

ANN Based Modified Zeta Converter for EV Charging

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Abstract

Power converters are critical components in EV charging systems, responsible for transforming electrical energy into a form compatible with the vehicle's battery. Most EVs use lithium-ion batteries, which require regulated DC to charge, while the electrical grid supplies AC. Power converters bridge this gap by rectifying AC power from the grid to DC, ensuring efficient energy transfer. The off-board converters use advanced semiconductor technologies to enhance efficiency, reduce heat loss and handle extreme power levels. As EV adoption grows, innovations in power electronics aim to make converters smaller, cheaper, and more adaptable, supporting faster charging times and smarter integration with renewable energy systems. Thw power converters are the unsung heroes of EV infrastructure, enabling seamless interaction between the grid, charging stations, and the vehicle's battery. This paper discusses a modified zeta converter based EV charging with ANN based control. The MATLAB simulation results are discussed to demonstrate the effectiveness of ANN based control in achieving fast dynamic response and removal of overshoots. The simulation results are validated with a prototype hardware model.

Keywords: Zeta converter, ANN, EV charging, PWM

Introduction

The rapid growth of electric vehicles (EVs) has emerged as a key solution for reducing greenhouse gas emissions, minimizing dependence on fossil fuels, and promoting sustainable transportation systems. The increasing adoption of EVs worldwide has created a significant demand for efficient, reliable, and intelligent battery charging infrastructures capable of supporting diverse charging requirements while maintaining grid stability and power quality [1], [2]. However, conventional charging systems often suffer from issues such as poor power factor, high harmonic distortion, limited voltage conversion capability, and inadequate control performance under varying operating conditions. Consequently, advanced power electronic

converters and intelligent control techniques have gained considerable attention in EV charging applications.

DC–DC converters play a crucial role in EV battery charging systems by regulating voltage and current according to battery charging profiles. Among the available converter topologies, the Zeta converter has attracted considerable interest due to its capability of operating in both step-up and step-down modes while maintaining continuous input current and reduced output current ripple [3], [4]. These characteristics make the Zeta converter highly suitable for EV charging applications where stable charging current, high efficiency, and improved power quality are essential requirements. Furthermore, the converter offers low electromagnetic interference (EMI), better dynamic response, and improved energy transfer characteristics compared to several conventional converter configurations [5].

Recent research has explored various modified Zeta converter structures to enhance voltage gain, reduce switching stress, and improve overall charging efficiency. Modified hybrid Zeta–Boost converters, integrated Zeta-Luo converters, and high-gain modified Zeta converters have demonstrated superior performance in renewable-energy-assisted EV charging systems [6]–[9]. These converter topologies enable efficient utilization of low-voltage renewable sources such as photovoltaic (PV) systems while satisfying the charging requirements of modern EV batteries. Additionally, interleaved and multi-stage Zeta-based architectures have been proposed to achieve higher power density and improved conversion efficiency [10].

Despite these advancements, the control strategy remains a critical factor influencing charger performance. Traditional proportional-integral (PI) controllers are widely used because of their simplicity; however, their effectiveness deteriorates under nonlinear operating conditions, parameter variations, battery aging effects, and fluctuating source conditions [11]. EV charging systems inherently exhibit nonlinear characteristics due to battery electrochemical behavior, converter switching dynamics, and variations in load demand. Therefore, intelligent control approaches capable of handling nonlinearities and uncertainties are required to ensure optimal charging performance.

Artificial Neural Networks (ANNs) have emerged as powerful tools for modeling and controlling nonlinear systems. Owing to their learning capability, adaptability, and fast response characteristics, ANN-based controllers can effectively estimate optimal control actions without requiring precise mathematical models of the system [12]. Several studies have reported the successful application of ANN techniques in EV charging systems, bidirectional

converters, DC–DC converter voltage regulation, and maximum power point tracking (MPPT) applications [13]–[16]. ANN-based controllers have demonstrated superior transient response, reduced steady-state error, improved voltage regulation, and enhanced robustness when compared with conventional PI-based approaches [14], [15].

