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Performance Analysis of Synchronous SEPIC Converter for a Stand-Alone PV System

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Abstract – The renewable energy resources are flattering a boon to the biosphere where electrical energy is an inadequacy. There are numerous forms of renewable energy resources in spite of their types the solar energy is particularly becoming prevalent due to its source abundance and direct conversion from the sunlight. The extraction of the solar power from the solar panel is a straight progression but obtaining high efficiency from the solar panel is really a challenging process. In order to obtain high efficiency and stable output a boost converter should be used. There are many types of boost converter but basically they are classified as synchronous and non-synchronous converter. The synchronous converters are now becoming more advantageous than the other converters due to its reduced current ripple and better efficiency. Most importantly synchronous converters limit the usage of maximum power point tracking techniques that is without the closed loop maximum power point is achievable. The synchronous single-ended primary inductance converter (SEPIC) is analyzed with different parameters. The above stated converters are designed, modeled and simulated using MATLAB/SIMULINK. The simulation results are compared in terms of voltage ripple, current ripple, output power and efficiency.

Index Terms – Photovoltaic (PV) Energy, PWM Control, Synchronous SEPIC, Ripples, Efficiency.

1. INTRODUCTION

The renewable energy resources are becoming a boon to the developing world where the necessity of electrical energy is increasing day by day. There are many types of renewable energy resources among them the solar energy is the superlative. Though photovoltaic (PV) cell has some limitations of high capitation cost, lower conversion efficiency, partial shading and seasonal energy production [1], It has seized the attention of many researchers because of its special virtues. The special virtues include costless source and maintenance free system. These systems are also pollution free that is environmental contamination is reduced to the minimum of zero percentage [2].

The power obtained by the panel is very low and not regulated [3]. In order insure impedance adaptation between the PV source generation and the main utility a boost converter is employed. There are many types of boost converter but basically these are classified as synchronous and non-synchronous converter [4]. The synchronous converters are now becoming more advantageous than the other converters due to its reduced current ripple, voltage ripple and better efficiency [5]. The most importantly synchronous converters eliminate the usage of maximum power point tracking techniques that is without the closed loop maximum power point is achievable and therefore ordinary PWM controllers are enough to control the circuits. Therefore the high efficiency converters can be achieved by reducing the switching losses, the output voltage ripple, the output current ripple, reducing the number of parasitic elements and the stress of the individual elements which is possible easily in these two converters [6], [7].

There are many researches made in the pitch of the PV conversion and based on this research work the PV panel is modeled mathematically [1]. This paper analyzes each converter operating modes, design constraints, the importance of these converters about their output voltage and current ripples and output power. This paper also concludes about the efficiency deviation and efficiency performance of the converter. These converters are designed and simulated using the MATLAB/SIMULINK.

2. CHARACTERISTICS OF PV PANEL

The presence of diffuse and drift current for the reverse and direct polarization in the PN junction describes the operation of solar cell. When the PN junction is exposed to sunlight electron hole pair is created, when the photons with energy greater than the band gap energy are observed. Thus a current proportional to the solar irradiance is created when these carriers are separated in the junction under the influence of the electric field [2]. The block diagram is shown in Figure 1. The block diagram of PV powered converters is a necessity because we need to find the best converter with the higher efficiency [8], [9].

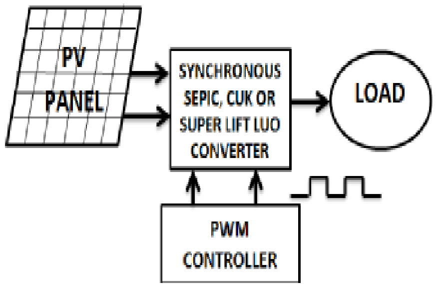

Figure 1: Block diagram of PV powered converters

The solar cell naturally exhibits nonlinear characteristics of I-V and P-V curve that varies with solar irradiance and temperature [1]. The Characteristics of I-V and P-V curve of the solar cell are shown in Figure 2.

