

Performance Analysis of Isolated Zeta Converter Used for 2-Wheeler EV Charger

Saurabh Shukla^{1*}, Mahendra P. Prajapati¹, Vinay Singh²

Abstract

Electric vehicles (EVs), particularly two-wheelers, are gaining traction as sustainable urban mobility solutions. However, the lack of quick and easy charging infrastructure makes it difficult for them to be widely adopted. It's no surprise that the electric vehicle (EV) market is expanding very quickly. With the many benefits of EVs, such as lower emissions, reduced fuel costs, and quieter operation, they are becoming an increasingly attractive option for environmentally conscious consumers. The need for effective charging infrastructure systems to charge EVs more quickly is growing globally as more EVs are put on the road. Thankfully, there are various types of chargers being developed for EVs, including off-board chargers, onboard chargers (OBC), and various DC-to-DC converter architectures. Of all the components that make up an EV, the battery is the most critical, as it supplies energy to the entire system. With advancements in battery technology, an EV can now charge faster, which not only extends the battery's service life and lifespan but also paves the way for a cleaner, more sustainable future. This project focuses on developing a quick charging solution using a Zeta Converter-based DC–DC charger for two-wheeler EVs. Because of their great efficiency, minimal output voltage ripple, and suitability for applications needing high power density and low noise, zeta converters are recommended. A fourth-request DC converter is cognized as the Zeta Converter known for giving voltage move-forward and step-down capacities, which can fundamentally upgrade the presentation for ideal similarity with the EV battery framework. Through this joining, the research seeks to achieve a lower ripple at the Output in an isolated zeta converter. This research evaluates the performance and reliability of isolated Zeta Converter chargers to meet the growing demands of modern EV technology.

Keywords: Electric vehicles (EVs), sustainable transportation, two-wheeler EVs, urban mobility, rapid charging infrastructure, convenient charging, quick charger, DC–DC converter, Zeta converter, isolated Zeta converter, performance

INTRODUCTION TO ISOLATED ZETA CONVERTER

A fourth-request DC converter is fathomed as the Zeta Converter known for giving voltage move-forward and step-down capacities, which can fundamentally upgrade the presentation for ideal similarity with the EV battery framework. Through this joining, the research seeks to achieve a lower ripple at the Output in an isolated zeta converter. A DC voltage can be changed from one level to another using the DC–DC converter, an electromechanical device or circuitry, depending on the needs of the circuit. A member of the electric power converter family, the DC–DC converter can be used for both low voltage applications, like batteries, and high voltage applications, like HV power transmission. To achieve a controlled DC Output voltage, which would otherwise require numerous battery sources, switched DC–DC

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converters help to increase the voltage from a low battery voltage.

The ZETA converter topology produces a positive output value from an input voltage that fluctuates above and below the output voltage, much like the SEPIC DC/DC converter topology. Two inductors and a series capacitor – sometimes known as flying capacitors, are also required for the ZETA converter. The ZETA converter is set up from a buck controller that drives a high-side PMOSFET, in contrast to the SEPIC converter, which is set up with a conventional boost converter. The ripple current in buck-boost, buck, and Zeta converters is higher compared to that in Ćuk and SEPIC converters [1]. The power factor will also improve using single stage zeta converter circuit for different power applications like white LED [2]. The Zeta converter functions on a similar principle as the buck-boost converter, operating through two distinct states within a single switching cycle [3, 4]. Another choice for controlling an uncontrolled input-power source, such as an inexpensive wall wart, is the ZETA converter. It is possible to employ a linked inductor to reduce board space [5].

The isolated Zeta converter is a type of DC–DC converter used to adjust voltage levels efficiently. This converter combines the features of a traditional buck-boost converter and the Zeta converter, providing step-up and step-down capabilities in one circuit. A non-inverted output is possible because the inductor is connected in series with the input and output is necessary for all non-conventional energy systems, and the power electronic converter is the core component of the entire system. Zeta converters, like other DC-to-DC converters, produce a controlled output. Isolated Zeta converters contain a transformer that delivers electrical isolation flanked by Input and Output. These converters are used in applications that require galvanic isolation, such as power supplies for sensitive electronics or renewable energy systems. They offer advantages, such as high efficiency, smaller size and weight, and improved transient response compared to other isolated converter topologies. The Zeta converter can either provide electrical isolation or not depending on whether it is isolated or non-isolated. Non-isolated Zeta converters lack electrical isolation, making them suitable for low-voltage power supplies in consumer electronics or automotive applications. Conversely, isolated Zeta converters provide electrical isolation between the input and output by means of a transformer. This allows for different Input and Output voltages while still providing a galvanic barrier. These converters are commonly used in industrial power supplies, medical devices, or telecommunications equipment where electrical isolation is necessary.

