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Analysis of Power Electronic Converters for Electric Vehicle Applications

Mrs. J Jency Joseph^a, Dr. F.T.Josh^a, Ronaldo Lamare^b, Blessen Varghese Mathew^b

^aAssistant Professor, Karunya University, Coimbatore, jencyjoe@karunya.edu.

^bPG students Karunya University, Coimbatore.

Abstract — this work presents a performance analysis of various power electronic converters with RL load to reduce the total harmonic distortion. The power converters inspected are: ZETA converter, single-ended primary inductance converter, often written SEPIC converter and Z SOURCE converter. The objective is to analyze which power electronic converter exhibits less total harmonic distortion (THD) and more efficiency in order to select the suitable converter for electric vehicle propulsion system. Three above mentioned converters are designed, modeled, and simulated. The zeta converter is advantageous over other converters inspected and have reduced total harmonic distortion, higher output power and hence improved efficiency. The simulations are done with MATLAB/SIMULINK and the results are presented.

Keywords: Total Harmonic Distortion (THD), MATLAB simulation, Z-SOURCE converter (ZSC), Zeta converter, Sepic converter

1. Introduction

Due to the advancement of the usage of Battery and Solar energy, the power electronic converters plays major role between the source and the load. DC-DC converter is widespread in modern portable electronic equipment and systems. To select the proper converter with less THD for the DC drives, here three converters are considered, based on the output power requirement the converters have been designed and modeled in MATLAB/SIMULINK. ZSC is an advancement in dc to dc converters in power conditioning of alternative energy sources and applications like HEVs & utility interfacing[1]. Unique buck boost capability of ZSC allows a wider input voltage range & eliminates the usage of traditional converter [2-3]. The single-ended primary-inductance converter (SEPIC) is a DC/DCconverter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage[4]. ZETA converter analysis provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. The ZETA converter is configured from a buck controller that drives a high-side PMOS FET. The ZETA converter is another option for regulating an unregulated input-power supply [5]. Hence in this paper we are going to discuss and find out the most reliable DC- DC converters which are used in low power application and which gives out maximum output with reduced THD.

2. Methodology for Design

To design the converters, the RL load has been considered. the input and the output voltages have been assumed and the circuit parameters have been calculated using the design equations. The design equations are given below,

A. Zeta Converter Designing Equations:-



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The zeta converter with regard to energy input, it can seen as buck-boost-buck converter and with regard to the output, it can be seen as boost-buck-boost converter.



Fig. 1: Basic Zeta converter circuit

The ideal switch based realization of zeta converter is depicted. A non-isolated zeta converter [2] circuit is shown in the figure 1 above. Although several operating modes are possible for this converter depending on inductance value, load resistance and operating frequency, Zeta converter exhibits two different modes as follows:

Mode1: The first mode is obtained when the switch is ON (closed) and instantaneously, the diode D is OFF. An equivalent circuit shown in Figure 2.



Fig. 2: Mode 1 of operation Fig.2: Mode 1 equivalent circuit

During this period, the current through the inductor L1 and L2 are drawn from the voltage source Vs. This mode is the charging mode.

Mode2: The second mode of operation starts when the switch is OFF and the diode D is ON position, the equivalent circuit shown in Figure 3. This stage or mode of operation is known as the discharging mode since all the energy stored in L2 is now transferred to the load R.

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Fig: mode2 of operation Fig.3: Mode 2 equivalent circuit

Maximum allowed ripple is 1% in the input side and Maximum output ripple is 25mV, Assuming 100% efficiency, the duty cycle D, for a ZETA converter operating in CCM is given by

$$D = \frac{V_{out}}{V_{in}} + V_{out}$$
(1)
$$\frac{D}{1-D} = \frac{I_{in}}{I_{out}} = \frac{V_{out}}{V_{in}}$$
(2)

One of the first steps in designing any PWM switching regulator is to decide how much inductor ripple current, $\Delta I_{L(PP)}$, to allow. A value for K between 0.2 and 0.4 of the average input current is taken . A desired ripple current can be calculated as follows

$$\Delta I_{L} = k \times I_{in} = k \times I_{out} \times \frac{D}{1 - D}$$
(3)

In an ideal, with each inductor having the same number of windings on a single core, the coupling forces the ripple current to be split equally between the two coupled inductors. In a real coupled inductor, the inductors do not have equal inductance and the ripple currents will not be exactly equal. Regardless,- for a desired ripple-current value, the inductance required in a coupled inductor is estimated to be half of what would be needed if there were two separate inductors,

$$L_{\text{la min}} = L_{\text{lb min}} = \frac{1}{2} V_{\text{in}} \times \frac{D}{\Delta I_{\text{L}}} \times f_{\text{sw(min)}}$$
(4)

To account for load transients, the coupled inductor's saturation current rating needs to be at least 1.2 times the steady-state peak current in the high-side inductor, as

$$I_{Lla} = I_{out} \times \frac{D}{1-D} + \frac{\Delta I_L}{2}$$
(5)

$$I_{Llb} = I_{out} + \frac{\Delta I_L}{2}$$
(6)

Like a buck converter, the output of a ZETA converter has very low ripple. Equation below computes the component of the output ripple voltage that is due solely to the capac-itance value:

$$\Delta V_{c \text{ out}} = \frac{\Delta I_{\text{Llb}} (\text{at } V_{\text{in}} \text{ max})}{8 \times f_{\text{sw(min)}} \times C_{\text{out}}}$$
(7)

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Equations below compute the component of the output ripple voltage that is due solely to the capacitance value of the respective capacitors

$$\Delta V_{c in} = D_{max} \times \frac{I_{out}}{C_{in\times} f_{sw(min)}}$$
(8)

$$\Delta V_{cc} = \frac{D_{max} \times I_{out}}{C_{cx} f_{sw(min)}}$$
(9)

B. Sepic Converter Designing Equations:-

The SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S, which is typically a transistor such as a MOSFET. MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs. However the working operation of Sepic Converter is similar to a zeta Converter. Figure 4 shows the basic sepic converter circuit diagram.



