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A Modified Sepic DC-DC Converter for Higher Energy Step-Up Conversion with Fast Response Time Based Photovoltaic (PV) Applications

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Abstract

A single-ended primary inductor converter (SEPIC) has been modified in this work. The modification involves addition of some few components to the traditional SEPIC topology. The additional components are filter capacitor and a zener diode. The modification was done in such a way that the filter capacitor will receive the loss energy from opposite terminal of the circuit, filter it and deliver it to the zener diode. The benefits of the new topology are; higher voltage transfer ratio, less time delay and low duty ratio. Following the realization of the new topology, a prototype-based topology was created for simulation and laborary test. The simulation was carried out with MATLAB/SIMULINK. The results obtained from simulation provides a voltage value of 114V DC at the output when an input voltage value of 8V DC was applied. The results indicated a fast response time of 0.00005s by the on/off of power switch, higher voltage transfer ratio of 14.25 against a duty ratio value of 0.84. Laboratory results validated the feasibility of the simulation.

Keywords: PV panel, DC-DC SEPIC Converter, Higher voltage transfer ratio, Duty ratio, fast response time.

INTRODUCTION

The continuous depletion of fossil fuel and the threats pose by a climate changes are warning signs to narrow efforts in targeting an alternative power source (clean energy) (Isah, Sagagi and Tampul, 2020; Saravanan and Babu, 2017). Renewable energy is a clean, non-threatening and never run-out energy supply that if properly utilized, is capable of replacing fossil fuel as a global source of electricity generation (Isah, Sagagi and Aliyu, 2021). Recent exploitations in PV power system have shown the potentiality of power generation year by year. PV panel is a solar power made up of cells from semiconductor materials which receive solar as a form of heat energy and convert it into electrical energy (Mitra and Rout, 2017; Ahmad, Murtaza and Ahmed, 2019). This

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energy transition can enhance economy, save more lives and convey power to the rural areas thereby creating a utility substations.

Solar cells are naturally known to generate low voltage per PV panel which is not enough for consumer applications (Saravanan and Babu, 2017; Abdi, Beigvand and Scala, 2017; Kuo, Huang and Liu, 2015). Depending on the temperature, the intermittent behavior of the PV panels necessitated the DC-DC converter technology for the aforementioned energy transition. There are two types of DC-DC converters, they are, isolated and non-isolated (Nakpin and Khwan-On, 2016; Navamani, Vijayakumar and Jegatheesan, 2016; Revathi and Prabhakar, 2016; Vijayakumar and Jegatheesan, 2017), the isolated types require transformer and non-isolated are transformerless (Revathi and Prabhakar, 2016; Vijayakumar and Jegatheesan, 2017; Fathabadi, 2017; Hossain and Rahim, 2018). The former are expensive and the conversion efficiency depends on duty-cycle and turn-ratio of the transformer (Manuel, Enrique and Javier, 2018; Ostia *et al.*, 2017). While the latter are transformerless and depend on duty-cycle only for conversion efficiency (Gopi and Sreejith, 2018) hence, the latter technology is termed as promising to the future of power converters technology. DC-DC converter can be used as an interface unit between a PV panel and load or inverter.

DC-DC converters are affected by some technical problems that can hinders their growth. The low voltage transfer ratio against a moderate duty ratio value, and on/off delay of the response time of the power switch and low voltage transfer ratio are some of the biggest that are not well exploited in the literature. A power switch has to be rapidly active for a converter to be effectively working. A fast response in the power switch yields a good duty ratio value, which yield a good input/output ratio of a converter. The other parameters for a good converter are size, effective cost and less stress.

