A Novel High Efficiency Zeta Converter for Non-Isolated Buck-Boost Applications

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Abstract— ***This research proposes a unique hybrid Zeta converter with a low duty cycle that is based on an uncoupled inductor. Potential advantages of the converter include constant input current, high efficiency, ease of implementation, and buck and boost operation modes. Because of the constant input current, the converter has a larger voltage gain than a traditional Zeta converter and is suitable for EV and LED applications. Through the use of two separate electronic switches, each with a different duty ratio, the suggested converter may function in three different modes. The performance of the converter is also examined in this work using similar circuits, and analytical waveforms for each operating mode and design process are displayed. For the hybrid Zeta converter, the voltage gain and dynamic modelling are calculated for both the buck and boost operating modes.***

With MATLAB/Simulink, the converter's effectiveness and performance in both working modes are verified.

On the RT-LAB OP-5700, hardware in the loop (HIL) testing is carried out for the converter's two operating modes. With a 36 V input voltage, the suggested converter's max efficiency is 95.2%. The suggested converter has fewer components, is highly efficient, and provides a broad voltage gain at a low duty cycle. Experiments and simulations conducted under various settings have demonstrated the viability of the suggested converter.

Keywords— Hybrid Zeta converter; non-isolated DC-; small signal analysis, DC converter

I. Introduction

As non-renewable energy sources grow scarcer, renewable energy sources are becoming more and more important. Unfortunately, the output voltage level of renewable energy sources like solar, wind, and hydrogen fuel is quite low. Several research projects have tackled this problem by looking at several types of power converters, including buck, boost, and buck-boost. In renewable energy systems, power converters with voltage boost or buck operations dependent on the load ratings are crucial [1-3]. In addition, these converters control the output voltage in addition to a broad variety of input voltages. The selection of component ratings and the effective performance of the converter are influenced by the regulated DC power supply. Therefore, one of the main factors affecting the performance of the converter is component selection. Many non-isolated DC-DC converter topologies have been presented throughout the years; however most power converter researchers have been interested in converter topologies with few components that provide high voltage gain with low duty cycles. There are several varieties of buck-boost converters, including the SEPIC [6], Zeta [5], and CUK [4].

The duty cycle of classic buck-boost converters runs from 0 to 1, with a maximum voltage produced at higher duty cycles and a low output voltage at lower duty cycles. Their voltage gain ratio is $D/(1-D)$. However, the limits of semiconductor devices prevent the adoption of high duty cycle [7]. Additionally, the current and voltage strains on the components are noticeably high because of the converters' simplistic design. and in buck mode, the voltage gain is likewise constrained.

A non-isolated single switch cascaded buck-boost converter was developed, as explained in [8], to address the aforementioned issues. This converter has a large voltage gain, but its step-down voltage gain is inadequate and its output voltage fluctuates.

A transformer-less buck-boost converter with high voltage gain was presented in [9]. The total losses of the converter are sizable due to the extreme current and voltage stress that semiconductor components experience. A high voltage gain four buck-boost converter with a single power switch and common ground was created in [10]. One drawback of this converter is that the duty cycle needs to be less than 0.5.

An alternate single-switch buck-boost converter with a voltage gain twice that of the standard buck-boost converter is detailed in [11]. The main drawbacks of the converter mentioned in [11] are its variable output voltage and its increased component count, which lowers converter efficiency. A KY converter with a quick transient response was given in [12], which is similar to a buck converter with less output voltage ripple and steady output current.

The KY converter voltage gain is neither too high nor too low to give the wide output voltage range, despite the complexity of managing power semiconductor components. In [13], a hybrid Zeta converter with zero voltage switching and active clamping was advised. The Zeta and fly back converters employed an equal number of active switches in order to restrict the total number of components in the converter. In [14], two cascading Zeta converters were employed to lower output voltage ripple. A transformer-less, single-active switch quadratic boost-CUK converter was invented in [15].

Despite having additional parts, the converter has a low voltage stress across the switches and a high voltage gain. The converter has significant losses as a result. In a similar vein, huge conversion ratio buck-boost converters have also been introduced [16–19].

A hybrid non-isolated DC-DC Zeta converter with a greater voltage gain and fewer components was shown in this study. Comparing the proposed converter to conventional buck-boost, SEPIC, CUK, and Zeta converters, it offers a large voltage gain with a minimal duty cycle. Additionally included are the converter design parameters and the suggested voltage gain assessment.