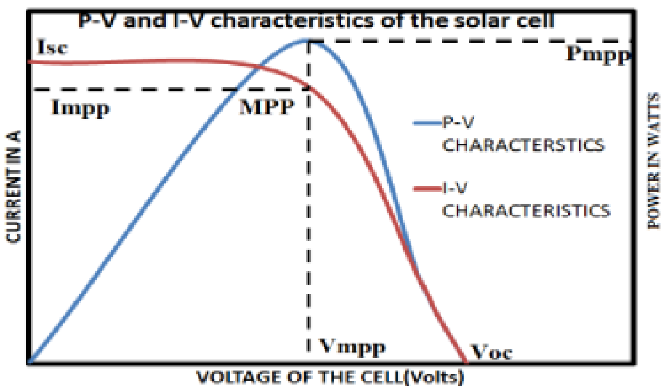

Figure 2: Characteristics of solar cell

The basic equation that describes the I-V curve characteristics of the photovoltaic model is as follows:

$$I = I_{ph} - I_s \cdot \left[\exp\left(\frac{q(V+R_S I)}{nkT}\right) - 1\right] - \frac{V+R_S I}{R_{sh}} \qquad (1)$$

Where:

I: cell current (A)

I_{ph}: Light generated current (A)

I_s: Diode saturation current (A)

q: charge of electron = 1.6×10^{-19} (Coulomb)

V: cell output voltage (V)

R_s: series resistor (Ω)

K: Boltzmann constant = 1.380662×10^{-23} (j/K)

R_{sh}: Shunt resistor (Ω)

3. SYNCHRONOUS SEPIC CONVERTER

Generally the synchronization of the circuit is investigated by swapping the diodes by switch. The term synchronization came from synchronizing the pulses of the MOSFET switch. The need for synchronization is to produce continuous conduction mode and the inverse voltage of the diode can be eliminated. The main role of the converter is to uphold the output voltage constant which can improve the photovoltaic systems efficiency and confirm a good transfer of energy [10], [11].

In Figure.3 shows the circuit diagram of SEPIC Converter. The SEPIC converter is a step up/step down converter that can produce a constant output voltage. In order to produce a continuous conduction mode the converter is to be synchronized [12], [13].

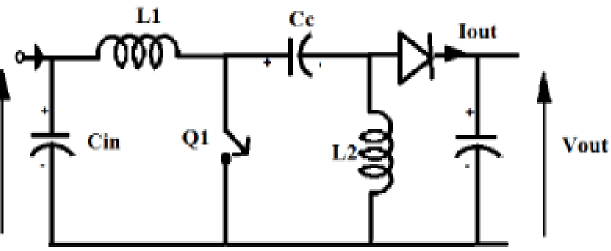

Figure 3: SEPIC Converter

The two switches are controlled by two complementary PWM signals. In the continuous mode the synchronous SEPIC converter has two modes of operation that is “Q1” on and “Q2” off and “Q1” off and “Q2” on and the discontinuous mode has to be avoided. The circuit diagram of synchronous SEPIC converter is shown in Figure 4.

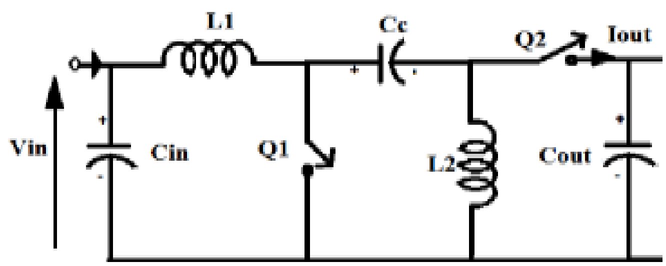

Figure 4: Synchronous SEPIC Converter

MODE1: When the “Q1” is on and the “Q2” off the current flows across the inductor L_1 and therefore L_1 and L_2 are charging and the capacitor C_c and are discharging.

MODE2: When the “Q1” is off and the “Q2” on the inductor L1 and L_2 discharges and the capacitor C_c and charges [14]-[16].

$$D = \frac{Time\ when\ Q\ is\ ON}{T} \qquad (2)$$

Where:

T: Period of the PWM signals (s).

D: Duty cycle of the PWM signal of the first switch [7].

From 0 to DT: The first switch Q1 is closed and the second switch Q2 is open, so the current across L1 increases at the rate of:

$$\frac{di_{L1}\text{-}}{dx} = \frac{V_{in}}{L_1}, 0 \leq t \leq Dt \quad (3)$$

So that L1 and L2 are charging; C_C and C_{out} are discharging.

