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An Adaptive controller based Bi-Directional Converter for Enhance the charging performance of EV charging system

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Abstract

This study presents an ANN-based bidirectional power converter for enhanced EV charging control networks. The proposed system is able to efficiently charge and discharge electric vehicles because it uses an ANN controller to dynamically manage the power flow in bidirectional converters. Through the utilisation of the ANN's adaptive capabilities, the converter adaptively adjusts to evolving charging demands in real time. This maximises the stability and efficiency of energy transfer under various load conditions. In contrast to conventional controllers, this approach minimises response time while simultaneously improving power quality, allowing for faster and more efficient charging. Results from the experiments demonstrate that the system can charge various electric vehicle batteries with differing levels of efficiency and accuracy. An ANN-based bidirectional converter could one day make electric car chargers smaller, lighter, and cheaper, all while offering a scalable solution to meet the needs of an expanding electric vehicle network.

Key Words: Electric vehicle, Charging control, Efficiency and ANN controller

I. Introduction

More and more, people are realising that electric vehicles (EVs) can help with the urgent problem of cutting down on emissions of greenhouse gases and improving energy efficiency. Electric vehicles (EVs) are essential for the transition to a sustainable transportation system because they reduce pollution and dependency on fossil fuels. Researchers are presently concentrating on wide-bandgap (WBG) semiconductor technologies including silicon carbide (SiC) and gallium nitride (GaN) because of their outstanding performance in power electronics. In terms of voltage, temperature, and frequency, these technologies are very versatile.

They outperform traditional devices made of silicon in terms of efficiency. In turn, this allows for electric vehicles to have more efficient power electronics, which drastically cuts down on energy losses and boosts fuel efficiency. This improved efficiency does double duty: it greatly extends the practical driving range of EVs and gives the electric car industry a huge boost in terms of growth. The high cost and difficulties in manufacturing WBG semiconductors are preventing their wider acceptance, despite the unique benefits of this technology. There was a heavy focus on the enormous costs and difficulties of artisanal manufacture as well as the difficulty of producing high-quality wide bandgap (WBG) semiconductors. The factors that make electric vehicles more efficient and smaller are examined in detail.

A thorough analysis of the data is also provided by the performance demands research. The significant promise of WBG semiconductors in assisting the automotive industry in reaching its zero emission goals has been highlighted in recent research. Furthermore, they highlighted the potential for lowering pollution levels through the use of WBG. To keep these broadband devices running at peak efficiency, temperature regulation is also essential. It can also help reduce the negative effects of electric cars on the environment even further. These factors show that WBG semiconductor technology's future in the electric car sector is looking more promising in terms of sustainability.

These days, there are a lot of problems with power management and energy efficiency technology. Electric vehicles have mostly replaced their gasoline-powered predecessors in the transportation sector during the last several decades. For a very long time, vehicles have been greatly impacting the degree of comfort in human society. A modern society cannot function without a reliable and speedy transportation system. One shocking fact about electric vehicles is that they predate the invention of cars powered by internal combustion engines (ICEs). Conventional automobiles are harmful to both humans and the environment because of the pollutants they produce. Reduced emissions of greenhouse gases are one way in which electric cars (EVs) and battery electric vehicles (BEVs) contribute to cleaner air. Battery electric vehicles (BEVs), electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) are all part of the electric vehicle movement, which is trying to reduce pollution and fuel consumption. In developed countries like the US, the target number of electric vehicles (EVs) and battery electric vehicles (BEVs) on American roads is one million by 2020. Public programs to encourage electrification have been established by the government. High prices, short battery life, charger limits, and an absence of charging infrastructure are major challenges for electric cars (EVs). In order to support electric cars (EVs), modern nations are embracing the traditional infrastructure of direct current charging stations.

A conventional power station with a capacity between fifty and one hundred and twenty kilowatts makes up these systems.

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a) Literature review

The demand for fast and ultra-fast charging infrastructure would rise in proportion to the number of electric vehicles, their range, and the capacity of their batteries, according to G. Town, S. Taghizadeh, and S. Deilami [1]. The effects on the power grid of unexpected increases in electrical demand are one of the numerous obstacles presented by proposals to extend the fast charging infrastructure. In this study, we survey all the systems and technologies that provide rapid and ultra-rapid charging. It explores various topics, including: the current and future trends in fast charging demand, the time- and location-specific patterns of electricity demand related to fast charging, the circuit technologies and devices typically found in fast chargers, the likely impacts of fast charging on the electricity distribution network and ways to mitigate these effects, techniques for the long-term planning of fast charging facilities, and predictions regarding the development of faster charging systems.

