Single phase inverter fed through a regulated SEPIC converter

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ABSTRACT

In power electronics, it is necessary to select the best converter circuit topology that has good performance among different converters. The single-ended primary inductor converter (SEPIC) has good performance and is advantageous among different direct DC/DC converters. In this paper, a design of a SEPIC converter is made by selecting the values of its components according to the required output voltage and power. The design is made by an assumption that both of its inductors have the same value. The converter is tested by using MATLAB/Simulink successfully. Later, its output voltage is regulated by using a proportional integral (PI-controller) through tuning its proportional and integral gains. Finally, the SEPIC converter is connected to a single-phase full-bridge inverter to supply its required DC voltage. The role of the SEPIC converter is to regulate the dc-link voltage between its output side and the inverter. The results showed the success of this connection to supply alternating current (AC) loads with low total harmonic distortion (THD).

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1. INTRODUCTION

In power electronics, there are many categories of DC/DC converters that are either stepping up or down or even both for the supplied voltage [1]-[3]. The single-ended primary-inductor converter (SEPIC) is a DC/DC converter that is stepping up or down of its supplied voltage. The circuit is built mainly from 2 inductors, 2 capacitors, and one switch. The switch is either metal oxide semiconductor field effect transistor (MOSFET) or insulated gate bipolar transistor (IGBT). Due to its design, the circuit is able to give output voltage at the same polarity as the supplied voltage [2]-[5]. There are many researchers who made their own design of SEPIC converter. The design may contain coupled or uncoupled inductors [6]. The work that was made by DeNardo *et al*. [7] is a design of SEPIC converter passive elements which is done by using the acceptability boundary regions (ABR) method. This method determines an area in the space of parameters according to commercial components. The reason behind using this method is to ensure acceptable ripples of voltage to attain maximum allowed power dissipation and non-pulsating source current absorption as well. A normal design and analysis of SEPIC converter for photovoltaic (PV) applications are made and simulated by MATLAB simulation environment but without output voltage regulation [8]. There is an analysis is made for a SEPIC converter with a proportional-integral-derivative (PID) controller to regulate its output voltage by Bhavin *et al*. [9]. Their system is simulated in matriks laboratory MATLAB/Simulink. Geeta and R. [10] are analyzed the diode part of the SEPIC circuit. They had replaced it with a switch to make better operating by avoiding the discontinuous conduction mode (DCM). This yielded to save the diode inverse voltage. Their design has a compound PWM technique to ensure the synchronization between two switches. A design of SEPIC boost converter is made by Alhamrouni *et al*. [11] for PV applications where the converter ensures continuous current and high voltage gain. The circuit design is able to reduce stress on the power switch as well. An extended high gain SEPIC converter for photovoltaic applications is made by Alishah *et al*. [12]. Their design merges SEPIC converter and switched capacitors. The design provides a constant dc voltage at its output side with tracking the maximum power point tracking (MPPT). A modified SEPIC circuit with and without winding isolation and connected with a three-phase PWM inverter is made by Yadav and Verma [13]. Their system is regulated and simulated via MATLAB/Simulink. A regulation by PID for a SEPIC converter is made by Pathirathne and Maduranga [14]. In their research, the converter design steps and its output voltage regulation are presented in a comprehensive way and the system is simulated by Simulink. The current paper presents a design of a regulated voltage SEPIC DC-DC converter. The converter is connected to a full-bridge inverter to supply AC loads. The role of the SEPIC converter is to regulate the voltage for the dc-link between its output side and the inverter. The paper involves the design of a SEPIC converter, regulating its output voltage, and then connect it to a single-phase full-bridge inverter. This paper is organized as follows: an introduction, analysis of SEPIC converter, design specification, simulation results, regulation of SEPIC converter, connecting SEPIC converter to a full-bridge inverter, and conclusion.

2. ANALYSIS & DESIGN OF SEPIC CONVERTER

The SEPIC converter contains 2 inductors, 2 capacitors, and 1 switch which are mainly MOSFET or IGBT as shown in Figure 1. There are two modes of operation according to switching conditions. In Figure 2 (a), if the switch S is ON, the inductor L_1 is charging, C_1 is charging the inductor L_2. In this case, the diode D is reverse biased. In Figure 2 (b), when the switch S is OFF, L_1 is discharging towards C_1 which is currently charging, and L_2 also discharging and D is forward biased [15]-[17].