From DT to T: The first switch is open and the second one is closed, and I_{L1} decreases at the rate of:

$$\frac{di_{L1}\text{-}}{dx} = \frac{-V_{out}}{L_1}, DT \leq t \leq T \quad (4)$$

So that L! and L2 are discharging; Cc and Cout are charging.

V_{L1} has two levels, their average equals zero, so:

$$\frac{(V_{in})DT + (-V_{out})(1-D)T}{T} = 0 \quad (5)$$

So that:

$$(V_{in})D + (-V_{out})(1-D) = 0 \quad (6)$$

Simplifying the above equation, the final input-output voltage expression:

$$V_{out} = V_{in} \times \frac{D}{1-D} \quad (7)$$

Thus, the converter performs buck function mode for D less than 0.5, and boost function mode for D greater than 0.5.

Assuming lossless circuit, the input power equals the output power, so:

$$V_{out}I_{out} = V_{in}I_{in} \quad (8)$$

So that:

$$I_{out} = I_{in} \times \frac{1-D}{D} \quad (9)$$

The ripple current across both inductors L1 and L2 is given approximately by:

$$\Delta I_L = 30\% I_{in(max)} \quad (10)$$

So that, the values of L1 and L2 are as next:

$$L1(min) = L2(min) = \frac{V_{in(min)} \times D}{2 \times \Delta I_L \times f} \quad (11)$$

The selection of the AC coupling capacitor is as follows [4]:

$$C_C(min) = \frac{I_{out} \times D}{\Delta V_{C\,ripple} \times f} \quad (12)$$

Also, the capacitor is given by [6]:

$$C_{out}(min) = \frac{I_{out} \times D}{\Delta V_{ripple} \times f} \quad (13)$$

With:

$$\Delta V_{ripple} = 1\% \times V_{out} \quad (14)$$

4. SIMULATION RESULTS

The Table 1 contains the synchronous SEPIC converter specification; these are designed based on the designed constraints which are present in equation. The table 1 contains the parameter specification for the synchronous SEPIC converter and these specifications are based on the section describes the design constraints for the synchronous SEPIC converter [17], [18].

Table 1 Synchronous SEPIC Specification

Sl. No.	Parameters	Value
1	Inductor	200 μH
2	Coupling Capacitor	20 μF
3	Output Capacitor	475 μF
4	Switching Frequency (Fs)	40kHz
5	Duty Cycle (D)	0.41 - 0.81
6	Input Voltage	12V
7	Output Voltage	8.3V- 47.5V
8	Load Current	1 .6A

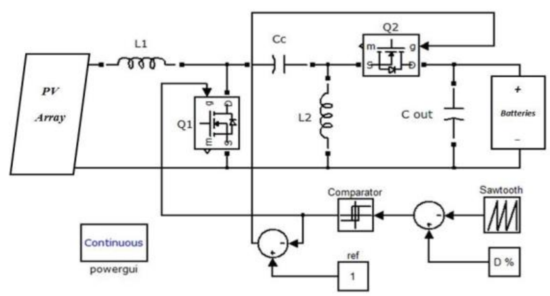

Figure 5: Simulation diagram of synchronous SEPIC with PV

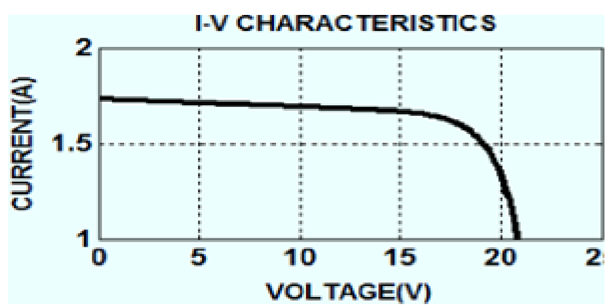

Figure 6: I-V Characteristics of the PV panel

The Figure 5 shows the simulation diagram of PV based synchronous SEPIC Converter. The proposed synchronous

SEPIC converter is designed and simulated using MATLAB functioning platform. Then the performance of the converters was tested with the photovoltaic energy generation system [19], [20]. The various parameters of the converter for which the converters are designed are tabulated in Table 1,

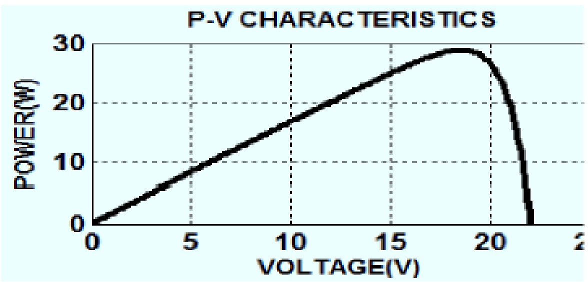

Figure 7: P-V Characteristics of the PV panel

The PV panel I-V and P-V characteristics are shown in Figure 6 and Figure 7 and therefore we can infer from that input current and input voltage to the proposed synchronous SEPIC converter are 1 .73A and 12V respectively [21]. The Figure 8 shows the PWM pulses for switch Q1 and Q2.

