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Adaptive Control Strategy for Bidirectional Converters to Improve EV Charging Efficiency

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Abstract: This research introduces an ANN-based bidirectional power converter designed to enhance EV charging control networks. The proposed system efficiently manages the charging and discharging of electric vehicles by employing an ANN controller that dynamically regulates the power flow in bidirectional converters. By leveraging the adaptive capabilities of the ANN, the converter adjusts in real time to changing charging requirements. This approach maximizes the stability and efficiency of energy transfer across various load conditions. Unlike traditional controllers, this method reduces response time while simultaneously enhancing power quality, facilitating quicker and more efficient charging. Experimental results indicate that the system is capable of charging different electric vehicle batteries with varying degrees of efficiency and precision. An ANN-based bidirectional converter has the potential to make electric car chargers smaller, lighter, and more affordable, while also providing a scalable solution to accommodate the growing electric vehicle network.

I. INTRODUCTION

Increasingly, individuals are recognizing that electric vehicles (EVs) can play a significant role in addressing the pressing issue of reducing greenhouse gas emissions and enhancing energy efficiency. Electric vehicles (EVs) are crucial for the shift towards a sustainable transportation system as they diminish pollution and reliance on fossil fuels. Currently, researchers are focusing on wide-bandgap (WBG) semiconductor technologies such as silicon carbide (SiC) and gallium nitride (GaN) due to their exceptional performance in power electronics. These technologies exhibit remarkable versatility in terms of voltage, temperature, and frequency. They surpass traditional silicon-based devices in efficiency. Consequently, this enables electric vehicles to utilize more efficient power electronics, significantly reducing energy losses and enhancing fuel efficiency. This enhanced efficiency serves a dual purpose: it substantially increases the practical driving range of EVs and provides a considerable boost to the growth of the electric car industry. However, the high costs and challenges associated with the manufacturing of WBG semiconductors hinder their broader adoption, despite the distinct advantages offered by this technology. There has been considerable emphasis on the substantial costs and challenges of artisanal production, as well as the complexities involved in creating high-quality wide bandgap (WBG) semiconductors. The elements that contribute to the increased efficiency and reduced size of electric vehicles are thoroughly analyzed. A comprehensive examination of the data is also presented by the performance demands research. Recent studies have underscored the significant potential of WBG semiconductors in aiding the automotive sector to achieve its zero-emission objectives. Additionally, they have emphasized the capability of WBG to reduce pollution levels. To ensure these broadband devices operate at optimal efficiency, temperature management is crucial. This can further mitigate the adverse environmental impacts of electric vehicles. These elements indicate that the future of WBG semiconductor technology in the electric vehicle industry appears increasingly promising in terms of sustainability. Currently, there are numerous challenges related to power management and energy efficiency technologies. Over the past few decades, electric vehicles have largely supplanted their gasoline-powered counterparts in the transportation industry. For an extended period, vehicles have significantly influenced the level of comfort in human society. A modern society cannot thrive without a dependable and efficient transportation system. An astonishing fact about electric vehicles is that they existed before the advent of internal combustion engine (ICE) vehicles. Traditional automobiles are detrimental to both human health and the environment due to the emissions they generate. One way in which electric cars (EVs) and battery electric vehicles (BEVs) contribute to cleaner air is through reduced greenhouse gas emissions. The electric vehicle movement, which includes battery electric vehicles (BEVs), electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs), aims to decrease pollution and fuel consumption. In developed

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nations such as the United States, the goal was to have one million electric vehicles (EVs) and battery electric vehicles (BEVs) on American roads by 2020. The government has initiated public programs to promote electrification.