Past studies have explored many methods of designing a power converter, the most commonly methods in the literature are integrating method, cascading method, and incorporation a converter with a voltage multiplier, and serial-Parallel arrangement and so on. The integration methods adopted for a single topologies in (Kuo, Huang and Liu, 2015; Fernão, Foito and Fernando, 2017; Kumar, Ashirvad and Babu, 2017; Pires *et al.*, 2016) yield positive results but the delay in the response time affected the outcomes of the converters. Studies conducted by incorporating a single, and/or double converters with a voltage multiplier cells in (Navamani, Vijayakumar and Jegatheesan, 2016; Prudente, Pfitscher and Gules, 2005) affected the voltage transfer ratio through the delay in the response time too. Integration methods presented in (Kumar, Ashirvad and Babu, 2017) increase the size and cost of a converter. Besides, having too much components in a single converter can increase leakage in the power switch (Gowtham *et al.*, 2017; Oulad-abbou, Doubabi and Rachid, 2019). For instance, cascaded boost-boost in (Krishna *et al.*, 2017), boost-SEPIC in (Sabzali, Ismail and Behbehani, 2014), quadratic boost in (Navamani, Vijayakumar and Jegatheesan, 2016), and interleaved converter in (Mirzaei and Rezvanyvardom, 2020). A good power DC-DC converter should have higher ratio of voltage transfer, low duty ratio and a fast response time in its power switch.

Herein, a filter capacitor and a zener diode were added to a traditional topology of SEPIC DC-DC converter and the modified SEPIC was realized. The modified topology presented exhibits a past response time for turning on/off of its power switch, low duty-ratio and extended voltage transfer ratio. Simulation and experimental strategy were implemented for the validation of the modified topology.

MATERIALS AND METHODS

Materials:

The components used in modifying the traditional SEPIC topology are: 3-capacitors (C_1, C_2 and C_o), 2-diodes (D_1 and D_O), 2-inductors (L_1 and L_2), and MOOSFET (active power switch) *(Q)*, Other tools used in the laboratory are: oscilloscope, DC source, which was used in lieu of PV panel in the laboratory,

Methods:

Modification approach was employed in this work, two components were added to traditional SEPIC and the modified topology was designed. The additional components are filter capacitor and a zener diode. The modification was done in such a way that the filter capacitor will receive the loss energy from opposite terminal of the circuit, filter the signal, and deliver it to the zener diode. The inductor L2 received energy and deliver it to the output capacitor. A big size of output capacitor was chosen such that it create a time delay in discharging the energy coming from C1 alone until the energy coming C2 is arrived. The output capacitor Co will combine the energy of C1 and C2 and deliver it to the load. This methods is similar, but in modification to the methods adopted by (Saravanan and Babu, 2017). After the modification, a software (MATLAB/Simulink) was used for the simulation test. Experimental work was also done to validate the results obtained from simulation.

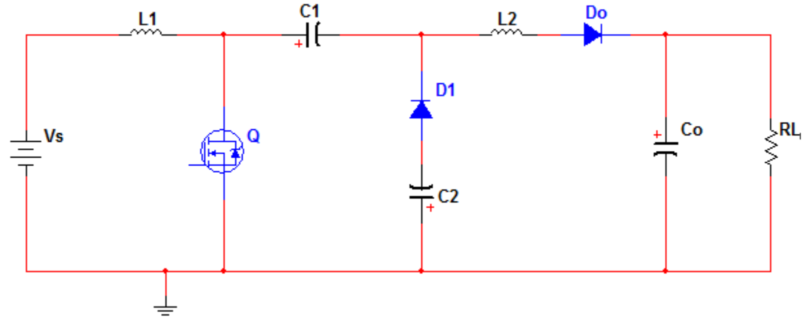

Figure 1: Proposed SEPIC topology

Mathematical Computations of the Proposed Converter

We assumed the source and load voltages to be $V_S = 8V$ and $V_o = 114\ V$ respectively. All the computations of the proposed SEPIC topology were derived from the circuit in figure 1. The hypothesis of the parameters for voltage transfer ratio, duty ratio equation and voltage across components are evaluated using Kirchhoff's voltage law.

$$V_i = V_Q + V_{L1} \quad (1)$$

V_i is the voltage of the PV panel (source voltage), V_Q and V_{L1} are the voltages of the power switch and inductor L1.

