comparison to the input voltage. Then the boost converter is employed [6].

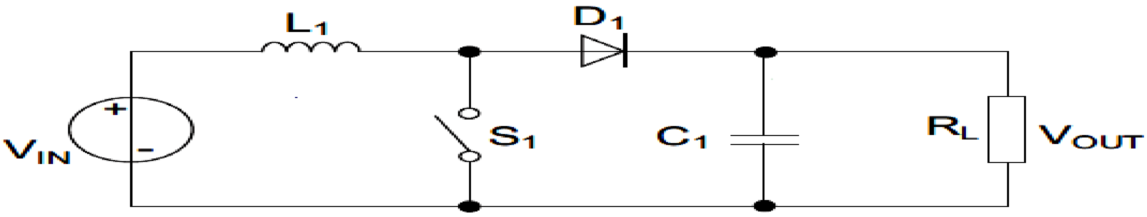


Figure 4: Boost or step-up converter [6]

The DC voltage transfer function is as follows:

$$\frac{1}{1-D} = \frac{V_{out}}{V_{in}} \qquad (3)$$

Where D is the duty cycle.

The value of inductor L is

$$L = \frac{V_{in}(V_{out}-V_{in})}{f_s \times \Delta I_L \times V_{out}} \qquad (4)$$

The value of capacitor C is

$$C = \frac{I_{out} \times D}{f_s \times \Delta V_{out}} \qquad (5)$$

f_s= minimum switching frequency of the converter

The boost converter is implemented in MATLAB/ Simulink using the above L and C formulas.

3.2 Buck-Boost Or Step-Up-Down Converter

The buck-boost converter is the cascade of the conventional buck (step-down) with conventional boost (step-up) converters as shown in Figure. 5. The converter consists of controlled switch S, inductor L, diode D, capacitor C, and resistive load R_L. It is also called a step-down/ step-up converter because output voltage can be either lower or higher than the input voltage [7].

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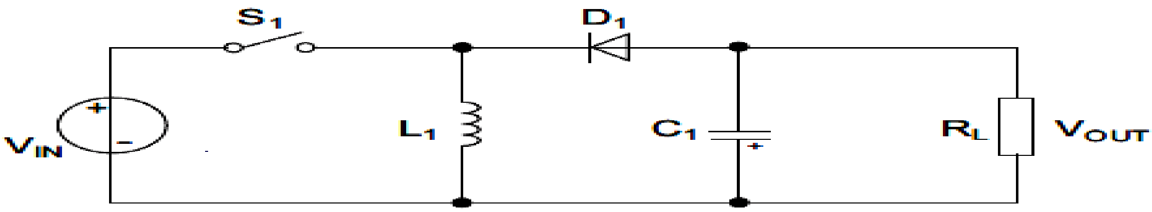

Figure 5: Buck-boost or step-up-down converter[7]

The DC voltage transfer function of the buck-boost converter is

$$\frac{-D}{1-D} = \frac{V_{out}}{V_{in}} \tag{6}$$

The value of the inductor L is

$$L = \frac{V_{in} \times D}{f_s \times \Delta I_L} \tag{7}$$

The value of the Capacitor C is

$$C = \frac{V_{out} \times D}{f_s \times \Delta V_{out} \times R} \tag{8}$$

Using above formulas buck-boost converter is designed in MATLAB/Simulink.

3.3 Ćuk Converter

The circuit diagram of Cuk converter is shown in Figure. 6. It has an output voltage magnitude that is either greater or less than the input voltage with a polarity inversion due to its voltage conversion ratio. It consists of input inductor L_1, controllable switch S_1, energy transfer capacitor C_1, diode D_1, inductor L_2, capacitor C_2, and resistive load R_L. The polarity inversion is represented as a negative sign. The Cuk converter has three modes like buck mode, boost mode, and buck-boost mode [8]. The Cuk converter has advantages such as having an energy transfer capacitor, a good steady-state performance, continuous input and output currents, and a low output voltage ripple[9]. The overall efficiency of the modified Cuk converters is recommendable for an optimal bidirectional operation that aims to regulate the voltage and current [10].

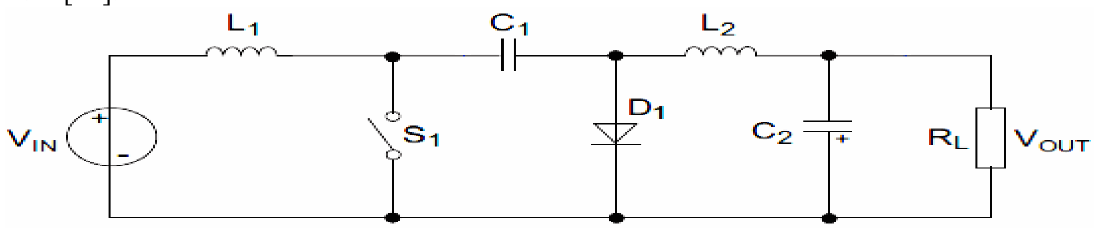

Figure 6: Ćuk Converter[7]