The integration of ANN control with modified Zeta converter topologies presents a promising solution for next-generation EV charging systems. By exploiting the nonlinear mapping capability of neural networks, the converter can dynamically adjust its duty cycle according to variations in battery state-of-charge (SOC), input voltage fluctuations, and charging requirements. This intelligent control mechanism improves charging efficiency, minimizes overshoot and settling time, and enhances overall system reliability [13], [15]. Furthermore, ANN-based control facilitates adaptive charging operation, which is particularly beneficial for renewable-energy-assisted charging stations and vehicle-to-grid (V2G) environments [17].

Motivated by these advantages, this paper proposes an ANN-based Modified Zeta Converter for EV charging applications. The proposed system combines the high voltage conversion capability and improved power quality characteristics of a modified Zeta converter with the adaptive learning capability of an ANN controller. The objective is to achieve efficient battery charging, reduced current ripple, enhanced dynamic performance, and improved voltage regulation under varying operating conditions. Simulation studies are conducted to evaluate the effectiveness of the proposed approach and compare its performance with conventional control techniques.

Zeta Converter

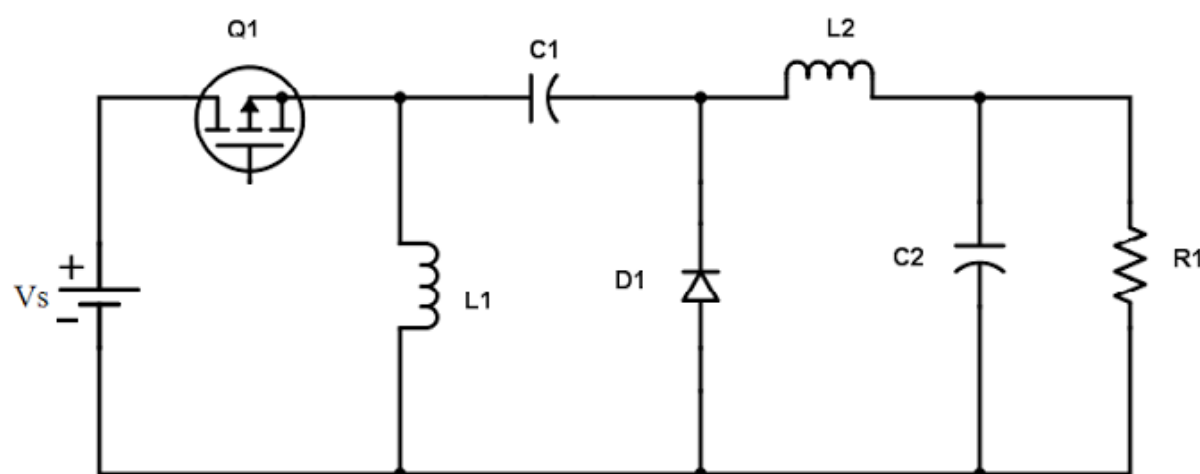


Figure 1: Zeta Converter

The Zeta converter functions by continuously cycling between two operational states managed by high-frequency pulse-width modulation. When the Q1 switch turns on, the input voltage directly charges the inductor L1, causing its magnetic field to grow. Simultaneously, the series coupling capacitor C1 discharges its stored energy into the inductor L2 and the load, while the diode remains reverse-biased and blocked. During this active phase, the current flowing through both inductors rises linearly, storing the necessary energy to sustain the system through the next phase.

When the switch Q1 turns off, the circuit enters its second state as the input source is completely disconnected. The sudden drop in current causes the inductor L1 voltage polarity to reverse, which forward-biases the diode and forces it to conduct. In this loop, the inductor L1 transfers its accumulated energy to recharge the series coupling capacitor C1. Concurrently, the inductor L2 releases its stored magnetic energy through the diode to power the load and replenish the output filter capacitor. This alternating cycle ensures a smooth, continuous delivery of power to the output.

The transition between stepping the voltage up or down is entirely governed by the switching duty cycle, which represents the percentage of time the switch remains on. If the switch is active for less than half of the total cycle, the system operates in buck mode to lower the output voltage. Conversely, keeping the switch active for more than half of the cycle shifts the system into boost mode to raise the output voltage. This precise control allows the converter to maintain a steady, regulated output even when the input source fluctuates widely.

