ISSN 2063-5346

BI-DIRECTIONAL DC-DC POWER FLOW USING ZETA CONVERTER

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Article History: Received: 12.05.2023 **Revised:** 25.05.2023 **Accepted:** 05.06.2023

Abstract

The bidirectional converters are used to transfer energy between two DC sources and the power can flow between input and output sides depending upon the requirements of users. Depending upon the flow of power in either direction, the bidirectional converters operate in buck and boost mode. The step-up and step-down of voltage levels are possible with these types of converters. The energy storage is utilized for an effective and efficient transfer of energy flow between source and load sides. The bidirectional converter finds its applications

in energy storage systems, electric vehicle batteries, and renewable energy systems. The proposed converter provides various benefits like lower switching loss and lower total harmonic distortion value. The proposed converter also provides other benefits like a lower value of conduction loss, low value of EMI and less stress across switches. The validity and viability of proposed converter have been tested in a simulation environment. The simulation results are also validated with the help of an experimental prototype.

Keywords- Power electronic converter, dc-dc converter, bidirectional, zeta converter, power flow.

1. Introduction

Electronic devices called power electronic converters can transform electrical power from one form to another. They control voltage and current levels, regulate the flow of electrical energy, and convert power between various voltage and frequency levels, making them crucial parts of modern power systems. There is a wide range of applications, including electric vehicles, industrial drives, consumer electronics, renewable energy systems where power electronic converters are employed. The development of power electronic converters has been fueled by advances in semiconductor technology, which led to the creation of high-power, high-voltage devices capable of switching at high frequencies. These parts, including MOSFETs, IGBTs, and thyristors, act as switching elements in power electronic converters. There are many topologies available for power electronic converters and these topologies convert the nature of voltage source. The bidirectional transmission of energy between two DC voltage sources with different voltage levels is made possible by a power electronic circuit known as a bidirectional DC-DC converter. These converters find applications in many applications like electric vehicles, renewable energy sources, storage systems etc. Each topology has unique characteristics and advantages. Overall, because they provide dependable and effective power conversion and control for a variety of applications, power electronic converters are essential components of modern power systems. The converter's ability to function in both buck and boost modes allow it to transmit power in either direction.

In recent years, the demand for DC-DC converters which operates in both directions has significantly enhanced. These sources of energy generate DC power, which must be converted into AC power before being integrated into the grid. These types of converters are very crucial for energy conversion and it provides an efficient way of transfer of energy between utility grid and source. The output voltage and current of the power electronic converter are controlled by varying the duty cycle of switches used in the power circuit and this variation in duty cycle is possible with the help of control circuit. Energy transfer in both directions is the primary objective of these types of converters, but it also has other benefits like power conditioning, voltage management, and fault protection. A Zeta converter is a kind of power electronic circuit that uses the Zeta architecture to enable energy transfer in forward and reverse directions between two DC voltage sources and this transfer is possible at different levels of voltage. The Zeta topology combines the Buck and Boost topologies with a single inductor to produce voltage gain and reduction. The converter can operate in buck and boost modes, transferring power in either direction. A Zeta converter typically comprises two power switches, an inductor, and a control circuit. Power electronics have replaced conventional systems in many applications and transformed many aspects of modern power systems. The proposed topology eliminates various drawbacks of isolated DC-DC converters.

2. Proposed Zeta Converter

Figure 1 as shown below shows the schematics of the proposed converter. It comprises two voltage sources connected as shown in the figure one on input side rated as 12V and another on output side rated as 24V.

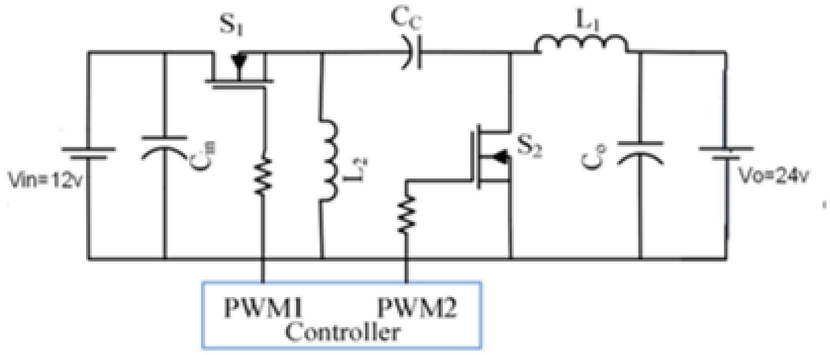

Fig. 1- Schematics of proposed converter.