Based on how the inductor current behaves, Power Factor Correction (PFC) converters can be classified into three operating modes: Continuous Conduction Mode (CCM), Discontinuous Conduction Mode (DCM), and Boundary Conduction Mode (BCM).

For high-power applications, converters are typically designed to operate in CCM due to their advantage of lower RMS (Root Mean Square) current flowing through both the device and the inductor. This characteristic significantly mitigates electromagnetic interference (EMI) concerns.

Conversely, DCM is often selected for low-power applications, as it accommodates higher peak currents. However, this mode requires more sophisticated EMI filtering solutions to effectively manage the increased interference [6].

DC–DC converters are used in various applications, such as hybrid electric vehicles, regenerative braking systems for DC motors, trolley buses, forklift trucks, and Uninterruptible Power Supply (UPS) systems [7].

WHY WE NEED ISOLATION FOR DC–DC CONVERTERS

Performance Centric

Power converters are essential tools in electrical engineering because they can transform electrical energy into a variety of forms. Isolation of these converters is essential for optimal performance, safety of equipment and users, and easy integration into various applications.

Safety Precautions

Isolation acts as a safety barrier, preventing hazardous voltage levels from reaching sensitive components or unintended paths. This safeguards users from electric shocks and minimizes the risk of electrical fires, upholding stringent safety standards across various industries. In consumer electronics and industrial machinery, the incorporation of isolation mechanisms is indispensable for safeguarding personnel and property.

Open Loop isolated Zeta converter with bridge rectifier (Figure 1) to meet the required power conversion and minimize harmonic and power factor issues, a variety of AC–DC converter types have been introduced. Ćuk, SEPIC, and Zeta converters are advanced topologies that combine both step-down (buck) and step-up (boost) characteristics, like the conventional buck-boost converter [5, 8, 9].

These include, among others, the zeta converter, the Cuk converter, the Sepic converter, and the combined boost with double winding flyback converter. When an isolated transformer is added, one of those, the zeta converter, which was initially the buck-boost type, might be considered a flyback type. Among the benefits of an isolated zeta converter are output side safety and output adjustment flexibility [10].

The DC–DC converters with high gain have been studied in a lot of papers. This converter has the advantage of high static gain, the low current ripple at the output, in addition to the possibility to have a lift or lowering on output tension depending on the duty cyclic value applied to the converter [11].

The Open-Loop Isolated Zeta Converter (OLIZC) is a crucial topology used in power electronics systems, such as renewable energy and electric vehicle charging stations. It is a DC–DC converter that offers galvanic isolation between Input and Output while maintaining the advantages of the Zeta converter. The OLIZC consists of an inductor, a capacitor, and a transformer with specific winding arrangements for isolation. It can function in either continuous or discontinuous conduction mode (CCM or DCM), depending on the duty cycle of the switches.

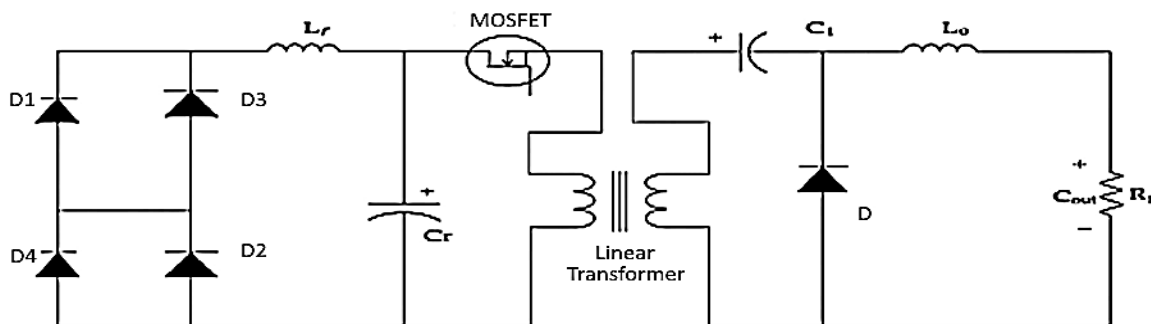


Figure 1. Open loop isolated zeta converter with bridge rectifier.

The Open Loop Isolated Zeta converter offers excellent voltage regulation capabilities and high efficiency due to reduced switching losses and optimized component utilization. In addition, the converter ensures galvanic isolation, thereby enhancing operational safety. As illustrated in Figure 3, the corresponding waveform clearly demonstrates that this configuration provides a stable and reliable output. Because of its quick transient reaction, it can be used in applications with different load circumstances. Various control strategies, such as voltage mode and current-mode control, can be implemented to regulate Output voltage and current.