Here is a description provided by S. Habib, M. M. Khan, F. Abbas, A. Ali, M. T. Faiz, F. Ehsan, and H. Tang [2]. To electrify the transportation sector and achieve reliable and efficient electric vehicle (EV) charging solutions, new power electronics converter choices must be developed. Electric vehicle (EV) range extensions are within reach, thanks to persistent improvements in power electronics converters, which make it possible to reduce petrol use and increase battery capacity. Electric vehicle (EV) battery systems rely on power electronics converters as their principal point of connection to the power grid. So, to help with the enhanced charging of EVs, there is a big need for new power converters that are dependable and inexpensive. A bright future for charging electric vehicles may lie ahead, thanks to the rapid development of power converter topologies. In order to suggest improvements for electric vehicle charging systems, this study analyses the key components, current developments, and challenges associated with different power converters. The book examines converter systems from every angle, from the front end to the back end. In addition, the similarities and differences between resonant converter topologies and other DCDC converters are thoroughly examined in this work.

Isolated and non-isolated topologies that use soft switching techniques are also categorised and studied in detail in this analysis, with an emphasis on the benefits and drawbacks of each.

Josip Ro, S. Hameed, M. R. Khalid, I. A. Khan, and M. S. J. Asghar are in attendance [3]. Traditional ICE vehicles still rule the transportation business, even if electric automobiles (EVs) are on the rise. Achieving environmentally friendly transportation and speeding up the adoption of electric vehicles (EVs) require resolving a number of critical issues. The high cost of EVs, worries about their short range, a lack of convenient charging locations, and the possibility of power system pollution are the main issues. Electric vehicle (EV) prices are high because of the high

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energy density of the energy storage systems (ESS) used in these vehicles. This research provides an in-depth analysis of EV technology, with a special emphasis on EV chargers, energy storage systems, and electric vehicle supply equipment (EVSE). From on-board to off-board chargers, this article covers it all when it comes to electric vehicle charging. Among the several topologies covered is the use of transformers with either low or high frequency operation. The many charging power levels that are available are being spoken about. Concerns of short driving range are addressed by focussing on electric vehicle chargers that use inductive power transfer (IPT). In the study's last section, the negative effects of electric vehicle charging are discussed, along with possible remedies.

The authors S. Chakraborty, H.-N. Vu, M. M. Hasan, D.-D. Tran, M. E. Baghdadi, and O. Hegazy thoroughly examine several layouts of DC-DC converters utilised in BEVs and PHEVs [4]. Power output, number of components, switching frequency, electromagnetic interference (EMI), losses, efficiency, reliability, and cost are some of the criteria used to design, assess, and compare converter topologies. The essay analyses the construction, pros, and cons of AC-DC and DC-DC converter topologies utilised in FCHARs. Power outputs above 10 kW in high-power Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are best handled by the Multidevice Interleaved DC-DC Bidirectional Converter (MDIBC), according to this study. This is because of its dependability, efficiency, bidirectional operation, and low electromagnetic interference, as well as its low input current variations and large output voltage fluctuations.

Though it is difficult to find a single electric car that meets all the requirements with a small power output of less than 10 kW. The Sinusoidal Amplitude Adapter, a boost DC-DC converter with resonance circuit, or the Z-Source DC-DC converter [5] are more appropriate for low-power BEVs and PHEVs due to their exceptional efficiency, low switching loss, and silent operation. Potential use of wide band gap chips (WBGSs) in DC-DC converters for full-hybrid electric vehicles (FCHARs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs) is the focus of this research. This book delves deep into the future of research on wide bandgap semiconductor devices (WBGSs), as well as novel topologies and design methodologies for the control system of BEV and PHEV powertrains. Data like this might be useful for researchers and solution engineers in the automotive sector when deciding on converter topologies to boost power density.