II. SYSTEM MODELING

The research introduced a proposal for a high-power Fast DC charging station that employs power devices constructed from ultra-wideband gap (UWBG) materials. This high-capacity fast charger, which is based on Ga2O3 (UWBG) power devices, has a power output of approximately 500 kW (equivalent to three times 165 kW) and is specifically designed for charging electric vehicles, as illustrated in Figure 1. The architecture of the 500kW power EV charger features a topology that includes three separate interleaved DC-DC converter modules. Each module possesses a capacity of around 165 kilowatts and can deliver charging voltages ranging from 100 to 950 volts, along with charging currents from 0 to 200 amperes. This extensive range of output options ensures compatibility with all types of electric vehicles, including future E-buses and heavy transport trucks (HTV). The subsequent text offers a thorough analysis and assessment of the design characteristics and specifications of the 165kW charger module. Three-phase bi-directional power converters are capable of performing both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) functions. One approach to managing the flow of electricity is through the use of a bi-directional converter, which connects the DC bus to the high-power AC bus. This converter can switch between rectifying (converting AC voltage to DC) and inverting (returning DC voltage to AC) to supply power to the grid. A reduced filter and transformer size enables a higher switching frequency, which subsequently decreases the overall weight of the station. The electronic vehicle (EV) controller manages the DC-bus voltage and charges the batteries of the EV. The charger module employs the CC-CV mode, which stands for continuous current and voltage, during the battery charging process. If this technology is implemented, it could reduce heat impact, increase charging speed, and allow for uniform and rapid charging of the station. One set of regulators oversees the gate drivers that operate the MOSFETs, while another set manages the DC/DC regulators.