But $V_{C2} = V_{D1}$ and $V_{C2} + V_{D1} = V_{C1} + V_{C2}$ (2)

That is to say the combination of energy in D1 and C2 equal to energy in C1.

Then, $V_Q = (V_{C2} + V_{D1}) = V_{C2}$ (3)

V_Q is the energy across the power switch of the modified SEPIC.

The equation for the new topology in whole can be written as:

$$V_i\partial = (V_{C2} - V_i)(1 - \partial) \tag{4}$$

∂ is the duty ratio.

Solving equation (4), we have:

$$V_i\partial = V_{C2} - V_{C2}\partial - V_i + V_i\partial \tag{5}$$

From equation (5), V_{C2} can be evaluated as:

$$V_{C2} = \frac{V_i}{(1-\partial)} \tag{6}$$

Equation (6) can be written in terms of equation (3) as:

$$V_Q = \frac{V_i}{(1-\partial)} = V_{C2} \tag{7}$$

The signal value of the capacitor C2 and the signal value of the power switch can be evaluated using Equation (7).

Using equation (6) in terms of the duty ratio (∂), we have:

$$V_i = V_{C2} - V_{C2}\partial \tag{8}$$

or, in simply as:

$$\partial = \frac{V_{C2} - V_i}{V_{C2}} \tag{9}$$

Voltage transfer ratio can written as:

$$\text{Voltage transfer ratio} = \frac{V_{CO}}{V_i} = \tag{10}$$

Equations of the Components Used in Designing the Proposed Converter

8V DC was assumed as an input value during the modification of the proposed topology. The average currents of first and second inductors used during the conduct of laboratory work as 1.5A and 3A.

$$L_1 = \frac{V_i \times \partial}{f_s \times I_{L_1}} \tag{11}$$

$$L_2 = \frac{V_{C_1} \times (1-\partial)}{f_s \times I_{L_2}} \tag{12}$$

$$C_1 = \frac{I_O}{f_s \times \Delta V_i} \tag{13}$$

$$\Delta V_i = \frac{V_S}{(1-\partial)} \times 10\% = 5.33\ V \tag{14}$$

$$\Delta V_{out} = \frac{V_i}{(1-\partial)} \tag{15}$$

$I_{L_1}, I_{L_2}, f_s, \Delta V_i, \Delta V_{out}$ represents the average current of inductor L1, L2, switching frequency, average input and output voltages.

RESULTS AND DISCUSSIONS

Simulation and Experimental Results

Simulation

Figures 2, 3, and 4 were obtained from simulation analysis.

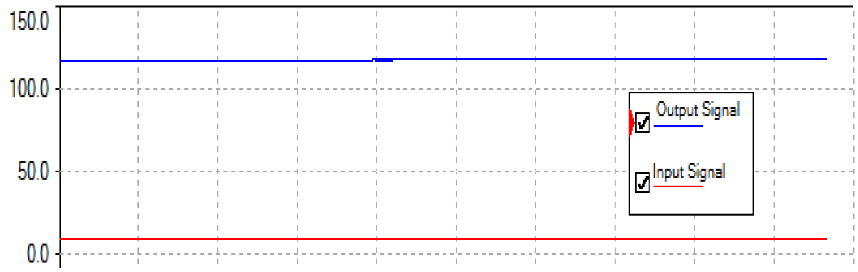

Figure 2: Output Against the Input Signals in volts.