. T. Gnann, S. Funke, N. Jakobsson, P. Plötz, F. Sprei, and A. Bennehag [6] are the authors of the publication. Prospective purchasers of plug-in electric vehicles frequently inquire about the availability of public charging infrastructure prior to making a purchase. Moreover, it is commonly anticipated that the rate of public charging will be comparable to that of traditional refueling. Consequently, there is an increasing emphasis in both scientific and political circles on rapid charging choices with greater power rates in the context of public charging. However, there is a scarcity of predictions of future requirements.

This research aims to address this deficiency by examining the present charging patterns using a comprehensive dataset from Sweden and Norway [7]. The objective is to utilize the findings to fine-tune a queuing model that can accurately predict the requirements for future fast charging infrastructure. Our research indicates that the proportion of battery electric vehicles to public fast charging points may become comparable to that of other alternative fuels in the future. Specifically, we expect to see approximately one fast charging point for every 1000 vehicles, assuming high power rates of 150 kW. Furthermore, the excess amount on the electricity bills for repayment is about 0.05–0.15 €/kWh per charging station. Nevertheless, the availability of charging infrastructure is heavily reliant on the size of batteries and the rate at which they can be charged, both of which are expected to rise in the next years.

II. SYSTEM MODELING

The study presented a proposal for a high-power Fast DC charging station that utilizes power devices made from ultra-wideband gap (UWBG) materials. A high-capacity fast charger, based on Ga_2O_3 (UWBG) power devices, with a power output of around 500 kW (equivalent to 3 times 165 kW), is specifically intended for electric car charging, as depicted in Figure 1.

The architecture of the 500kW power EV charger utilizes a topology consisting of three distinct interleaved DC-DC converter modules. Each module has a capacity of around 165 kilowatts and is capable of providing charging voltages ranging from 100 to 950 volts and charging currents ranging from 0 to 200 amperes. The wide range of output options makes it compatible with all types of electric vehicles, including future E-buses and heavy transport trucks (HTV). The following text provides a comprehensive examination and evaluation of the design features and specifications of the 165kW charger module. Three-phase bi-directional power converters have the capability to carry out both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations.

The use of a bi-directional converter, which links the DC bus to the high-power AC bus, is one method of controlling the flow of electricity. You can toggle it between rectifying (that is, converting the voltage from AC to DC) and inverting (that is, sending the DC voltage back to AC) to power the grid. A lower filter and transformer size allows for a higher switching frequency, which in turn lowers the station's overall weight. The electronic vehicle (EV) controller regulates the DC-bus voltage and charges the EV's batteries. The CC-CV mode, which stands for continuous current and voltage, is utilised by the charger module when charging batteries. If this technology is used, the heat impact could be decreased, the charging speed could be raised, and the station could be charged uniformly and swiftly. One set of regulators controls the gate drivers that run the MOSFETs, and another set controls the DC/DC regulators. Power converters (AC/DC and DC/DC) and control and power signals are seen in Figure 1, a detailed schematic of the charging station.