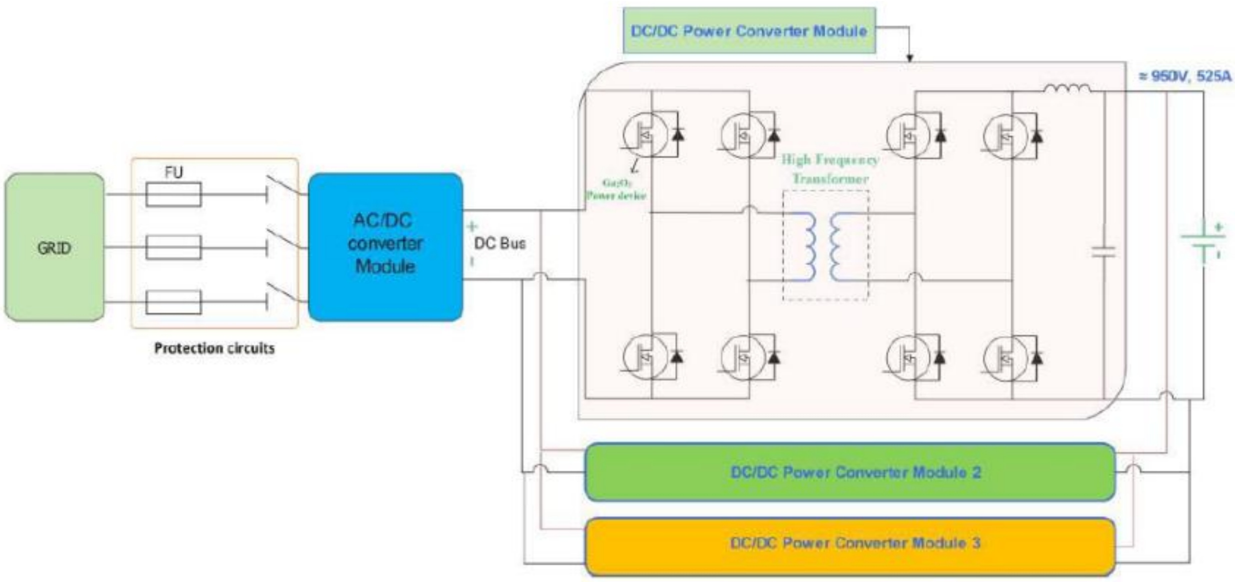

Fig.1 EV super charger

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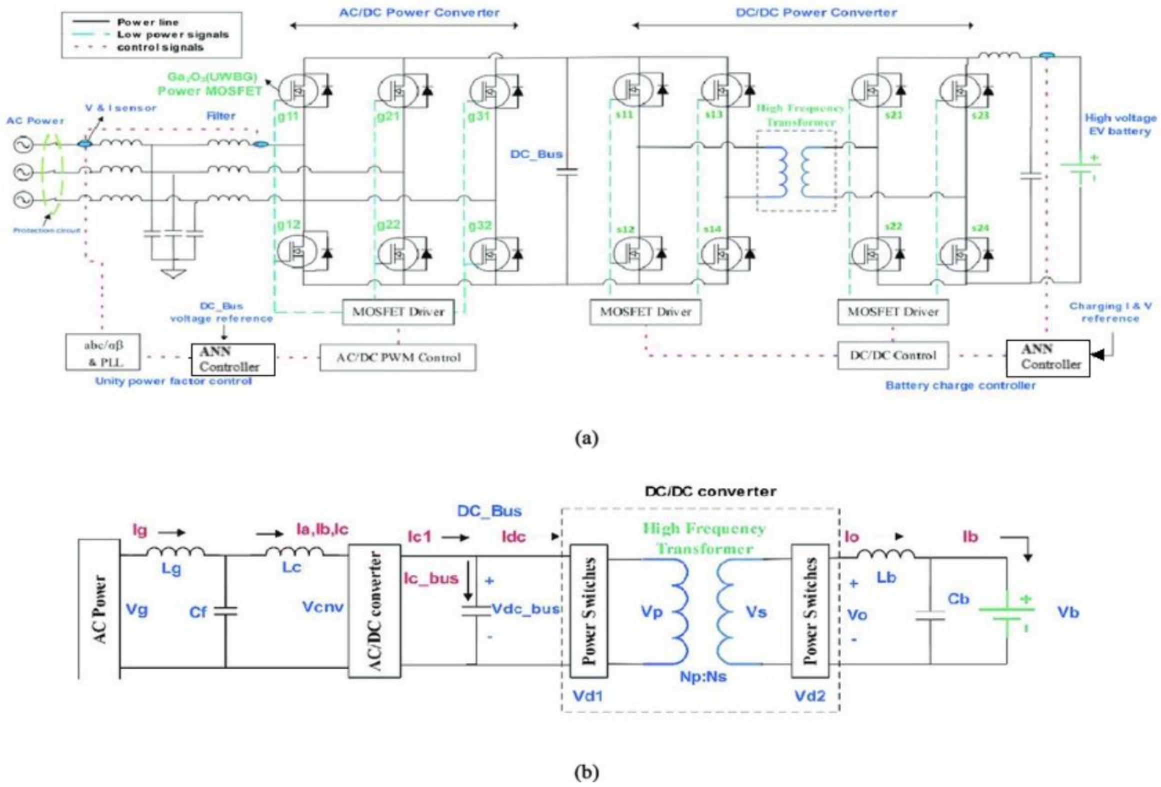

Figure 2 Proposed (a) EV charger (b) Single line Representation

The LCL filter, positioned between the grid and the AC/DC converter, reduces harmonics and aids in achieving a unity power factor on the grid side through PWM control.

When constructing the filter capacitor for the LCL filter, it is crucial to limit the total reactive power of the converter to match the grid frequency. A three-phase bidirectional power converter, often referred to as a PWM rectifier, is a commonly employed converter that uses a feedback control loop to secure the required DC bus voltage. The integration of an alternating current (AC) grid power with a direct current (DC) system via unregulated rectifiers has led to unwanted distortions in current and voltage on the grid side. The PWM rectifier produces a nearly sinusoidal current at the source end, and by applying the power factor (PF) control method, it is feasible to achieve a unity power factor at the grid end. By neglecting the filter capacitor, the voltages of the AC/DC converter can be aligned with the grid voltages as illustrated in figure 2b. The DC/DC full bridge power converter topology is employed to establish a connection between the DC-bus and the electric vehicle (EV) battery. This power converter regulates a wide range of charging voltages, from 100 to nearly Vdcbus, while also overseeing current regulation. A bidirectional power converter is realized by integrating a fully regulated power switch on both the primary and secondary sides. A High-frequency transformer (HFT) guarantees electrical isolation between the charger and the battery. The switching frequency of the DC/DC converter is set at 50kHz (fs2) in accordance with the frequency limitations of the currently available high-power HFT. Let Vd1 denote the voltage drop of the Ga2O3 power devices on the primary side of the HFT, while Vd2 signifies the voltage drop on the secondary side.