With the help of two bidirectional switches S_1 and S_2 and by controlling the turning ON and turning OFF of switches S_1 and S_2, power is made to flow between input and output sides. There are two inductors (L_1 and L_2) and a capacitor (C_c) between the source and load sides. This kind of configuration results in the creation of a buck-boost topology called a Zeta topology, which can offer voltage step-up and step-down functionality in both directions.

During Operation Mode-1 Forward Operation (Charging operation):

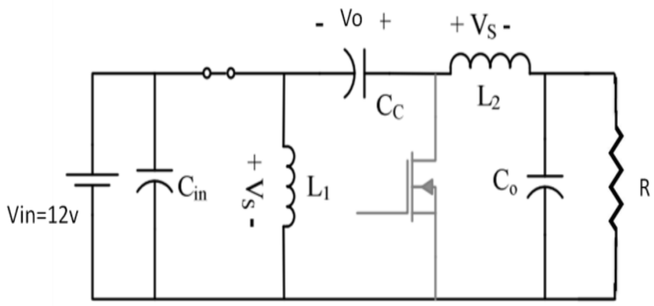

Fig. 2- Schematic of proposed converter during operation in mode-1 (Forward Operation)

When S_1 is ON and S_2 is OFF, the energy is stored in inductor L_1 and this energy is supplied from source voltage, while energy is stored in L_2 from source voltage and capacitor (C_c). Due to the linear growth of I_{L1} and I_{L2}, the capacitor (C_c) charging to V_{batt}, and the C_C being connected in series with L_2, the voltage across L_2 is V_S. The operational modes of the Zeta converter are shown in Figs. 2 and 3. Using KVL, the voltage across L_1 and L_2 in the circuit shown in Fig. 4 is stated as follows:

$$L1\frac{dL1}{dt} = Vs \quad (1)$$

$$L2\frac{dL2}{dt} = Vs \quad (2)$$

During Operating Mode-2 Reverse Operation (Discharging operation):

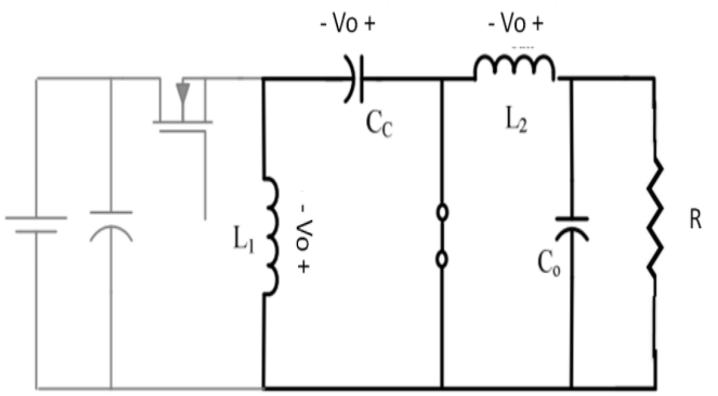

Fig. 3- Schematic of proposed converter during operation in mode-2 (Reverse Operation)

Inductors L_1 and L_2 discharge through switch S_2 during turning ON of switch S_2 and turning OFF of switch S_1. As a capacitor (C_C) charged to voltage V_{batt}, inductor L_2 comes in parallel with the battery. The following gives a description of the voltage between L_1 and L_2.

$$L1\frac{dL1}{dt} = -Vo \quad (3)$$

$$L2\frac{dL2}{dt} = -Vo \quad (4)$$

Average output voltage

$$Vo = Vs(\frac{D}{1-D}) \quad (5)$$

where D represents duty period of S_1

3. Simulation Results

The proposed converter is built in a simulation environment using the design equations (1) to (5) to test the Zeta converter's charging procedure. Below given are some of the MATLAB simulation of the converter which shows is shown in Fig.-4, which is simulation for mode-1 operation and in Fig.-5 which shows simulation in mode-2 operation with their output waveforms discussed below.