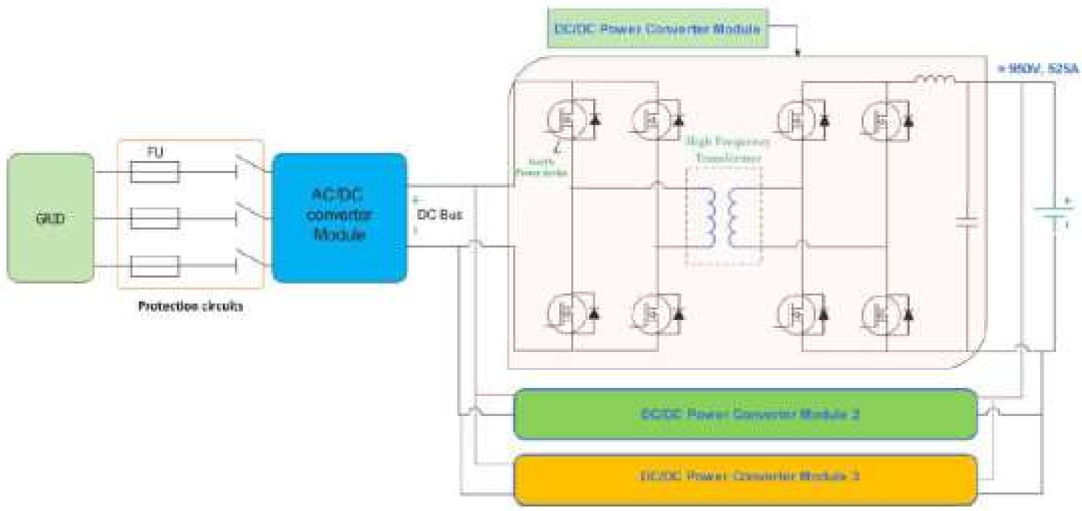
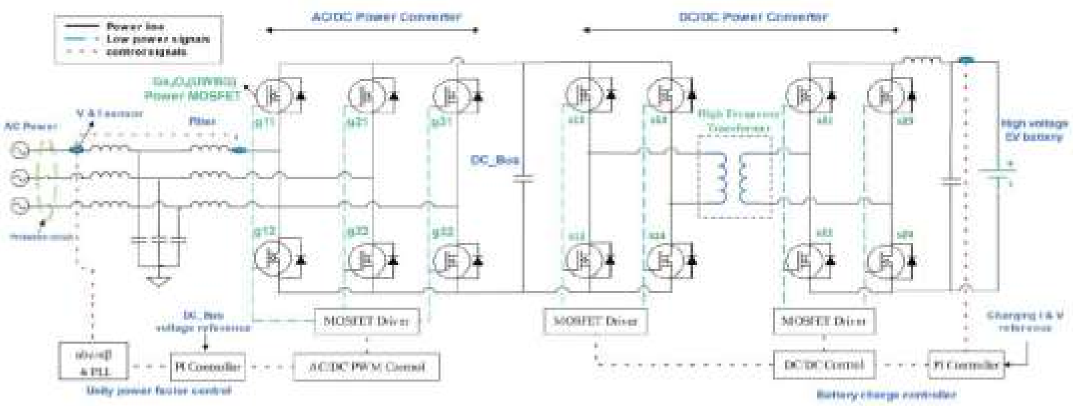
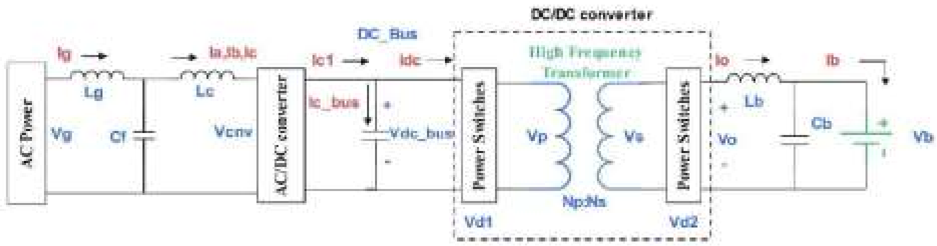


Fig.1 EV super charger



(a)



(b)

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

The LCL filter, which is placed between the grid and AC/DC converter, minimizes harmonics and facilitates the attainment of a unity power factor at the grid side through the use of PWM control.

When building the filter capacitor for the LCL filter, it is important to restrict the total reactive power of the converter to the grid frequency. A three-phase bidirectional power converter, commonly known as a PWM rectifier, is a widely used converter that utilizes a feedback control loop to obtain the necessary DC bus voltage. The connection of an alternating current (AC) grid power with a direct current (DC) system through unregulated rectifiers resulted in undesired distortion in current and voltage on the grid side.

The PWM rectifier generates an almost sinusoidal current at the source end and by utilizing the power factor (PF) control approach, it is possible to achieve a power factor of unity at the grid end. By disregarding the filter capacitor, the voltages of the AC/DC converter can be equated with the grid voltages as shown in figure 2b. The DC/DC full bridge power converter topology is utilized to provide a connection between the DC-bus and the electric vehicle (EV) battery. The power converter regulates the broad spectrum of charging voltage, ranging from 100 to almost Vdc-bus, while also managing current regulation. A bidirectional power converter is achieved by incorporating a fully regulated power switch on both the primary and secondary sides. A High-frequency transformer (HFT) ensures electrical isolation between the charger and battery. The switching frequency of the DC/DC converter is chosen as 50kHz (fs2) based on the frequency restrictions of the high-power HFT currently available. Let Vd1 represent the voltage drop of the Ga_2O_3 power devices on the primary side of HFT, and Vd2 represent the voltage drop on the secondary side.