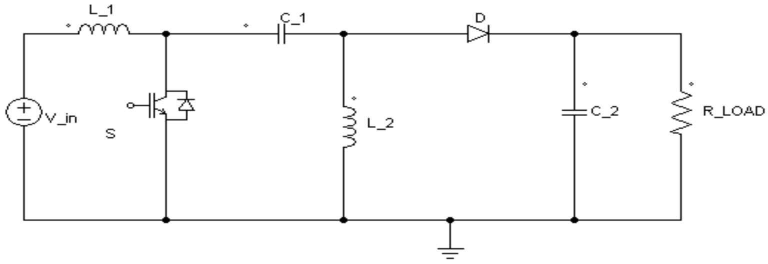
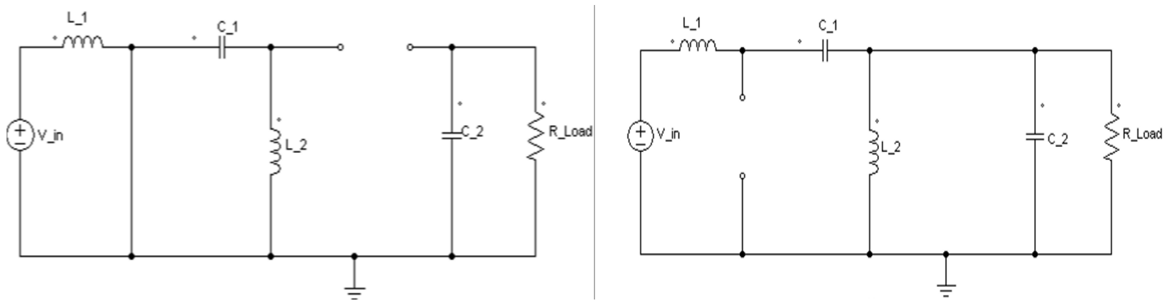


Figure 1. SEPIC converter circuit



(a) (b)

Figure 2. Modes of SEPIC converter operation, (a) mode 1, S is ON, (b) mode 2, S is OFF

The duty cycle is defined as the ratio between the time when S is ON and the whole cycle period. According to the duty cycle of the switch S, the voltages and currents of each component in the circuit are varied. The following mathematical expressions are used to find the value of each of the converter components where an assumption can be made which is the change in input current is 20% of the full load input current. Another assumption can be made which is the change in L_1 current is similar to the L_2 current change. L_1 and L_2 can be calculated by the following formula:

$$L\_1 = \frac{V_{s\,min} * D_{max}}{f_s * \Delta I_{L\_1}} \tag{1}$$

$$L\_2 = \frac{V_{s\,min} * D_{max}}{f_s * \Delta I_{L\_1}} \tag{2}$$

f_s is known as the switching frequency in Hertz. The maximum duty cycle D_{max} can be calculated by the following formula:

$$D_{max} = \frac{V_O + V_D}{V_O + V_D + V_{\_in\,min}} \tag{3}$$

The coupling capacitor C_2 can be found from the formula:

$$C\_1 = \frac{I_{Omax} * D_{max}}{\Delta V_1 * f_s} \tag{4}$$

Where $\Delta V_{\_in}$ is about 1% of the required input voltage whereas the output capacitor C_2 value becomes:

$$C\_2 = \frac{I_{Omax} * D_{max}}{\Delta V_O * f_s} \tag{5}$$

ΔV_o is about 1% of the required output voltage. The maximum output current can be calculated by using the formula:

$$I_{Omax} = \frac{P_{Omax}}{V_O} \tag{6}$$

The ration between the V_in and Vo can be calculated by the following formula and shown in Figure 3.

$$\frac{Vo}{V\_in} = \frac{D}{(1-D)} \tag{7}$$

where D is the duty cycle.