Open Loop Isolated Zeta converters are commonly used in photovoltaic systems, wind energy converters, energy storage systems, electric vehicle charging stations, industrial power supplies, telecommunications, and aerospace and *defence* due to their compact size, efficiency, and reliability. Understanding the operational principles, advantages, and applications of OLIZC is crucial for engineers and researchers to harness its potential in diverse power electronics applications. Moreover, Figure 2 shows the MATLAB simulation of open loop isolated zeta converter with bridge rectifier.

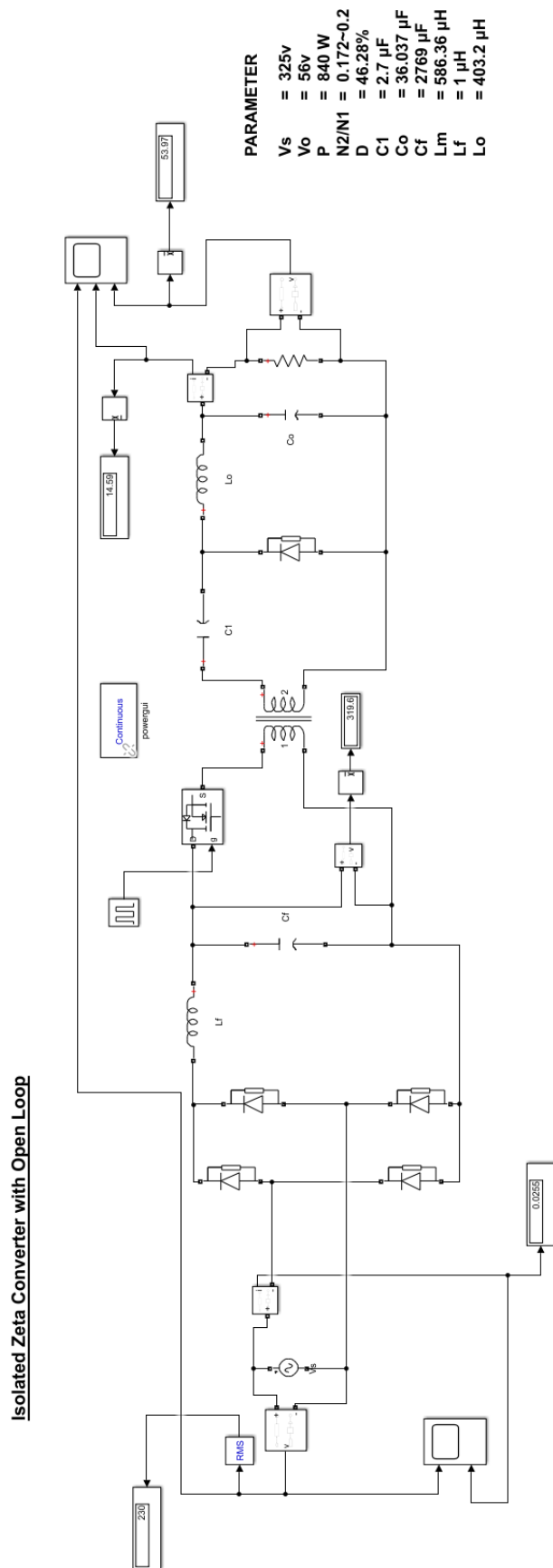


Figure 2. MATLAB simulation of open loop isolated zeta converter with bridge rectifier.