Bidirectional converter:

The DC-bus and the EV battery are connected using a DC/DC full bridge power converter architecture. The power converter regulates the extensive charging voltage range, which extends from 100 to almost Vdc-bus together with current control. A bidirectional power converter, it features a completely regulated power switch on both the primary and secondary sides. In order to prevent any potential damage to the battery or charger, a high-frequency transformer (HFT) is used.

In order to work within the frequency constraints of the currently available high-power HFT, the DC/DC converter's switching frequency was set to 50 kHz (fs2). Let us pretend that Vd1 is the voltage drop across the main side of the HFT's and Vd2 is

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the voltage drop across the secondary side of the same devices. Here is the formula for the DC/DC converter's output voltage

$$V_o = \left[\left(V_{DC_{bus}} - 2V_{d1} \right) \frac{N_s}{N_p} - 2V_{d2} \right] \frac{2T_{on}}{T_{sw2}}$$

$$I_o \approx I_{dc} \approx (g_{11} I_a + g_{21} I_b + g_{31} I_c) - C_{bus} \frac{d}{dt} V_{DC\_bus}$$

.

III. Artificial Neural Network

Artificial neural networks (ANNs) have been utilized in automated recognition and analysis of machine states, treating them as classification or prediction problems by learning patterns from examples or experimental data. However, traditional neural network methods have limitations in their ability to generate models that may excessively fit the training data. The absence of this feature is due to the optimization algorithms employed in artificial neural networks (ANNs) for parameter estimation, as well as the statistical metrics used for model selection. Recently, support vector machines (SVMs), based on statistical learning theory, are being increasingly used in the fields of machine learning, computer vision, and pattern recognition due to their high accuracy and strong predictive capacity. The study investigates the recurring patterns of different vibration-based signals, obtained under varying loads and sampling speeds, including both normal and bright conditions. The results demonstrate the efficacy of the extracted features from the obtained and preprocessed signals in analyzing the status of the machine.

ANN Modeling

Modeling an Artificial Neural Network (ANN) controller involves designing a neural network that can adjust the control inputs of a system to achieve desired outputs, often in real-time. The steps to create an ANN controller typically include data collection, training the network, and validating its performance. Here’s an outline of the process:

1. Define the System and Controller Goals
   - Identify the system that needs to be controlled (e.g., a motor, robotic arm, HVAC system).
   - Set control objectives like maintaining a setpoint, minimizing error, or optimizing performance over time.
2. Data Collection
   - Collect or generate training data from the system. This data typically includes:
     - Input data (control inputs like torque, voltage, force, etc.)

- Output data (system states or variables to control, e.g., position, speed, temperature)
- If possible, simulate the system using a physics-based or mathematical model to get diverse data.

3. Design and Train the ANN Controller
- Network Architecture: Choose a suitable architecture, such as a feedforward or recurrent neural network.
    - Feedforward networks are typically used for static control.
    - Recurrent networks or Long Short-Term Memory (LSTM) networks are useful for systems with time dependencies.
- Training: Train the ANN with a large dataset, minimizing the error between the predicted control action and the actual output.
    - Use supervised learning if you have labeled data with desired output values.
    - Reinforcement learning (RL) can be used for more complex control systems where desired behavior is learned through trial and error.
- Loss Function: Define an error metric, like Mean Squared Error (MSE), to evaluate performance during training.
- Optimization Algorithm: Use an optimizer (e.g., SGD, Adam) to minimize the loss function during training.

4. Implement the Controller
- Once trained, embed the ANN controller in the system, where it receives feedback and adjusts its outputs accordingly.
- Typically, the ANN controller takes in system states and calculates the control input required to maintain or adjust the output as desired.

5. Testing and Validation
- Test the ANN controller on a separate dataset to check its performance.
- Use real-time feedback to evaluate the controller's response under various conditions and validate if it meets the desired objectives.

6. Fine-tuning and Iteration
- Fine-tune the model parameters and retrain if necessary, especially if the ANN is not performing well in real-world conditions.