The dc voltage transfer function of the cuk converter is

$$\frac{V_{out}}{V_{in}} = \frac{-D}{1-D} \tag{9}$$

The value of inductors are

$$L_1 = \frac{V_{in} \times D}{f_s \times \Delta I_{L_1}} \tag{10}$$

$$L_2 = \frac{V_{in} \times D}{f_s \times \Delta I_{L_2}} \tag{11}$$

The value of capacitors are

$$C_1 = \frac{V_{out} \times D}{f_s \times \Delta V_{C_1} \times R} \tag{12}$$

$$C2 = \frac{(1-D)}{f_s^2 \times \left(\frac{\Delta V_{out}}{V_{out}}\right) \times 8L_2} \tag{13}$$

Using the above formulas the Cuk converter is designed in MATLAB/ Simulink.

The boost converter, buck-boost converter and Cuk converter are implemented in MATLAB software in the following section. Then the comparison of output power characteristics for all converters is carried out.

4. SIMULATION OF THE CONVERTERS UNDER CONSIDERATION

The simulation of boost, buck-boost and cuk converter are carried out at switching frequency (fs) = 10 kHz, duty cycle D=0.6 and load resistance R = 10Ω.

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4.1 Simulation Of Boost Converter In Solar Pv System

The designed boost converter for solar PV system has been implemented in MATLAB Simulink as shown in Figure 7.

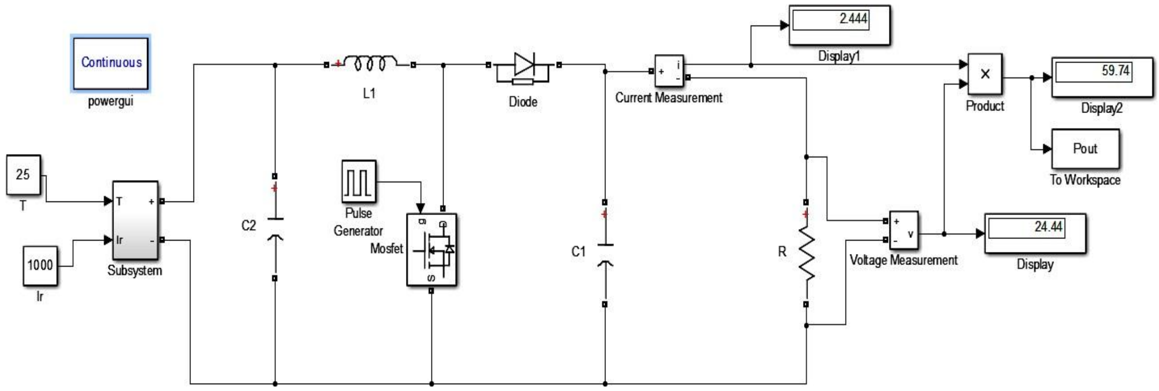

Figure 7: Simulation diagram of boost converter for photovoltaic system

The designed boost converter given only 50% output power, is usually not desirable.

4.2 Simulation Of Buck-Boost Converter In Solar Pv System

The designed buck-boost converter for given solar PV system is simulated as shown in Figure 8.

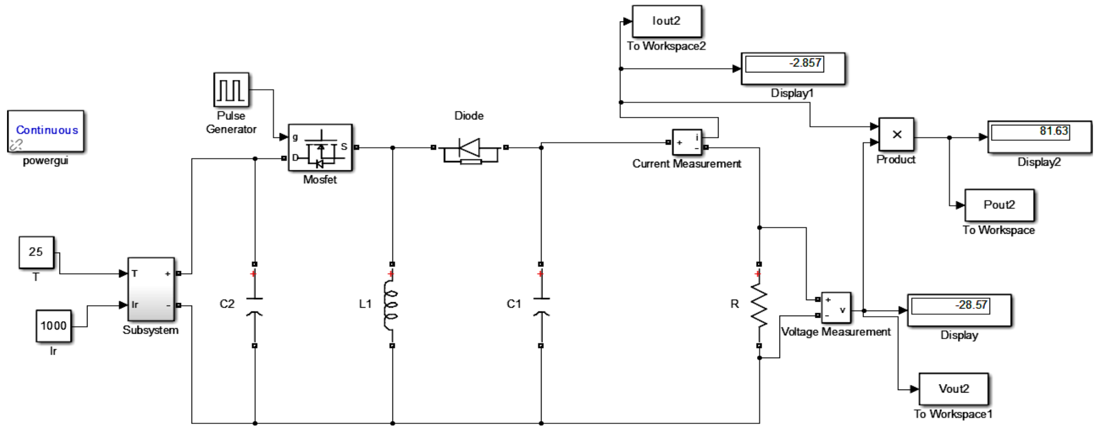

Figure 8: Simulation diagram of buck-boost converter for PV system

The designed buck-boost converter gives around 80% output power the polarity of output voltage and output current is opposite with respect to input.