The relationship between output and input voltage is determined by the duty cycle

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

Because inductor L₂ is in series with the output, the current flowing to the load stays continuous, resulting in much cleaner power compared to conventional buck-boost topology and hence makes it an ideal choice for battery charging applications.

ANN Control Technique

Artificial Neural Networks imitate the learning process of the human brain. An ANN controller learns the relationship between converter inputs and the required control action through training. The typical input and outputs of ANN are given as

Error signal

$$e(k) = V_{ref} - V_{out}$$

Change in error signal

$$\Delta e(k) = e(k) - e(k - 1)$$

Output

$$D = f(e, \Delta e, V_{in}, I_o)$$

Where, D = Duty cycle

f = nonlinear mapping learned by ANN

The generated duty cycle controls the MOSFET switching of the Zeta converter.

The neural network acts as an intelligent controller that computes the optimal duty cycle (D) for the PWM generator based on real-time feedback. The structure of ANN controller is seen in figure 2. The ANN structure is divided into three layers. The input layer computes the error signal which is the difference between the actual voltage and reference voltage. It also determines the change is error for each sample of the input and output. The hidden layer uses sigmoid function to model the system nonlinearity and the output layer computes the duty cycle to be passed to the PWM generator.

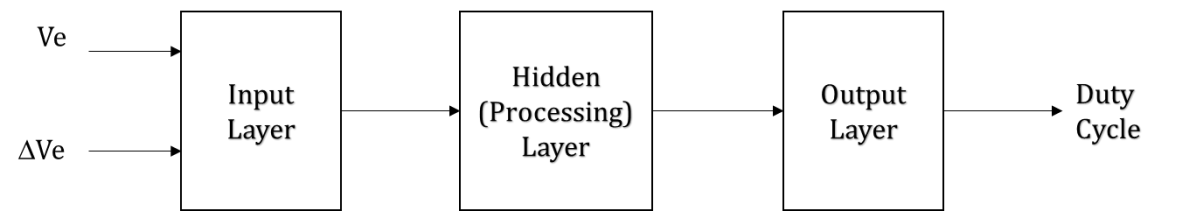


Figure 2: Structure of ANN Controller

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	517	1000
Elapsed Time	-	00:00:18	-
Performance	0.042	0.000831	0
Gradient	0.201	0.000352	1e-07
Mu	0.001	1e-08	1e+10
Validation Checks	0	6	6

Figure 3: Particulars of ANN Model

	Observations	MSE	R
Training	14001	8.3177e-04	0.9181
Validation	3000	7.0735e-04	0.9250
Test	3000	5.0874e-04	0.9423

Figure 4: MSE and R value of ANN upon training and testing

The Levenberg-Marquardt algorithm is used for training. The particulars of training are mentioned in figure 3 and figure 4. These particulars are obtained after ANN training with MATLAB platform.

Simulation and Results

The figure 5 shows MATLAB/Simulink model of high-efficiency EV charging topology that integrates AC-DC rectifier, a modified high-gain Zeta DC-DC converter and an intelligent Artificial Neural Network (ANN) control system. The ANN was trained with Levenberg – Marquardt algorithm by considering the data of voltage error computed as difference between reference and actual voltage and duty cycle output generated by a conventional PI controller. The detailed system specifications are mentioned in table 1.

Table 1: System Specifications

Source	230V, 50Hz
AC-DC Conversion	Diode bridge rectifier
DC-DC Converter 1	Diode – Capacitor Voltage Doubler
DC-DC Converter 2	Zeta Converter
Controller	ANN Epochs = 517 Layer Size = 10 Algorithm: Levenberg – Marquardt
C1 = C2	1 μ F
Inductor L1	21.8 μ H
C3	10 μ F
Battery:	48V, 10Ah Initial SOC = 20%
Cout	6600 μ F