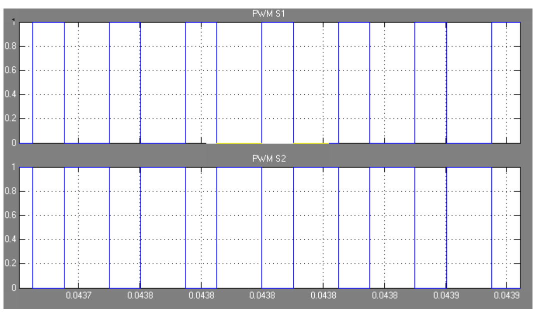

Figure 8 PWM pulses for switches

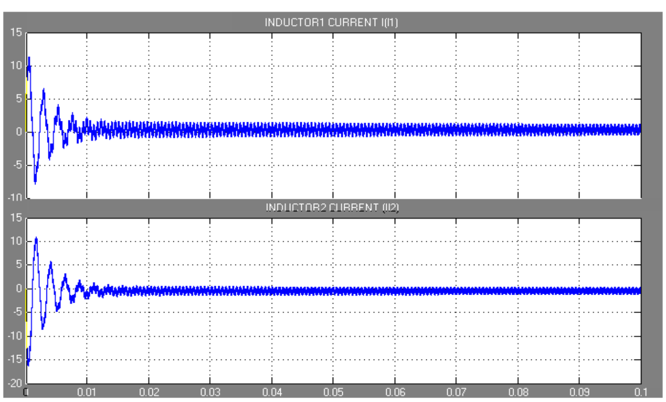

Figure 9: Inductor L1 and L2 current of synchronous SEPIC converter

The Figure 9 show the inductor L1 and L2 current of the synchronous SEPIC converter and Figure 10 (a), (b) and (c) show the Input voltage, output voltage and output current of the synchronous SEPIC converter. From these we can infer that the synchronous SEPIC converters show the high voltage gain and have reduced ripples. The synchronous SEPIC converter compared to SEPIC converter reduces the output power about 10% of the expected output. Therefore the synchronous SEPIC converter also proves that it works well with the high voltage gain.

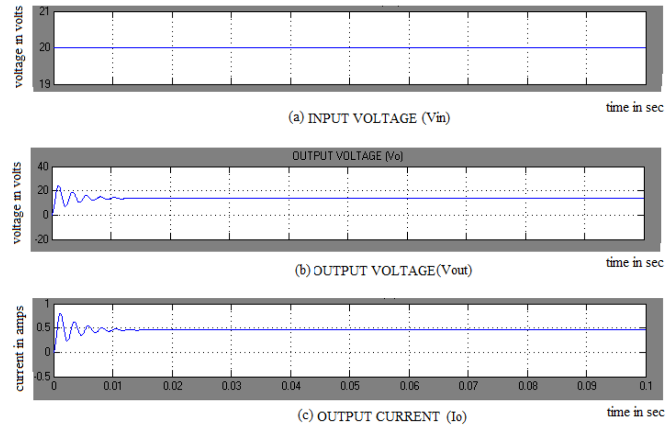

Figure 10: Input voltage, output voltage and output current of synchronous SEPIC converter

5. CONCLUSION

The converters were simulated using the MATLAB platform by the design parameters which were evaluated manually and the output performance was studied. Then from the output performance the efficiency of the converter and the variation with respect to the temperature and the irradiance were been tested using the interface with the PV system. The tested results prove that it produces continuous conduction and with the increase in the irradiance the output power increases and with increase in the temperature the output power decreases. The synchronous SEPIC converters possess the reduced current and the voltage ripples compared to the SEPIC converter and the switching losses are reduced by using the auxiliary circuit to the converter.

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