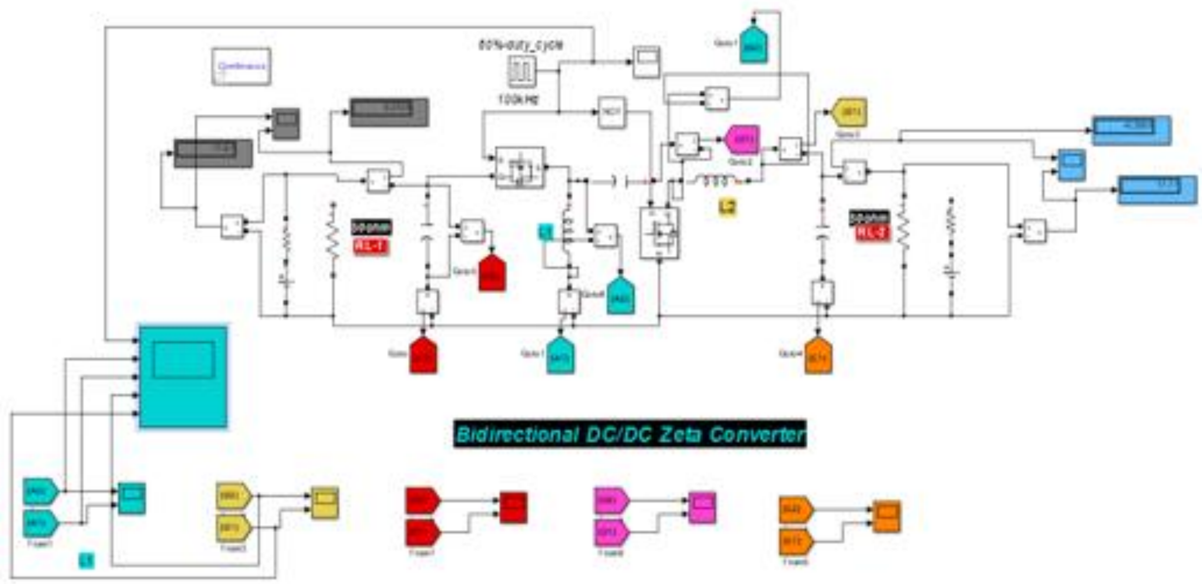

Fig. 4- MATLAB Simulation of zeta converter during operation in mode-1

To test the Zeta converter's charging procedure the charging method's simulation as shown in Fig.-5, simulation results are showcased in Fig. 6. S_1 & S_2 duty cycles are switched by the Zeta DC-DC converter. In Fig. 6, the characteristics of inductor voltage and inductor current are also displayed. The switching frequency for S1 in this experiment is set to 2500 Hz. The battery charging current is carried by an input capacitor (C_{in}) with a minimum value of 100µF, and 3mH inductors are also used and they are utilized for maintaining continuous conduction. The simulation result of the characteristic shown in Fig. 6 proves the point that the charge current varies by 1A from peak to peak.