III. ARTIFICIAL NEURAL NETWORK

Artificial neural networks (ANNs) have been employed in the automated recognition and analysis of machine states, treating these as classification or prediction challenges by learning patterns from examples or experimental data. Nevertheless, conventional neural network techniques exhibit limitations in their capacity to create models that may overly conform to the training data. This limitation arises from the optimization algorithms utilized in artificial neural networks (ANNs) for parameter estimation, as well as the statistical metrics applied for model selection. Recently, support vector machines (SVMs), grounded in statistical learning theory, are gaining traction in the domains of machine learning, computer vision, and pattern recognition due to their exceptional accuracy and robust predictive capabilities. The research examines the recurring patterns of various vibration-based signals, collected under different loads and sampling speeds,

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encompassing both normal and bright conditions. The findings illustrate the effectiveness of the features extracted from the acquired and pre-processed signals in assessing the machine's status.

ANN Modeling
Creating an Artificial Neural Network (ANN) controller entails the development of a neural network capable of modifying the control inputs of a system to achieve specified outputs, often in real-time. The process of establishing an ANN controller generally consists of data collection, network training, and performance validation. Below is a structured outline of the procedure:
1. Define the System and Controller Objectives
- Determine the system that requires control (for instance, a motor, robotic arm, or HVAC system).
- Establish control goals such as maintaining a setpoint, reducing error, or enhancing performance over time.

2. Data Collection
- Gather or produce training data from the system. This data usually encompasses:
- Input data (control inputs such as torque, voltage, force, etc.)
- Output data (system states or variables to be controlled, e.g., position, speed, temperature)
- If feasible, simulate the system using a physics-based or mathematical model to obtain varied data.

3. Design and Train the ANN Controller
- Network Architecture: Select an appropriate architecture, such as a feedforward or recurrent neural network.
- Feedforward networks are generally employed for static control.
- Recurrent networks or Long Short-Term Memory (LSTM) networks are advantageous for systems with temporal dependencies.
- Training: Train the ANN using a substantial dataset, aiming to minimize the discrepancy between the predicted control action and the actual output.
- Implement supervised learning if labeled data with desired output values is available.
- Reinforcement learning (RL) may be applied for more intricate control systems where the desired behavior is acquired through trial and error.
- Loss Function: Specify an error metric, such as Mean Squared Error (MSE), to assess performance during the training phase.
- Optimization Algorithm: Employ an optimizer (e.g., SGD, Adam) to reduce the loss function throughout the training process.

4. Implement the Controller
- After training, integrate the ANN controller into the system, allowing it to receive feedback and modify its outputs as needed.
- Generally, the ANN controller processes system states and determines the control input necessary to maintain or modify the output as required.

5. Testing and Validation
- Evaluate the ANN controller using a distinct dataset to assess its performance.
- Employ real-time feedback to analyze the controller's reaction under different conditions and confirm whether it achieves the intended goals.

6. Fine-tuning and Iteration
- Adjust the model parameters and retrain if needed, particularly if the ANN is not performing adequately in practical scenarios.