Fig.4: Basic Sepic Converter Circuit

The amount that the SEPIC converters step up or down the voltage depends primarily on the Duty Cycle and the parasitic elements in the circuit. The output of an ideal SEPIC converter is

$$\frac{D}{1-D} = \frac{V_{\text{out}}}{V_{\text{in}}} \tag{10}$$

However, this does not account for losses due to parasitic elements such as the diode drop V_D . These make the equation:

$$V_{in} \times \frac{D}{1-D} = V_{out} + V_D \tag{11}$$

$$D = V_{out} + V_D / V_{out} + V_D + V_{in}$$
(12)

In theory, the larger the inductors are the better the circuit will operate and reduce the ripple. However, larger inductors are more expensive and have a larger internal resistance. This greater internal resistance will make the converter less efficient. Creating the best converter requires choosing inductors that are just large enough to keep the voltage and current ripple at an acceptable amount.

$$L = \frac{V_{\text{in min}} \times D_{\text{max}}}{\Delta I_{\text{o max}} \times f_{\text{sw(min)}}}$$
(13)

$$\Delta V_{\rm crpl} \leq \frac{D_{\rm max} \times I_{\rm out}}{f_{\rm sw(min)} \times C_{\rm out}}$$
(14)

Using the above equations the Sepic converter can be designed.

C. Z-Source Converter Designing Equations:-

Z-source converters are recent advancement in DC-DC converters which can perform buck and boost operations. These converters offer greater range of DC output voltage, high reliability and reduce in-rush and ripple currents.



Fig. 5: Basic Z-Source Converter Circuit

Figure below is basic Z-Source dc-dc converter structure, which consists of inductors (Lz1 & Lz2) connected in X shape to couple the converter to the dc voltage source, which may be a battery, diode, rectifier or fuel cell. The Z-Source converter can produce a desired dc voltage regardless of dc source voltage. Figure 5 shows the simplified circuit diagram Z source dc-dc converter where diode is replaced by switch S1 & MOSFET switch is replaced by switch S2. The ZSC has two operating modes:

1)Non shoot through mode and

2) Shoot through mode.



Fig. 6: Shoot through Mode of operation

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In shoot-through mode as shown in switch S2 is switched on. In this mode Lz are energized by CZ. By applying Kirchhoff's voltage law voltage across diode (switch S1) comes out to be negative value. Diode becomes reversed biased and hence switch S1 becomes open .The load is meanwhile fed by filter inductor Lo and Co



Fig.7: On-Shoot through Mode of Operation

In non shoot through mode as shown in Figure below switch S2 is off in this mode where Z-source inductor LZ, transfer the stored energies on them to load also the input current is transferred to Z- source capacitor CZ and load. Inductor Lo is energized during this mode. In this mode as diode is forward biased switch S1 is closed.

Output voltage Vo can be derived as

$$\frac{V_{out}}{V_{in}} = \frac{1-D}{1-2D}$$
(15)

Similarly inductor current IL_z can be derived as

$$I_{LZ} = \frac{(D-1)^2 \times V_s}{(1-2D)^2}$$
(16)

From above derivation Z-source inductor L_z can be calculated as

$$L_{Z} = \frac{V_{out} \times D}{\Delta I_{LZ} \times f_{sw}}$$
(17)

Z-Source capacitance

$$C_{Z} = \frac{V_{out} \times D}{\Delta V_{CZ} \times f_{sw}}$$
(18)

Load Inductance

 $L_{o} = \frac{V_{out} \times D}{\Delta I_{Lo} \times f_{sw}}$ (19)

Load capacitance

$$C_{o} = \frac{V_{out} \times D}{\Delta V_{co} \times f_{sw}}$$

(20)

3. Results

The Z-Source, Sepic and Zeta converters have been modeled in matlab/simulink using the values calculated for the input volage of 5-20Volts and the output voltage of 15 volts using the equations from 1 to 20 and the simulation model and the results are given below for each converter separately.

A. Simulation Result for Z-Source Converter



Fig.8: Z-Source Converter RL load



Fig.9: THD waveform for Z-Source Converter

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B. Simulation Result for Sepic Converter:



Fig.10: Sepic Converter with RL load



Fig.11: THD for Sepic Converter

C. Simulation Result for zeta Converter:



Fig.12:Zeta Converter with RL Load

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Fig.13: THD waveforms for zeta converter

The comparison table has been formulated and given below:

Table 1:Comparison of Three Converters

Parameters	Z-Source	Zeta	Sepic
Input Voltage	10 volt	10 volt	10 volt
Inductance	150 µH	150 µH	150 µH
Capacitance	100 µH	100 µH	100 µH
frequency	50kHz	50kHz	50kHz
Output Voltage	13 volt	30 volt	38 volt
THD For	75.21%	56.45%	72.92%
RL load R=50 ohms			

4. Conclusion

In this paper we presented a comparative study of DC-DC converters in SEPIC, Z SOURCE nd ZETA topologies. The description and operation equations of main parameters were presented. The simulations of these three converters were done with RL load. Compared to all the above converters the total harmonic distortion of zeta converters is less. So this converter is suitable for many low power applications such as pumps, low speed electric trucks, electric scooters and so on. The Zeta converter not Journal of Physics: Conference Series

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only reduces the total harmonic distortion and also regulates the output voltage and also improves the power factor at the output side. The proposed converter can be operated between any DC source and the load. The DC source can be a battery, solar or fuel cell.

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