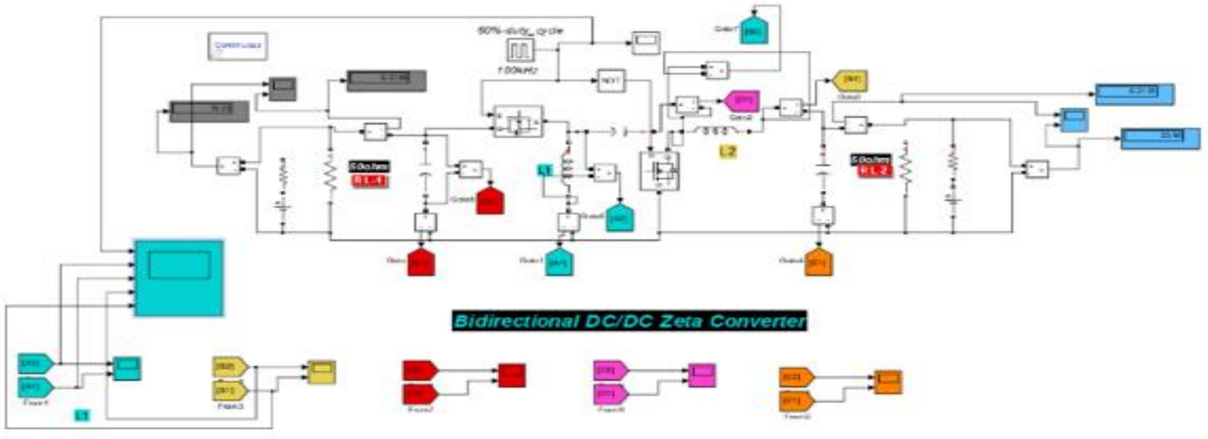

Fig. 5- MATLAB Simulation of zeta converter during operation in mode-2

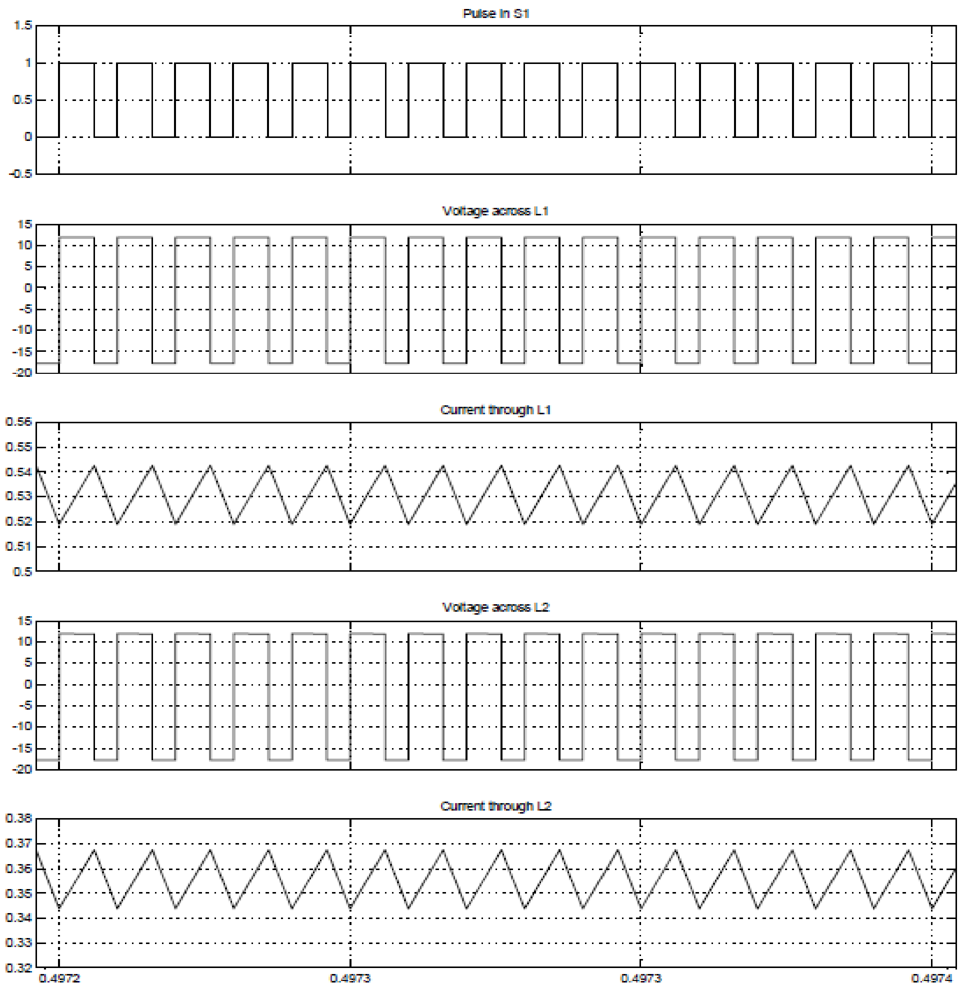

Fig. 6- Switching pulses to S_1, voltage across L_1 and L_2, current through L_1 and L_2 during forward operation (charging method)