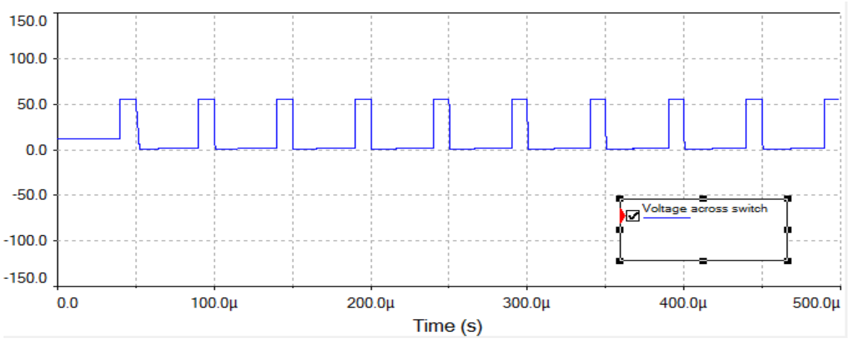

Figure 3: Signal Across the Power Switch in Volts (V_Q)

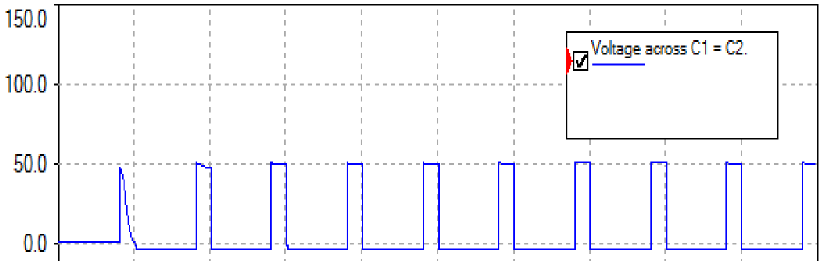

Figure 4: Signal Across Capacitors in Volts (C1 and C2).

Experiment

Graphical representation of the experimental results of the proposed SEPIC topology are depicted in figures 5, 6 and 7.

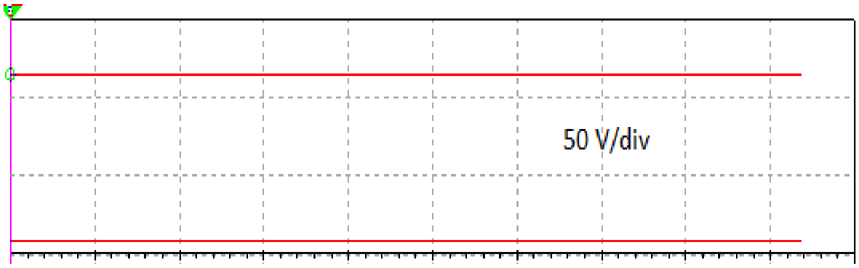

Figure 5: Output Against the Input Signals in volts.

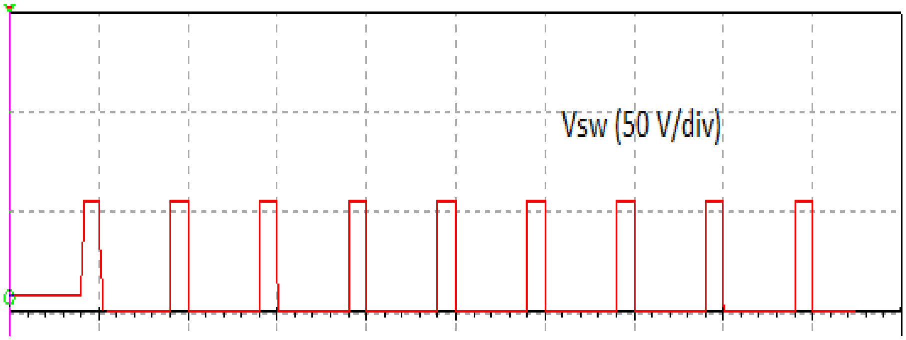

Figure 6: Signal Across the Power Switch in Volts (V_Q)

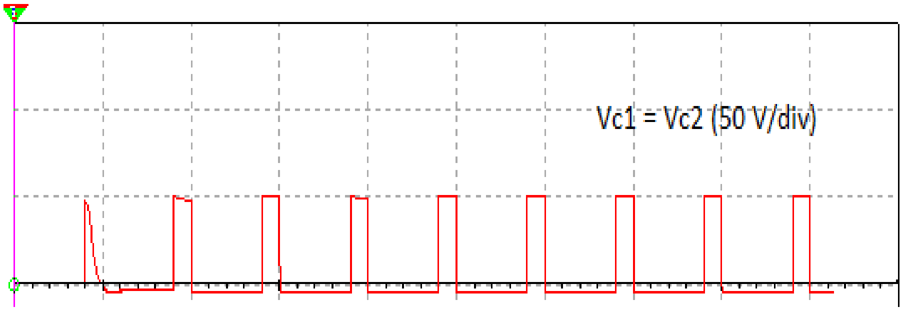

Figure 7: Signal Across Capacitors in Volts (C1 and C2).