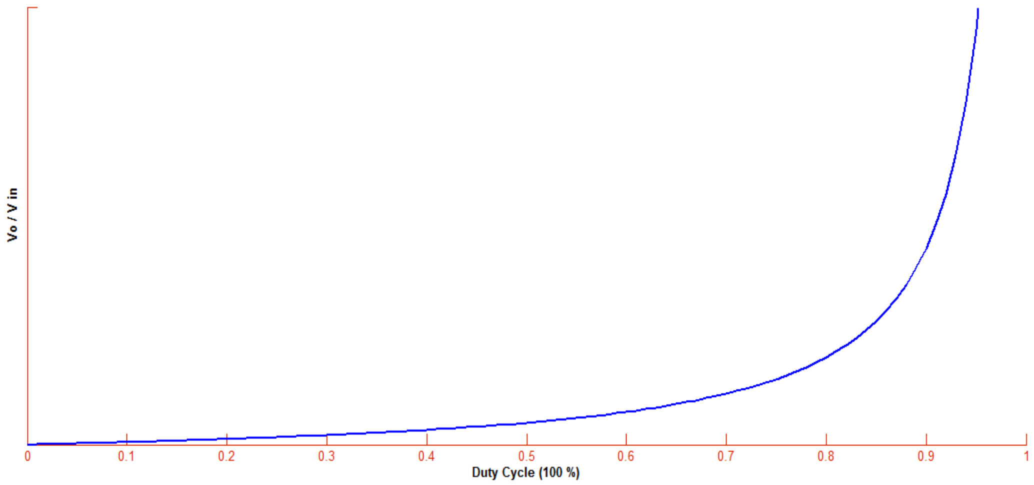


Figure 3. SEPIC converter voltage gain (V_o/V_{in}) and its duty cycle (D)

From Figure 3, it can be noted that the best working area when D is less than 90%. And below 50% the voltage change tends to be more linear. When D is 50% then Vo ≈ V_in. Acording to the required output power and voltage ranges, and by using the formulas in the previous section of this paper, the SEPIC converter parameters can be calculated and listed in Table 1 where the maximum output power is 2 kW.

Table 1. SEPIC converter components values

Component	Value/Type
L_1	750 uH
L_2	750 uH
C_1	200 µF
C_2	600 µF
S	IGBT
V_in	100 - 120 V
Vo	311 V
f_s	25 kHz

3. THE PROPOSED CONVERTERS CONNECTION

In this paper, the proposed connection of the converters is made where the designed SEPIC converter is connected to a full-bridge inverter [18], [19] to supply AC loads as shown in Figure 4. The SEPIC converter with the proportional integral controller (PI-controller) is responsible for fixing the DC voltage that is supplied to the inverter. The role of the SEPIC converter is to supply the required and regulated DC voltage to the input terminals of the inverter. A PI-controller [20], [21] is an efficient controller to regulate the output voltage of the SEPIC converter. The PI-controller is used to regulate the DC-link voltage between the SEPIC converter and the inverter. This voltage regulation aims to get constant DC voltage and to reduce the overshoot effect during load switching. As shown in Figure 4, the voltage signal is from the DC-link is compared with a set point (SP). The result of this comparison is the error that will be fed to the PI-controller. This controller is tuned to get its required proportional and integral gains [22]. The generated control signal is then modulated with a high-frequency carrier signal f_s to generate the required pulses for the S switching device.

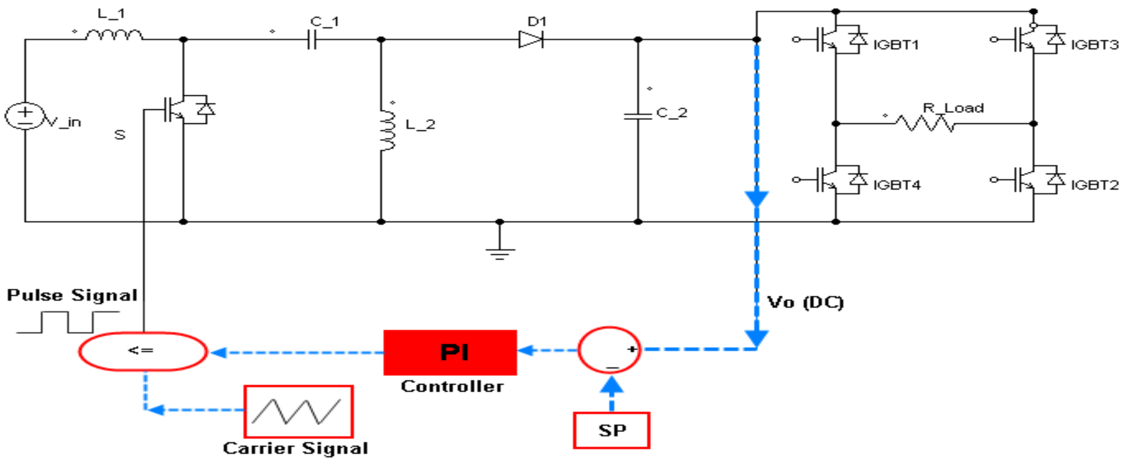


Figure 4. The proposed regulated SEPIC converter connected to single-phase full bridge inverter

4. SIMULATION RESULTS

The SEPIC converter of Figure 1 is simulated by using MATLAB/Simulink. The specifications of its components are as listed in Table 1. The simulation is made according to the following steps:

4.1. Test of the SEPIC converter individually

This test is made for SEPIC converter without any voltage regulation. Figure 5 shows the output voltage at starting of the converter. In this figure, it can be noted that the converter has a very fast response but, there is a huge overshoot percentage in the output voltage value which is 73.6% approximately at full load. If the load is decreased, this percentage may be more.