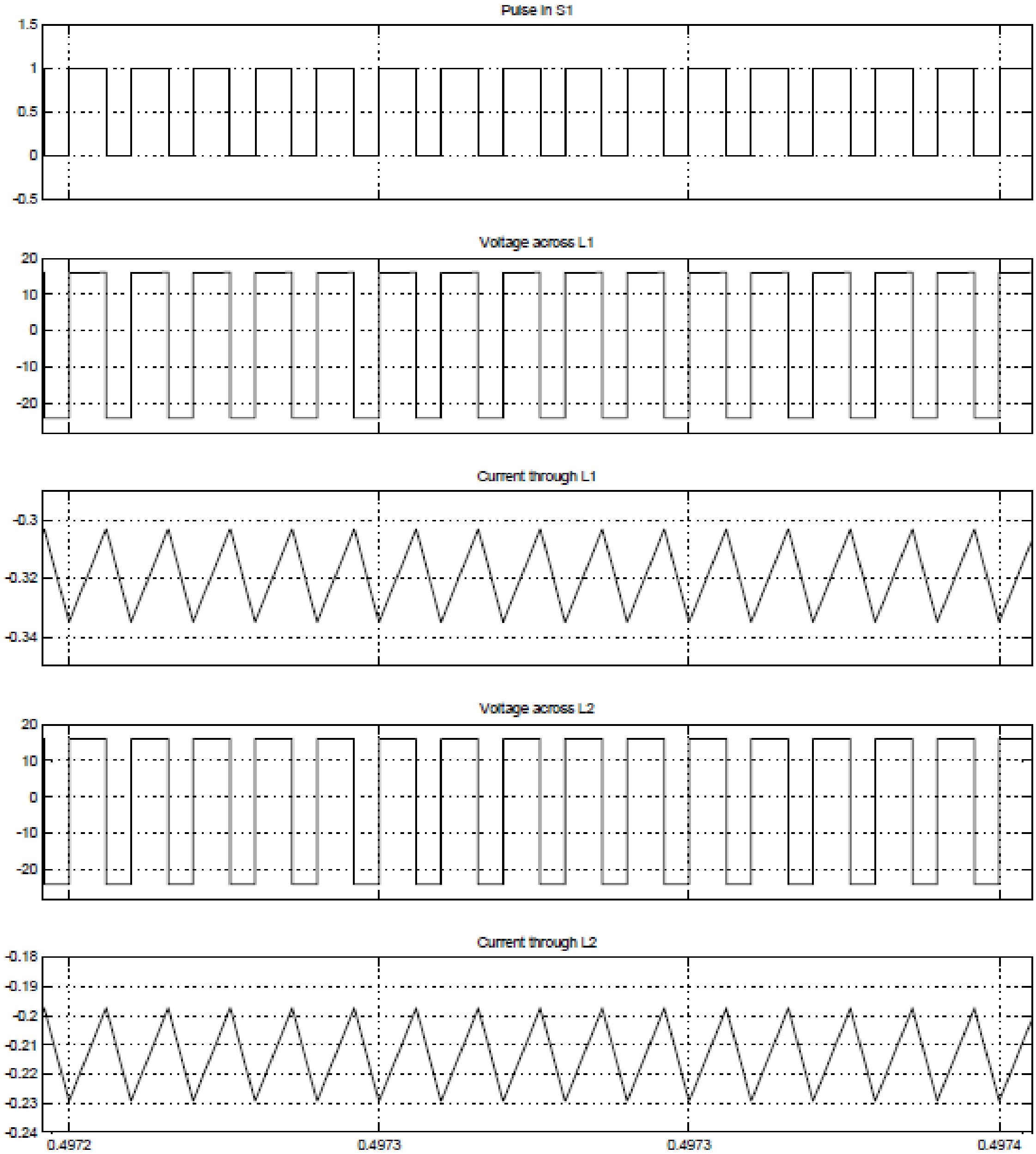

Fig. 7- Switching pulses to S_1, voltage across L_1 and L_2, inductor current through L_1 and L_2 during reverse operation (discharging method)

The discharging method's simulation is illustrated in the Fig-5 and its results are exhibited in Fig.-7. Inductor (L_1&L_2) voltage and current characteristics, and duty cycles of Zeta converter switches S_1 & S_2, are displayed in Fig. 7. A 12-volt input, 24-volt output, MOSFET, current sensor, and bidirectional DC-DC Zeta converter have all been developed. A bidirectional dc-dc converter is created that can function or transfer power on both sides, in the first operation (from load to source, or from 12V to 24V), and in the second operation (from source to load, or from 24V to 12V). The circuit includes a MOSFET for switching purposes and a current sensor to record the amount of current flowing through the circuit.