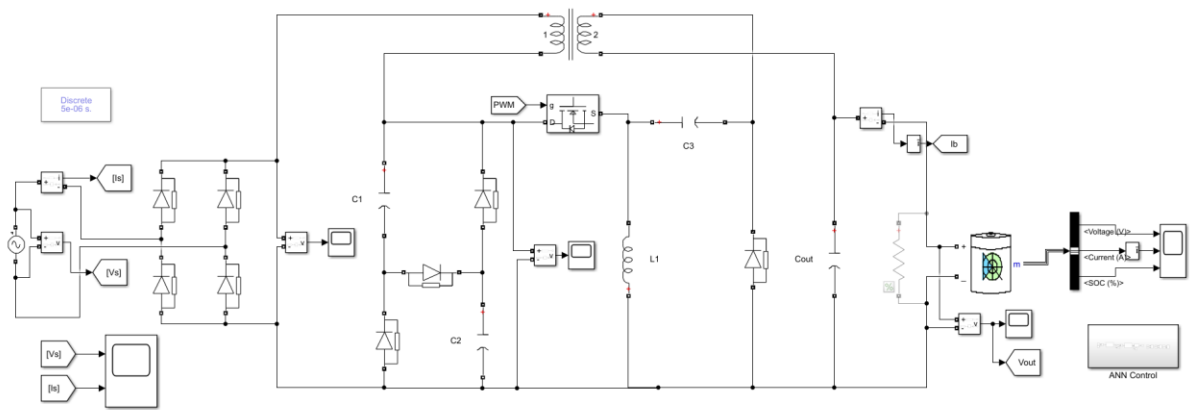


Figure 5: MATLAB Simulink Model

The AC power is immediately fed into an uncontrolled full-bridge diode rectifier to convert the grid's alternating current into a pulsating DC voltage, establishing the baseline input for the power conversion stage. The rectifier output is then fed to a voltage multiplier stage. The waveforms of source voltage and source current are seen in figure 6 and zoomed view of output voltage waveforms of diode bridge rectifier stage and voltage multiplier stage are seen in figure 7 and figure 8 respectively.