In another way, let's suppose there is a load switching from half load to full load for some period of time and then the load is repeated to be half-load again. This case is shown in Figure 6. It can be noted that there is a voltage dip when the load is increased and voltage swells when the load is decreased. The operation of each load changing is accompanied by voltage fluctuations for some time.

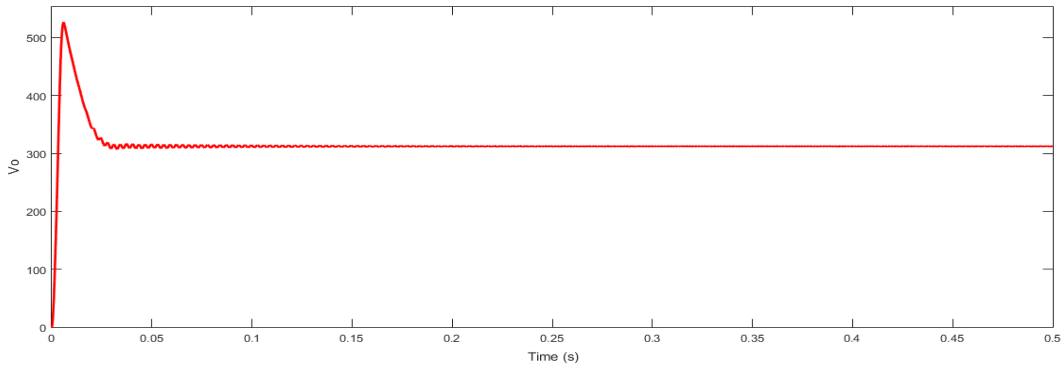


Figure 5. Output voltage of SEPIC converter during starting

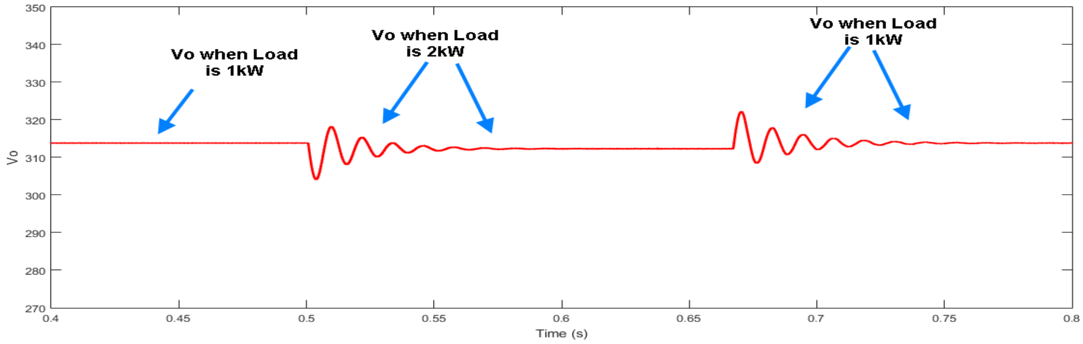


Figure 6. Output voltage of SEPIC converter load switching

4.2. Regulation of sepic converter

From the voltage results that are shown in Figures 5 and 6, it can be seen that during system starting there is a huge value of overshoot percentage and also there are more voltage fluctuations and decrease in the output voltage value. From these results, it can be concluded that there is a need for regulating the output voltage to absorb the high values of changes or fluctuations. From (7), it can be noted that only the duty cycle D is a regulating factor. Figure 7 represents the SEPIC converter output voltage at starting when PI-controller is used. In this figure, it can be noted that the overshoot is eliminated. Figures 8 and 9 represents the SEPIC converter output voltage and current respectively with load switching. In this figure, the load is changed from 1 kW to be 2 kW when the simulation time beyond 1 second. The load is switched again to be 1 kW when the simulation time is beyond 1.6 seconds. It can be noted that the PI-controller was able to absorb the load changing and fixing the output voltage at its desired value. In this simulation, the proportional gain (KP) was (0.1) and the integral gain (KI) is (4.5).