II. Materials and Methods

2.1. The Hybrid Buck-Boost Converter Operating Principle

Based on the Zeta topology, the circuit includes, as seen in Figure 1, two active power switches which are (S1 and S2), two diodes as (D1 and D2), two inductors which are (L1 and L2), two capacitors as (C1 and C0), and a load R0 as shows follows. The converter analysis has been simplified by making the following assumptions.

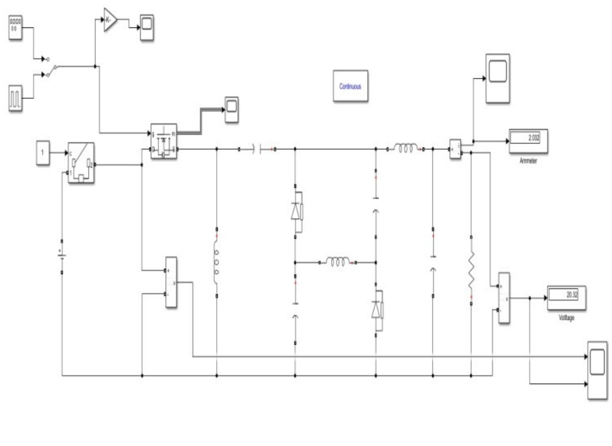

Figure 1. Proposed hybrid Zeta converter

A. Every semiconductor device, including diodes and MOSFETs, is regarded as perfect.

B. C1 and C2, two large enough capacitors, can keep the voltage steady.

Based on the status of the switches when they are switched ON and OFF, the converter can operate in three different modes, as seen in Figure 2. The corresponding circuits for each operating mode are shown in Figure 3.

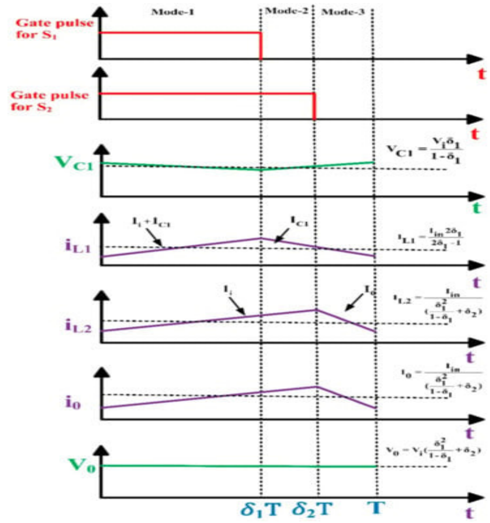

Figure 2. The proposed system converter’s waveforms for one switching interval.

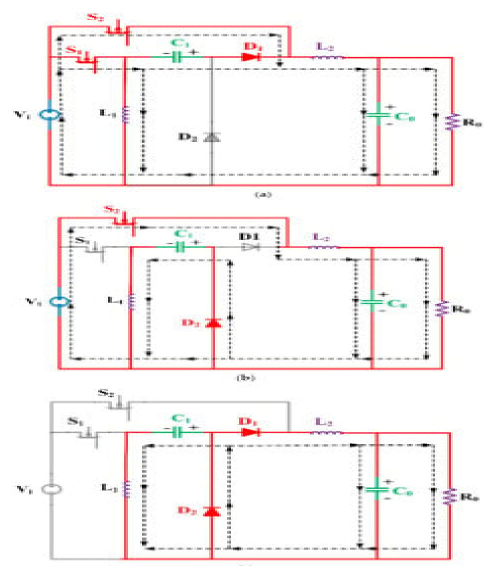

Figure 3. The proposed system of hybrid Zeta converter equivalent circuits. (**a**) Mode-1 (**b**) Mode-2 (**c**) Mode-3.

I. Mode-1 (0 < t < δ1T): When as shows Switch S1 and S2 are in this mode, in which the voltage across Inductor L1 is equal to Vi since Vi is in parallel with the inductor. As seen in Figure 3a, similarly L1 is charged through the Vi, L2 is charged through Vi + VC1, and capacitor C1 is discharged by L2 + V0. Consequently, the following formulas may be derived:

$$VL1 = Vi \quad (1)$$

$$VL2 = Vi + VC1 - V0 \quad (2)$$

II. Mode 2 (δ1T < t < δ2T): In this mode, switch S2 is switched ON while switch S1 is turned OFF. As shown in Figure 3b, L1 is discharged by VC1, L2 is charged through