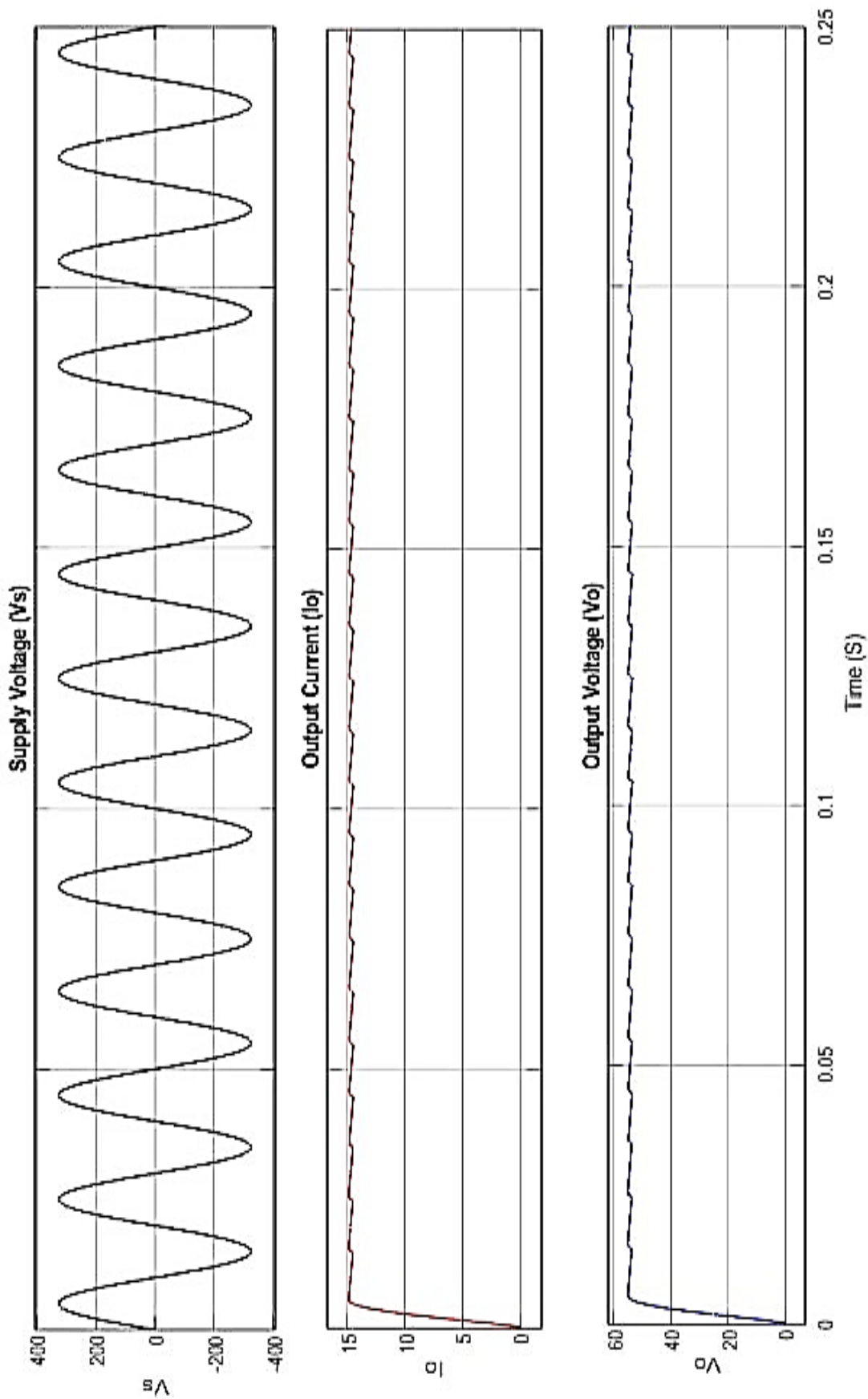


Figure 3. Waveform of open loop Isolated zeta converter with bridge rectifier.

A full-bridge converter is typically employed for high power and voltage applications, often in the range of several kilowatts. Its key advantage is that the voltage stress experienced by the power switches is restricted to the level of the input supply voltage [12, 13].

The following presumptions underline the analysis (Table 1). Results of the optimal operation of semiconductor switching devices are assumed, and the line-frequency ripple in the DC voltage is ignored [14].

Table 1. Isolated Zeta Converter with Open Loop.

Parameters	Values
(Vin)	325 V
(Vo)	56 V
(Io)	15 A
Switching Frequency (FSW)	50 kHz
O/p Power (Po)	840 W
Resistance (R)	3.7 Ω
Turn ratio (n)	0.2
Magnetizing Inductance (LM)	586.36μH
Duty Cycle (D)	46.28%
Resistance (R)	3.7 Ω
Intermediate capacitor (C1)	2.7 μF
O/p capacitor (Cout)	36.037 μF
O/p Inductor (L0)	403.2 μH

Calculation for Isolated Zeta Converter with Open Loop [10, 15, 16]

- Duty Cycle:

$$D = \frac{V_o}{nV_m + V_o} = \frac{56}{(0.2 \cdot 325) + 56} = 0.46280 = 46.28\%$$

- Magnetising Inductance:

$$L_m = \frac{R_s (1-D)^2}{2 \cdot D \cdot f_{sw} \cdot n^2} = \frac{3.7(1-0.46)^2}{2 \cdot 0.46 \cdot 50000 \cdot (0.2)^2} = 586.36 \mu H$$