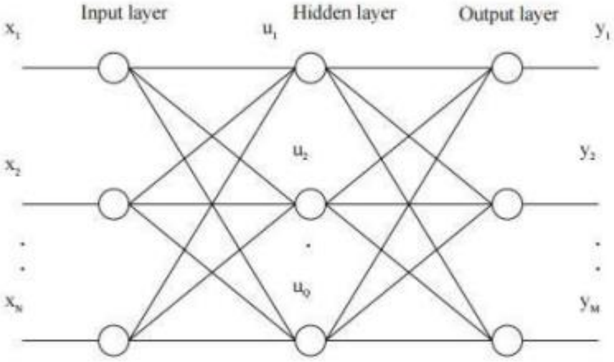

Figure 3 Artificial Neural Network

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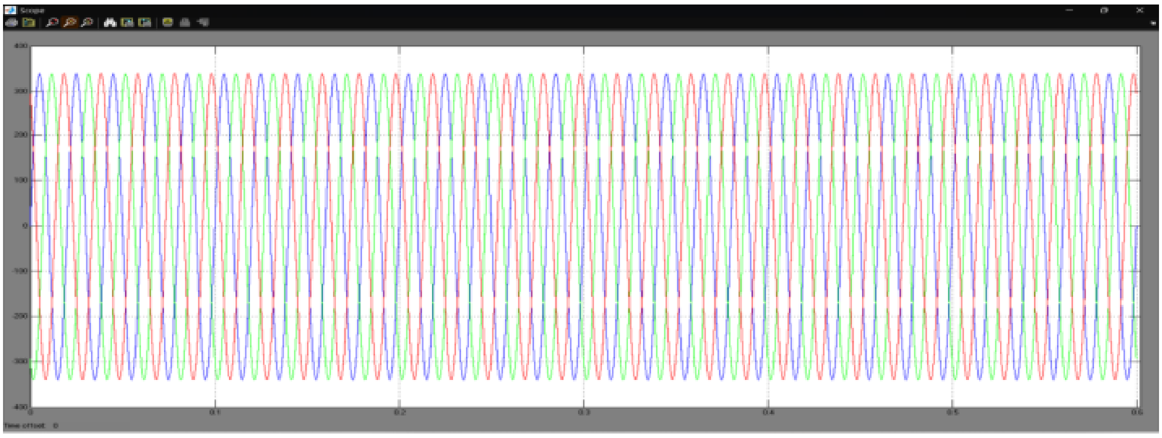
IV. SIMULATION RESULTS

A three-phase connection is established between the AC grid and the DC voltage bus through the configuration of the bidirectional AC-DC converter. By integrating a DC capacitor in parallel with the DC bus, the management of voltage can be enhanced. The bidirectional AC-DC converter is capable of rectifying and inverting voltages independently. This capability significantly facilitates the connection of electric vehicles to the grid and vice versa. The simulation exclusively addresses the rectification option, which entails charging the high voltage EV battery using grid power. Figure 4 illustrates the voltage behavior of the DC bus, while Figure 5 depicts the current and voltage responses of the three grid phases. The systems' Total Harmonic Distortion (THD) reactions at 50 Hz, the fundamental frequency, are observable. Within 0.15 seconds of initiating charging, current limiting protection devices can stabilize the system and mitigate excessive current during startup. This simulation employs unity power factor control through the phase-lock loop (PLL) technique and the abc/F & σ/dq transformations. Active power (P) is regulated along the d-axis of the d-q coordinate system, whereas reactive power (Q) is managed along the q-axis. The PWM rectifier can achieve its power factor-of-one mode by reducing the reactive power current to zero, or igq = 0.



(a)