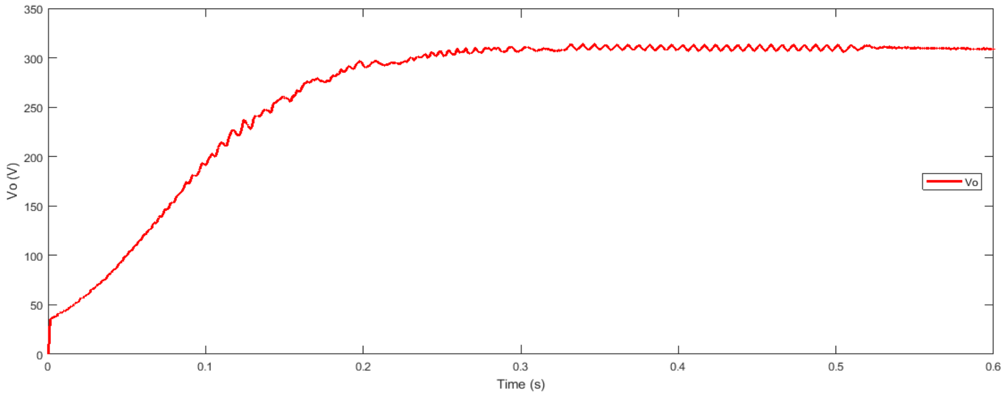


Figure 7. Output voltage of SEPIC converter during starting when PI-controller is used

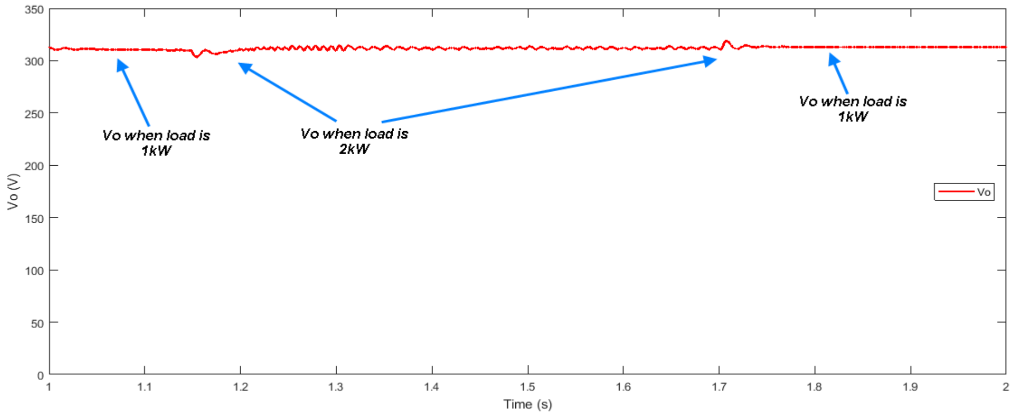


Figure 8. Output voltage of SEPIC converter with load switching when PI-controller is used

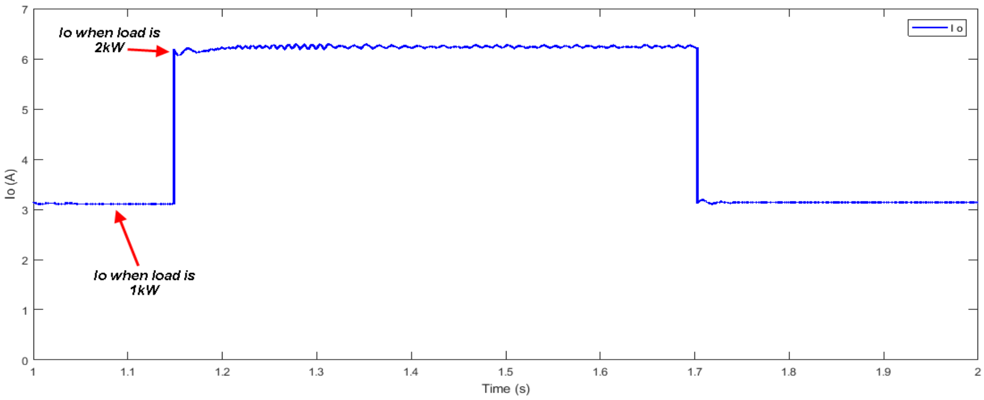


Figure 9. Output current of SEPIC converter with load switching when PI-controller is used

4.3. Connecting sepic convertoer to a full-bridge inverter

Figure 10 shows AC current and voltage for an R-L load where the RMS output voltage is 230 V. The pulses for the inverter switches are a result of sinusoidal pulse width modulation (SPWM) operation and fed each switch of the inverter [21], [23]-[27]. The modulation index is kept at 0.95. Figure 11 represents the total harmonic distortion for the output voltage value of the inverter which is 12.28%.