- Intermediate Capacitor:

$$C_1 = \frac{V_o D}{\Delta V_{C_1} \cdot f_s \cdot R_s} = \frac{56 \cdot 0.46}{0.1 \cdot (\sqrt{2}V_m + V_o) \cdot f_{sw} \cdot R_s} = 2.7 \mu F$$

- Output Inductor:

$$L_o = \frac{V_o(1-D)}{f_s \cdot \Delta I_o} = \frac{V_o(1-D)}{f_s \cdot 1.5} = \frac{56(1-0.46)}{50000 \cdot 1.5} = 403.2 \mu H$$

- Filter Inductor:

$$L_f = \frac{1}{4 \cdot \pi^2 \cdot f_{sw}^2 \cdot C_f} = 0.359 \mu H \approx 1 \mu H$$

- Output Capacitor

$$C_o = \frac{1}{8} \cdot \frac{D}{1-D} \cdot \frac{V_m(1-D)^2}{f_s \cdot \Delta V_o} = \frac{1}{8} \left(\frac{0.46}{1-0.46} \right) \frac{325(1-0.46)^2}{50000 \cdot 0.1 \cdot 5.6} = 36.037 \mu F$$

ISOLATED ZETA CONVERTER IN CLOSED LOOP WITH BRIDGE RECTIFIER

The Closed-Loop Isolated Zeta Converter with PI Controller (Figure 4) is an innovative power conversion system that combines the advantages of the traditional Buck-Boost converter topology with precise control provided by Proportional-Integral (PI) controllers. This system enhances the converter's performance by providing robust regulation despite changes in Input voltage, load, or other external factors.

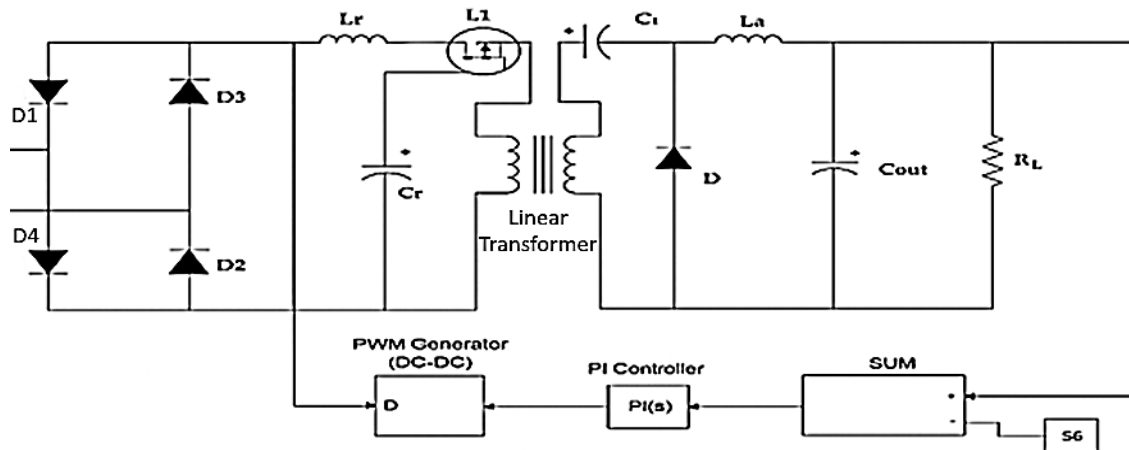


Figure 4. Circuit diagram of closed loop of Isolated zeta converter with bridge rectifier using PI Controller.

The Closed-Loop Isolated Zeta Converter with PI Controller (Figure 5) is a device that integrates into the Zeta converter's control loop. It makes possible to precisely control the output voltage even in the presence of variations in the input voltage, load, or other outside variables. The PI controller dynamically adjusts the duty cycle based on feedback, optimizing the converter's operation and minimizing energy losses to maximize efficiency. The closed-loop configuration enhances the converter's robustness against disturbances and parameter variations, making it appropriate for a wider range of applications. Table 2 shows the analytical results of the simulation. Additionally, Figure 6 shows the waveform of closed loop of Isolated zeta converter with bridge rectifier with only voltage controller. Moreover, The corresponding control circuit and output waveforms are illustrated in Figure 7 and Figure 8, respectively.

Table 2. MATLAB Simulation of Closed Loop Isolated Zeta Converter with Bridge Rectifier.