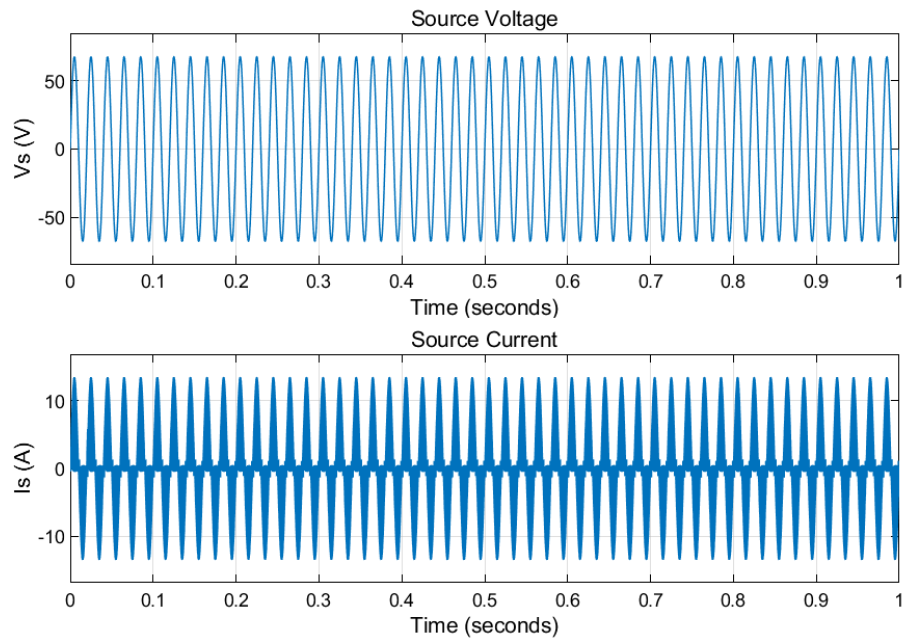


Figure 6: Source Voltage and Source Current Waveforms

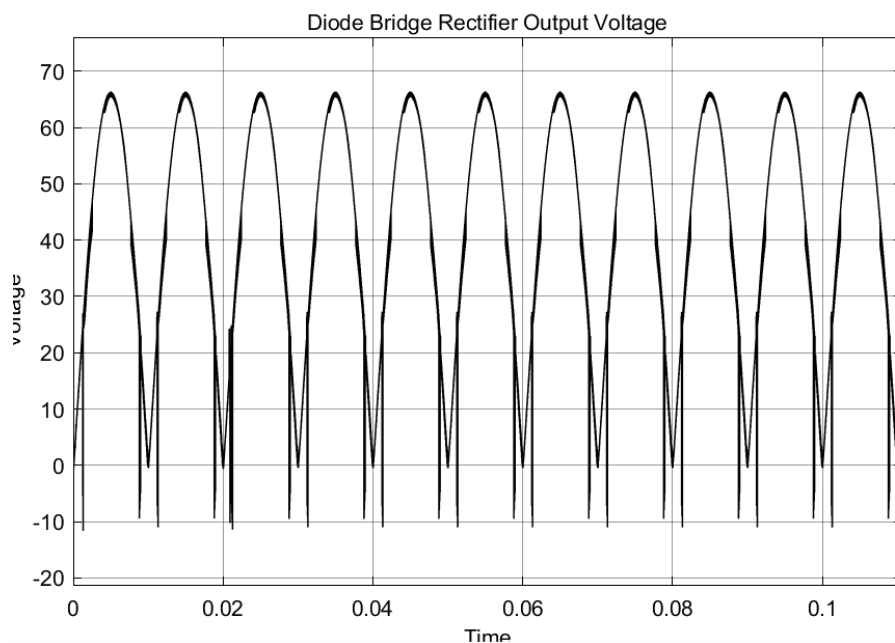


Figure 7: Diode bridge rectifier stage voltage waveforms

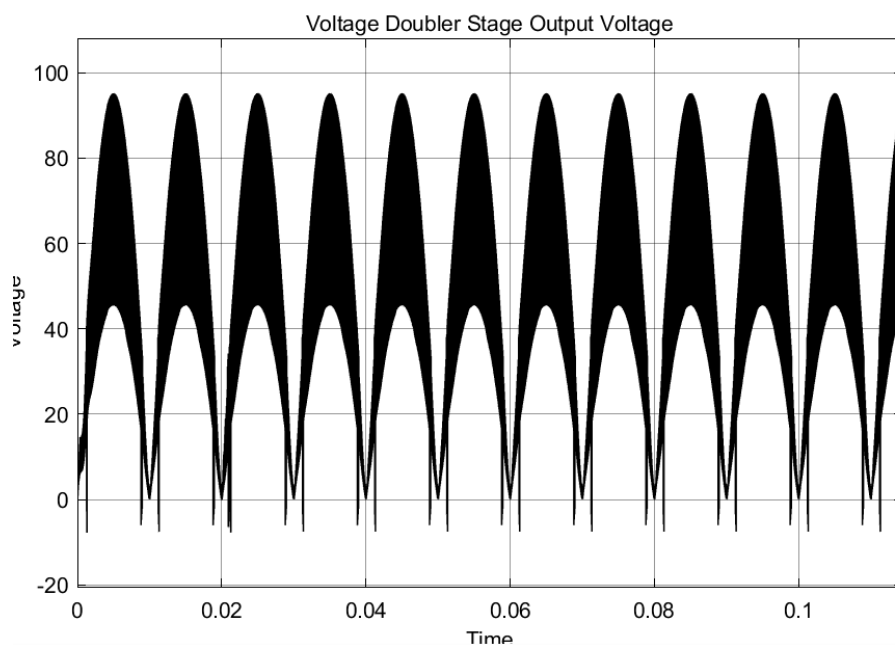


Figure 8: voltage doubler stage voltage waveforms

The modified Zeta converter stage fulfil the high voltage-gain demands of EV charging. Instead of a single intermediate capacitor, this design utilizes a specialized switched-capacitor network composed of capacitors C1 and C2 alongside steering diodes. This structural modification allows the capacitors to charge and discharge in a manner that doubles the voltage gain, preventing the system from having to operate at extreme, unstable duty cycles. A power

MOSFET acts as the main high-frequency switch, regulating energy transfer through the intermediate inductor L1 and coupling capacitor C3 toward the output filter capacitor Cout.