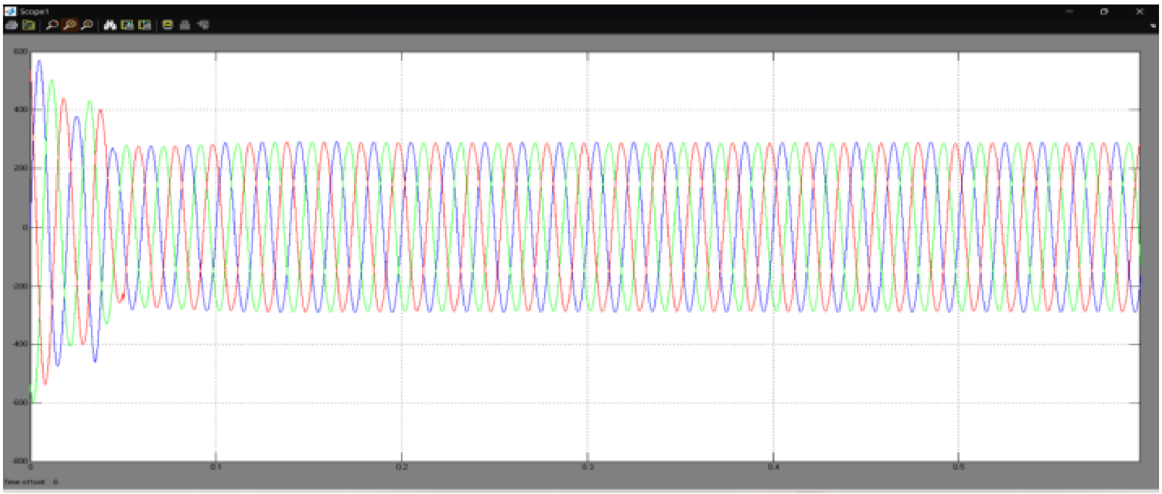


Figure 4 Proposed System (a) Vg (b) I

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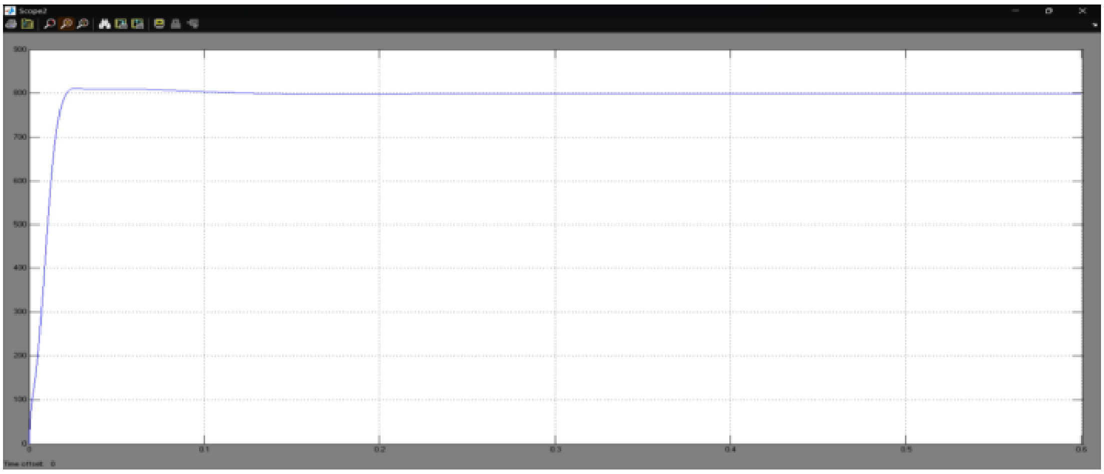
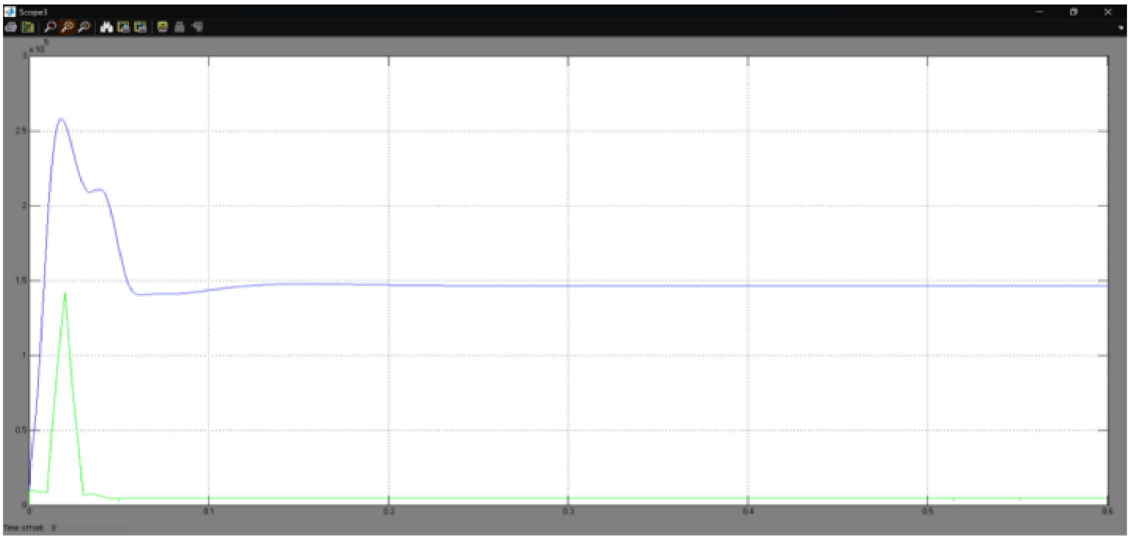
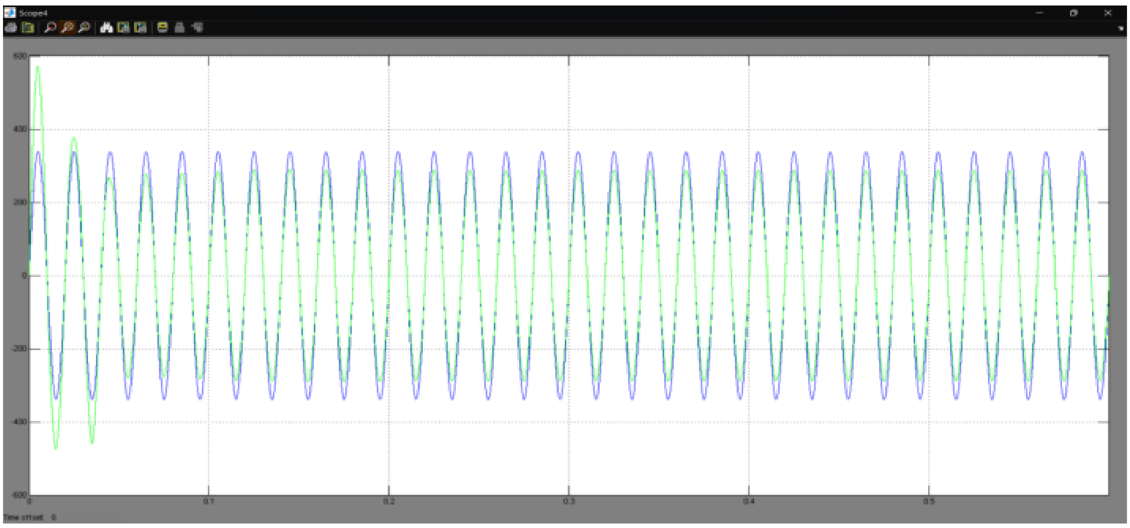


Figure 5 DC link Voltage



(a)



(b)

Figure 6 Proposed system (a) R & Q (b) Phase V & I.

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V. CONCLUSION

The bidirectional power converter utilizing Artificial Neural Networks (ANNs) represents a reliable option for improving EV charging control networks. By facilitating real-time power management, the adaptive characteristics of the ANN controller ensure effective and dependable energy transmission, irrespective of the charging condition. This technology surpasses traditional control techniques in aspects such as power quality, response time, and overall charging efficiency. With this advancement, we have the potential to enhance charging speed, develop high-power EV chargers that are compatible with a broader array of batteries, and create devices that are smaller, lighter, and more cost-effective. Promoted as both scalable and forward-compatible, the ANN-based bidirectional converter is capable of adapting to the changing requirements of EV infrastructure. Future investigations into the ANN model may focus on enhancing the model's precision and efficiency in high-capacity electric vehicle charging scenarios.

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