Parameters	Values
(Vin)	325 V
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(Io)	15 A
Switching Frequency (FSW)	50 kHz
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Intermediate capacitor (C1)	2.7 μF
O/p capacitor (Cout)	36.037 μF
O/p Inductor (L0)	403.2 μH

Only with Voltage Controller

Figures 1 and 2 show the closed-loop isolated Zeta converter with bridge rectifier, controlled by voltage and current controllers, illustrating the simulation setup and corresponding waveform response under dual-controller operation.

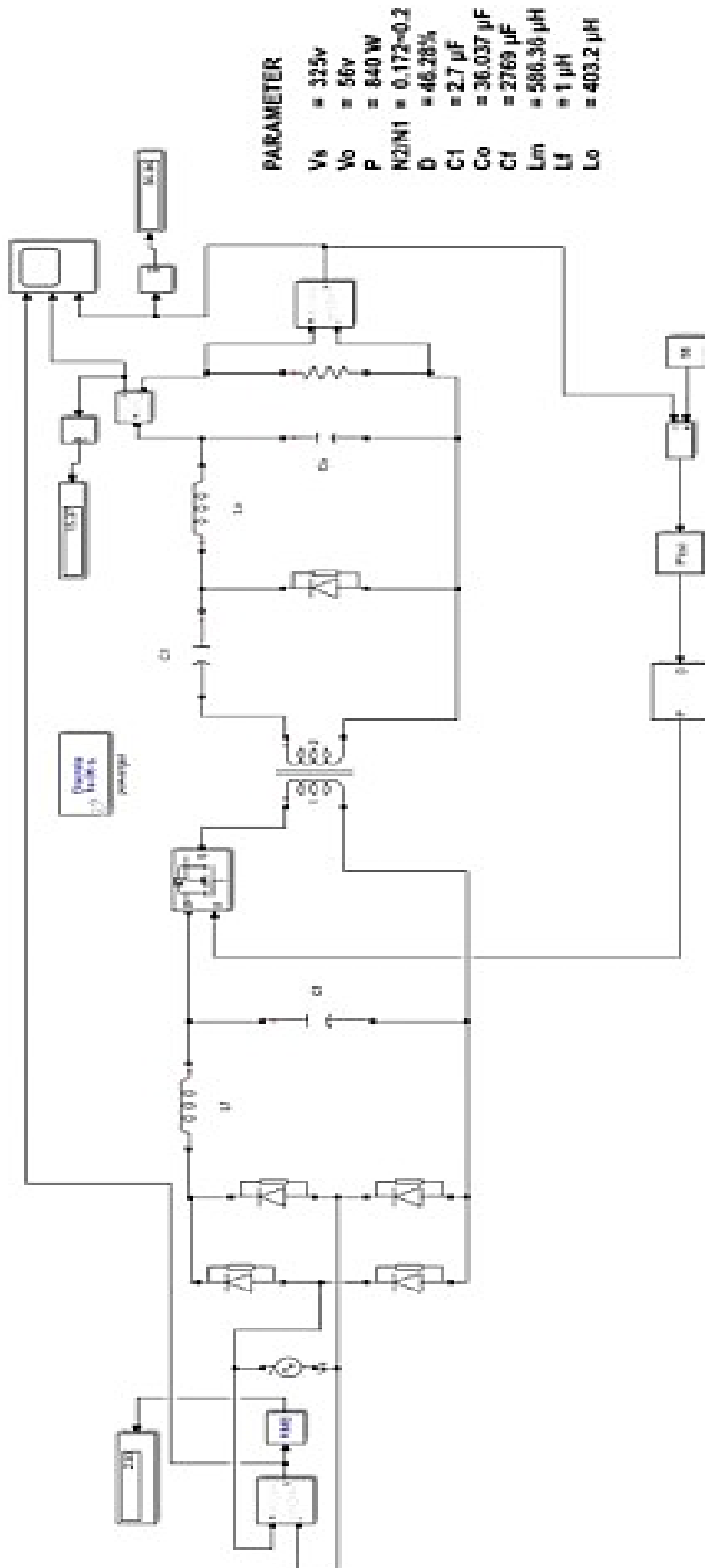


Figure 5. Simulation of closed loop of Isolated zeta converter with bridge rectifier with only voltage controller.