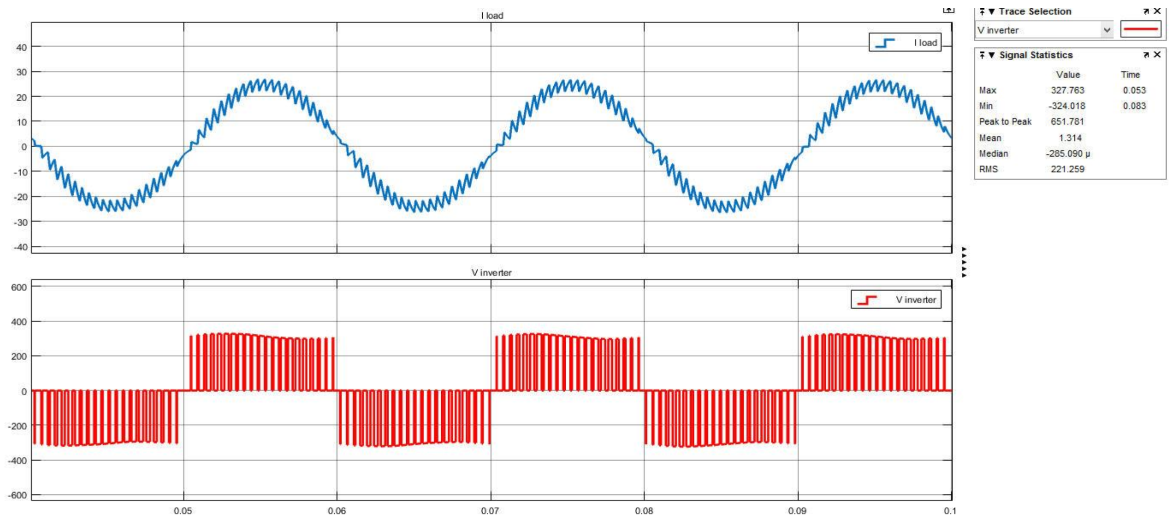


Figure 10. AC output voltage and current when the inverter is supplied by SEPIC converter output voltage

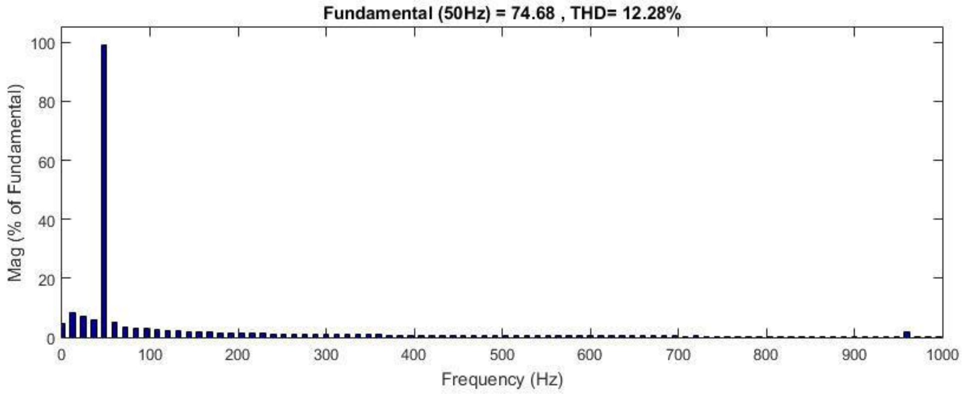


Figure 11. THD for the inverter output voltage

5. CONCLUSION

A design and simulation of the SEPIC DC/DC converter are made in this paper. In this design, an assumption is made that the change in each inductor current is the same so that the inductance of each coil will be the same. The measured output voltage of the converter is shown at system startup and during load switching. The results showed that a proper controller is needed to regulate the output voltage of the converter. When the converter is connected to a full-bridge inverter, the load has some voltage flickers so, a special filter in the DC and AC sides of the inverter is essentially required. Thus, it can be concluded that this merged system of SEPIC converter and full-bridge inverter is typical for general load applications.

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