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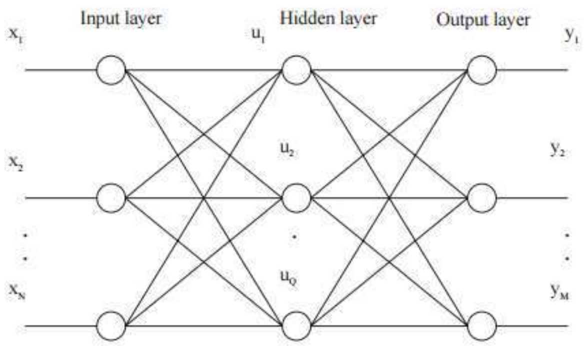
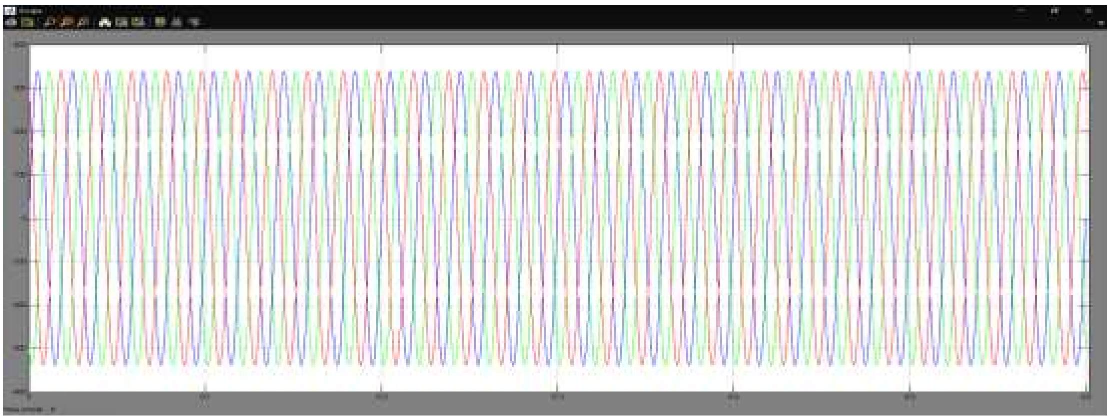


Figure 3 Artificial Neural Network

IV. Simulation Results

A three-phase connection is formed between the AC grid and the DC voltage bus by the structure of the bidirectional AC-DC converter. By connecting a DC capacitor in parallel with the DC-bus, voltage management can be improved. Separate from one another, the bidirectional AC-DC converter may rectify and invert voltages. Having this feature makes it much easier for electric vehicles to connect to the grid and for the grid to connect to electric vehicles. The rectification option, which involves charging the high voltage EV battery with grid power, is the only one covered in the simulation. Figure 4 shows the voltage behaviour of the DC bus, whereas Figure 5 shows the current and voltage responses of the three grid phases. We can see the systems' THD reactions at 50 Hz, which is the fundamental frequency. Within 0.15 seconds of charging, current limiting protection devices can stabilise the system and lessen the excessive current at startup. This simulation applies unity power factor control using the phase-lock loop (PLL) technique and the abc/F & σ/dq transforms. Active power (P) is controlled along the d-axis of the d-q coordinate system, whereas reactive power (Q) is controlled along the q-axis. The PWM rectifier can enter its power factor-of-one mode by reducing the reactive power current to zero, or igq = 0.



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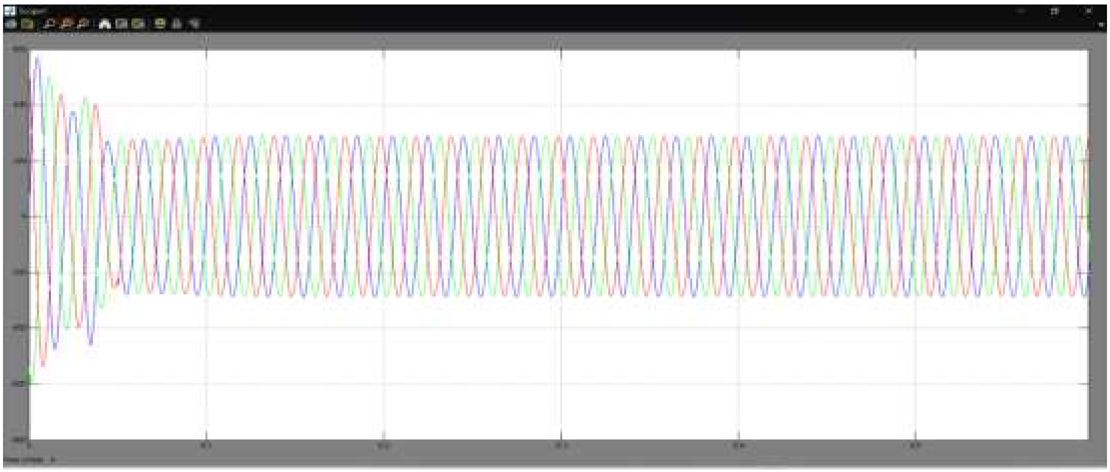
(a)