4. Experimental Prototype

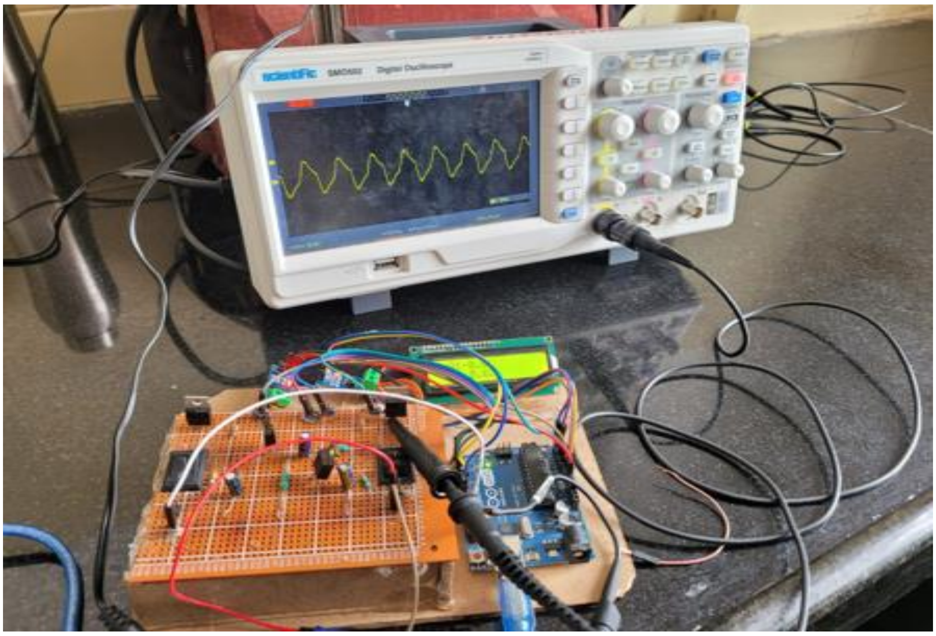

Fig.6 -Experimental hardware prototype of proposed Zeta converter

Depending on a MATLAB simulation which is shown in above figure that is Fig.4 and Fig. 5, a hardware prototype of a bi-directional DC-DC converter was successfully constructed which is shown in Fig. 6. With this converter, electrical energy can be seamlessly transferred between two separate DC power sources one with 12-volts and the other with 24-volts. By transforming the input voltage from one source into the desired output voltage for the other source, the proposed converter works. The performance characteristics of converter were thoroughly examined and optimised which is similar to the MATLAB simulation. The development of effective energy transfer systems has advanced significantly with the successful construction of the hardware prototype. Converter's performance under standard desired conditions with testing and validation will be carried out and the results are discussed below.

Fig.7- Output Waveform of hardware (Across the inductor L_1)

To evaluate the performance of the Zeta converter during hardware testing, a thorough comparison with the MATLAB simulation was conducted. The waveform of the inductor current was one important aspect that was looked at. Surprisingly, it was found that the hardware prototype's inductor current waveform displayed the same traits as those predicted in a simulation environment. It was found that the operation of proposed Zeta converter in the hardware prototype closely resembled the simulated behaviour by comparing the hardware test results with the results of the MATLAB simulation. The agreement between hardware and simulation results is a significant validation of the MATLAB model's accuracy and dependability.

Thus, during the testing of the hardware of bidirectional power flow using designed zeta converter the maximum current was found 0.19A during forward operation i.e., in mode-1 operation as illustrated in Fig.4 of MATLAB simulation and the maximum current of 0.63A was found during reverse operation or mode-2 operation as illustrated in Fig.5 of MATLAB simulation. Hence the hardware and the software results are assessed and are closed enough and hence bi-directional power flow using Zeta converter is obtained.

5. Conclusion

The bidirectional Zeta converter, in conclusion, is a fascinating new technology that provides soft switching and little harmonic distortion for a variety of applications. This topology has achieved high efficiency with minimal switching losses due to its gentle switching properties. The Zeta converter is suitable for various energy storage systems, electric vehicle charging systems, and unconventional energy systems because it provides a wide range of voltage conversion ratios. In comparison to other bidirectional DC-DC converters, the Zeta converter has a number of advantages, such as lower conduction losses, less stress across switches, and reduced electromagnetic interference. The proposed zeta topology can operate in both modes i.e., buck and boost, making it more flexible in a variety of applications. Overall, the suggested converter provides a reliable way to convert energy with little harmonic distortion and switching loss. It, therefore, makes for an excellent topic for further power electronics research.

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