The output stage features additional rectification and filtration to deliver a smooth, low-ripple DC current directly to the Simulink battery model. Because Zeta converters naturally feature an inductive output path, they supply exceptionally continuous current profiles, which minimizes battery overheating and significantly extends overall battery life. The waveforms of battery voltage, current and SOC are shown in figure 9.

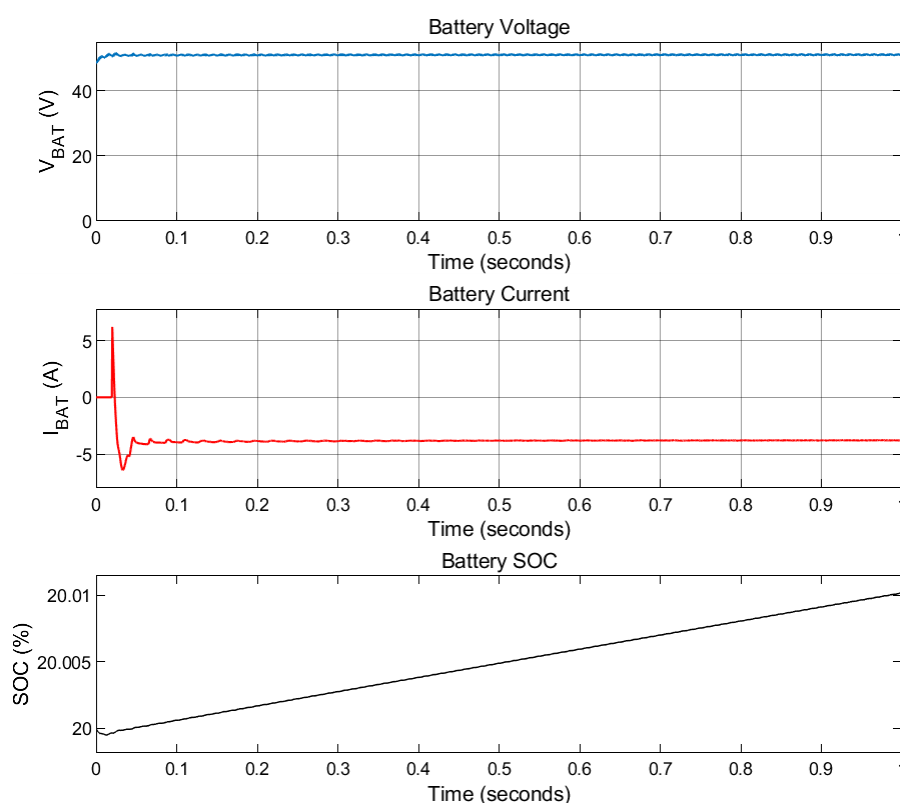


Figure 9: Battery Voltage, Current and SOC

The system's adaptability is driven by the ANN Control subsystem located at the bottom right of the model. Conventional PI controllers often struggle with the highly non-linear characteristics of EV batteries, such as shifting internal resistance during different SOC. The ANN block overcomes this by monitoring the battery's real-time voltage, current and SOC from the measurement bus. By processing these dynamic error signals through its trained neural layers, the ANN predicts and outputs the optimal duty cycle for the PWM generator. This intelligent feedback loop ensures that the converter maintains a tight CV/CC charging trajectory

Conclusion

Artificial Neural Network (ANN) control provides an intelligent and adaptive solution for regulating Zeta converters operating under nonlinear and varying conditions. By learning the complex relationship between converter states and switching duty cycle, ANN controllers achieve superior voltage regulation, faster transient response, lower overshoot, and improved robustness compared to conventional PI-based approaches. These characteristics make ANN-controlled Zeta converters highly suitable for electric vehicle charging systems, renewable energy integration, and smart energy management applications where efficiency, reliability, and dynamic performance are critical.

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