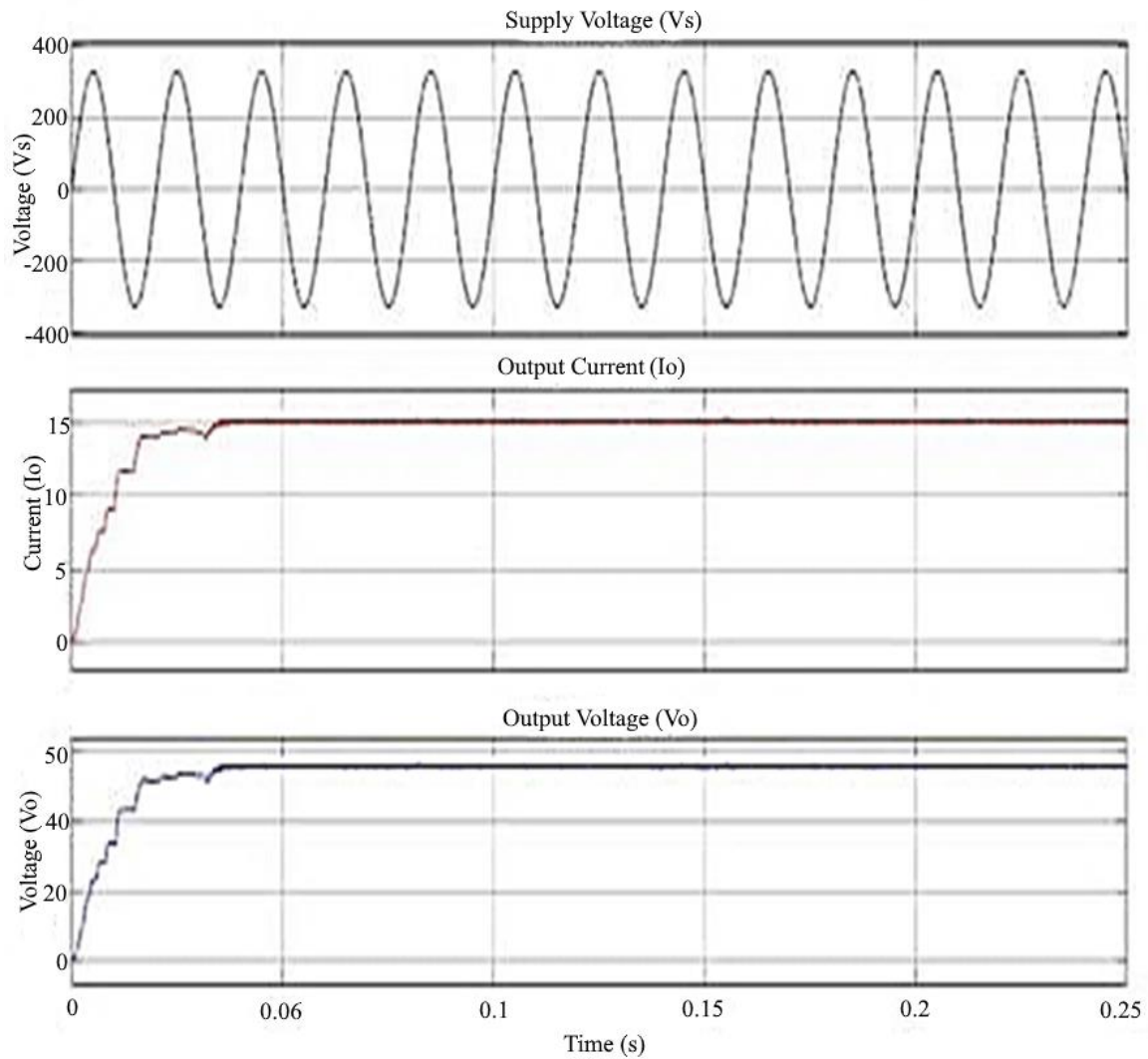


Figure 6. Waveform of closed loop of Isolated zeta converter with bridge rectifier with only voltage controller.