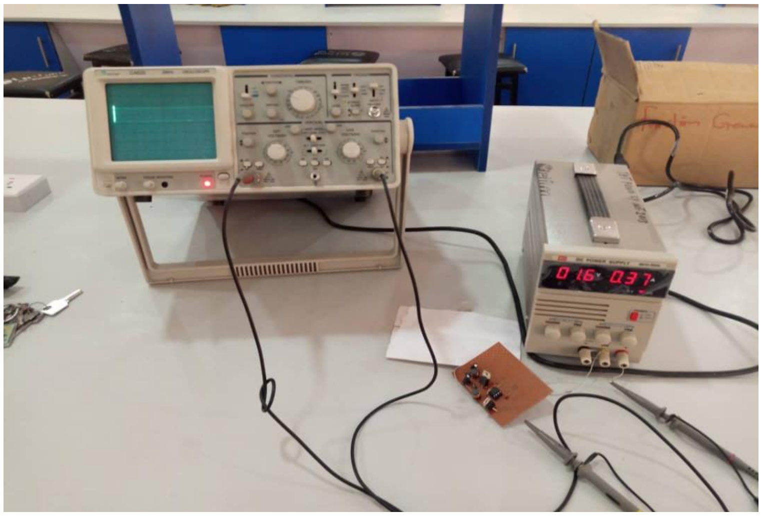

Figure 8: experimental set-up.

Table 1: list of parameters.

Parameters	Value
Input Voltage	8V DC
Output Voltage	114V DC
Switching Time	0.00005 seconds
Duty Ratio	0.84
Average Output Voltage	53.33 V
Average Input Voltage	5.33 V
Inductors (L1 and L2)	(200 µH and 125 µH)

DISCUSSIONS

Simulation

Following the mathematical computation of the input/output components of the new circuit, a simulation package (MATLAB/Simulink) was implored. Figure 2 is the input/output signals and it mean a voltage transfer ratio of 14.25 with a 0.84 duty ratio were realized. The quick response time can be evaluated from the phases of the signal in figure 2 and it can be seen that about 0.00005s can be deduced. The parameters obtained are tabulated in table 1. The results have shown the feasibility of the proposed converter compared to similar findings of SEPIC converter presented in (Saravanan and Babu, 2017) and interleaved converter in (Mirzaei and Rezvanyvardom, 2020).

Experiments

Converter's prototype was built in the laboratory for the validation of the simulated circuit. Digital oscilloscope was employed and DC source was in lieu of PV panel for simplicity purpose as shown in figure 8. Dx9 cable was plugged between the hub of computer and oscilloscope to capture the signals through the screen of computer. Input/output signals are depicted in figure 5 and a voltage transfer ratio of 14.16 was realized with a 0.84 as duty ratio. The results show promising future to the propose topology compared to the ones in (Mirzaei and Rezvanyvardom, 2020 ; Saravanan and Babu, 2017).

CONCLUSION

A modified SEPIC DC-DC converter for higher step-up energy conversion with fast response time based PV panel applications has been presented. The capacitor-diode components added to the traditional SEPIC have extended the value voltage transfer ratio better than the conventional SEPIC. The time response of the power switch rises significantly and the duty-cycle has been lowered relatively. These characteristics have made the proposed topology suitable for application in DC-DC step-up conversion systems like PV power and other renewable energy systems that require large voltage transfer ratio with fast response time.

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