Vi, and capacitor C1 is charged through L1. One way to calculate the inductor voltages is as,

$$VL1=-VC1VL1=-VC1 \quad (3)$$

$$VL2=Vi-V0VL2=Vi-V0 \quad (4)$$

III Mode-3 ($\delta_2 T < t < T$): Two switches are off in this mode. As shown in Figure 3c, capacitor C1 is charged via L1, L1 is discharged through VC1, and L2 is discharged through V0. One way to calculate the inductor voltages is as,

$$VL1=-VC1VL1=-VC1 \quad (5)$$

$$VL2=-V0VL2=-V0 \quad (6)$$

III. Results

The suggested converter was put to the test using both experimental and simulated techniques. The analytical data were evaluated using the OPAL-RT 5700 HIL setup. The simulation and HIL findings of the hybrid zeta converter in step-up and step-down operating modes are shown in this section. The converter was originally simulated using MATLAB/Simulink software to assess its capabilities. The parts that were used in both simulation and HIL mode are displayed in Table 2. Equations (20)–(23) have been used to select the values of the inductor and capacitor. Figure 4. Show this converter's simulated output voltage waveform

Figure 4 – output1

Figure 5 – output2

Figure5- show this converter's simulated output current waveform

The step-up mode is set to 72 V from 36 V, with a duty cycle of 79% for switch S2 and 65% for switch S1. The theoretical value derived from Equation (10), which is 72 V, is nearly identical to the simulated value that was achieved. Equation (V0/R0) yields the theoretical output current of the proposed converter at a load of 30 Ω, which is 2.5 A. Figure 5 shows the simulated output current, which is 2.4 A. The inductor L1 is connected in parallel to the input source for the time interval δ1T, and during this period, the current flowing through it reaches its maximum value of 6.4 A.

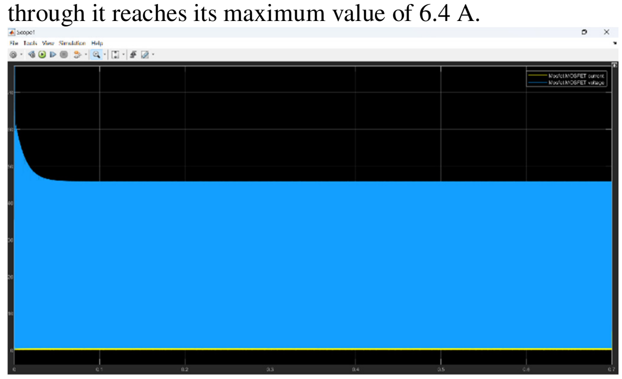

Figure 6 – output3

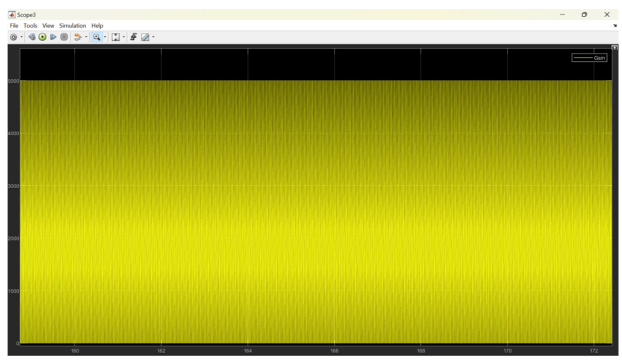

Figure 7 – output4

Figure 6. Show this converter's simulated output mosfet current and mosfet voltage,Figure 7. show this converter simulated waveforms of frequency

The inductor is then linked in parallel to the capacitor C1 for the remaining duration. After decreasing linearly, the current through the inductor approaches 3.1 A, which is its lowest value.

CONCLUSION

This research presented a non-isolated hybrid Zeta converter. High voltage gain is achieved by the suggested converter without the need of an isolated transformer or connected inductor. In addition, the converter is small in size and produces a high output voltage in both step-up and step-down operation modes with a low duty cycle. The performance analysis of the converter in step-up and step-down modes has been described in the CCM mode. There was discussion of the design process, tiny signal modeling, converter analysis, and schematic depiction. A comparison with various non-isolated DC-DC switch-mode converters was done in order to ascertain the performance characteristics of the suggested hybrid Zeta converter. To establish the stability of the suggested converter, a detailed description of its dynamic modeling was provided. Furthermore, the suggested converter's performance was confirmed through the use of the HIL testing experimental approach and the MATLAB/Simulink software.

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