4.3 Simulation Of Cuk Converter In Solar Pv System

Figure 9 shows the simulation circuit of the designed Cuk converter. It gives almost 80% output power.

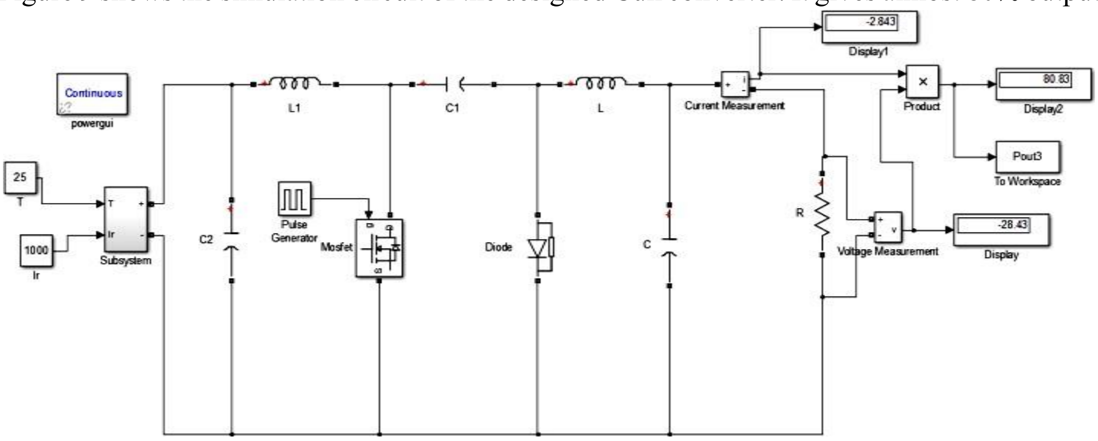

Figure 9: Simulation diagram of Cuk converter for PV system

The comparison of output power obtained from boost converter, buck-boost converter and Cuk converters is shown in Figure. 10.

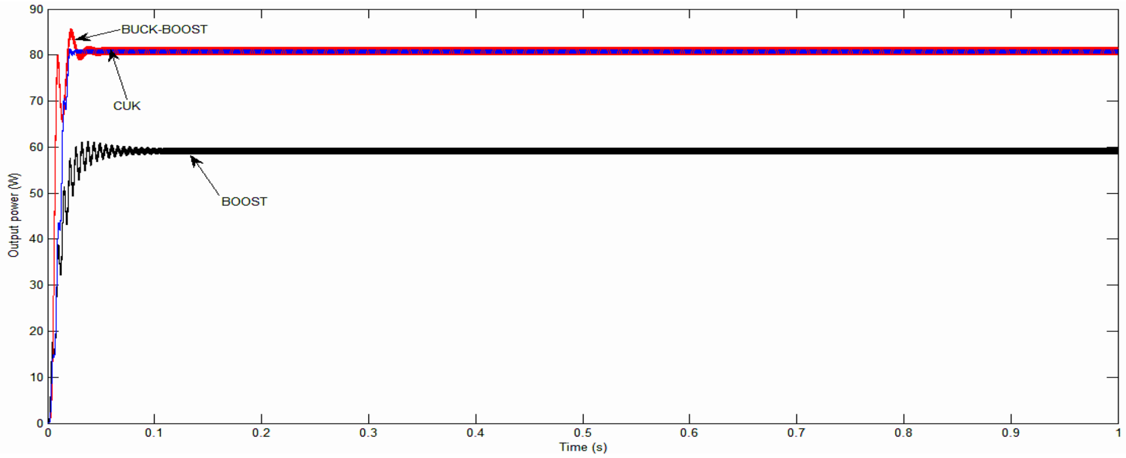

Figure 10: Output power characteristics of Boost, Buck-Boost, and Cuk converters

The power characteristics of all converters are shown in the above diagram. It has been seen that the designed Cuk converter gives an improved transient response with less ripple in output power. It is performing better than the other converters in standalone solar PV systems.

5. CONCLUSION

In this paper detailed study of solar PV system have been done and implemented in MATLAB/Simulink. The selection of the best converter for a PV system is a critical factor in designing of MPP tracker. Converters with high efficiency, such as buck-boost, and Cuk converters should be used. These converters indicate better performance due to their broad tracking range. The performance analysis for all converters in terms of output power oscillation and steady state has been carried out as shown in Figure 10. It has been seen that Cuk converter gives smooth power with less ripple characteristic. Finally is found that Cuk converters performance is good on standalone PV systems as it is highly efficient. The overall efficiency of whole system can be improved by selecting the appropriate MPPT technique.

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