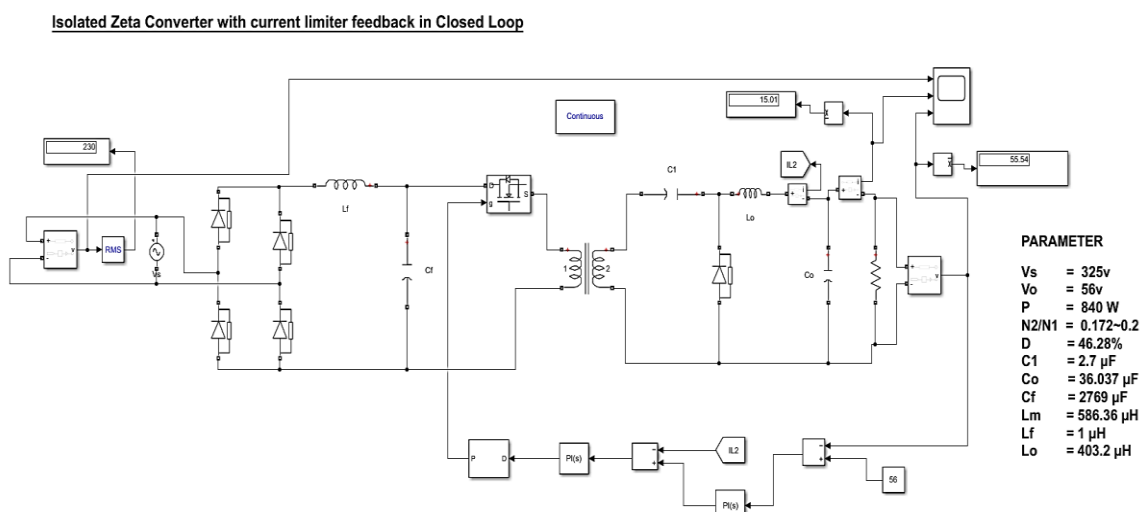


Figure 7. Simulation of closed loop of Isolated zeta converter with bridge rectifier with both voltage and current controller.

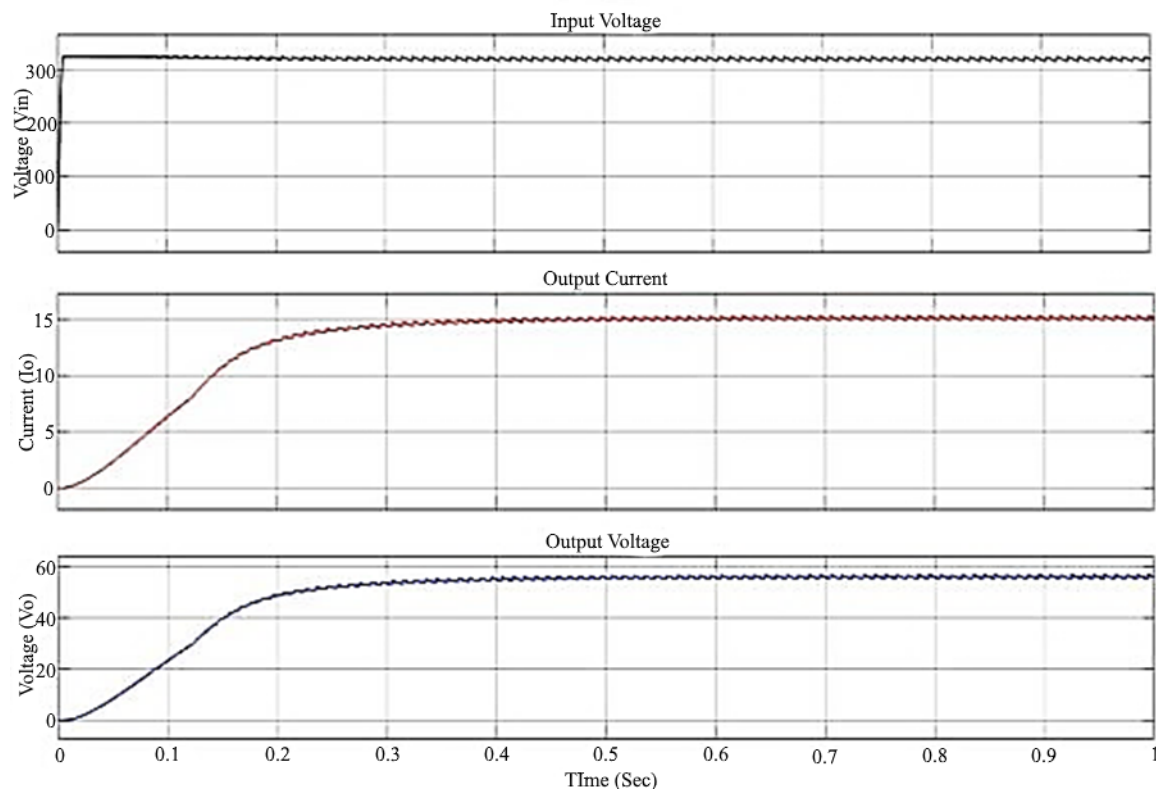


Figure 8. Waveform of closed loop of isolated Zeta converter with bridge rectifier with both voltage and current controller.

CONCLUSIONS

A simulation model was employed to assess the performance of the isolated Zeta converter using a rectifier source to maintain an Output voltage of around 56V and an Output current of 15A across the resistive load using closed-loop control. Additionally, a simulation model was devised for a closed-loop isolated Zeta converter circuit, including an isolated current and voltage controller feedback. Finally, the closed-loop isolated Zeta converter result was evident, and the simulation indicated that the topology was in operational condition.

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