(b)

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

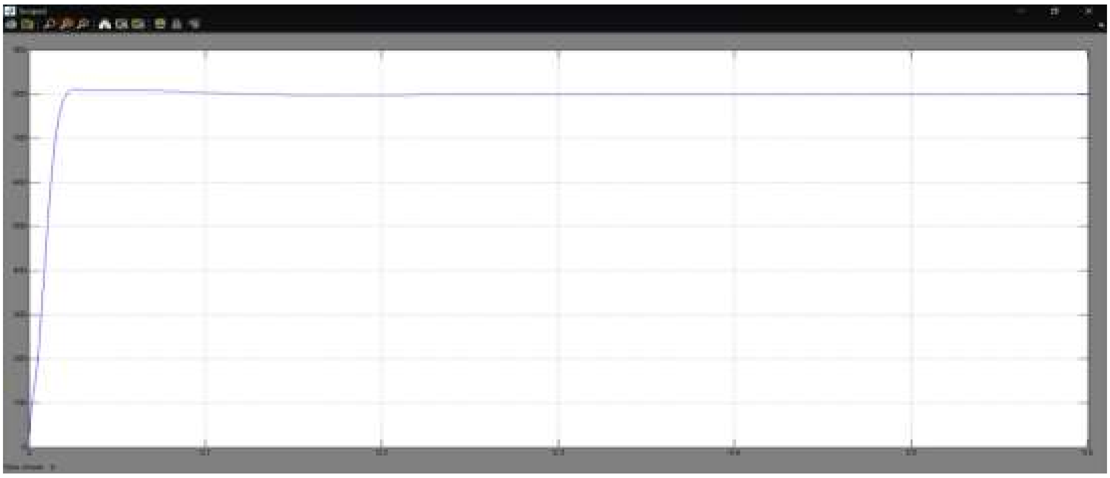


Figure 5 DC link Voltage

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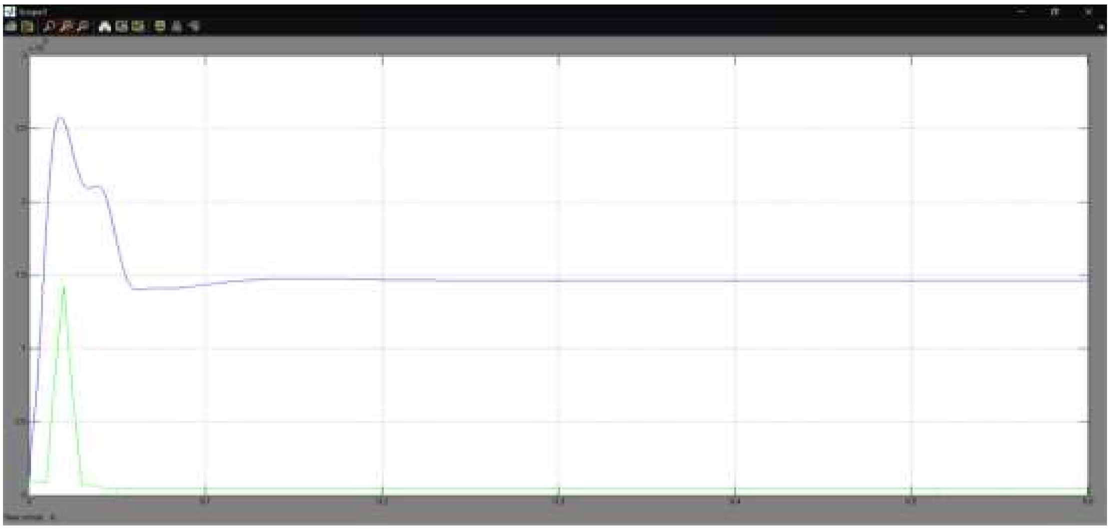
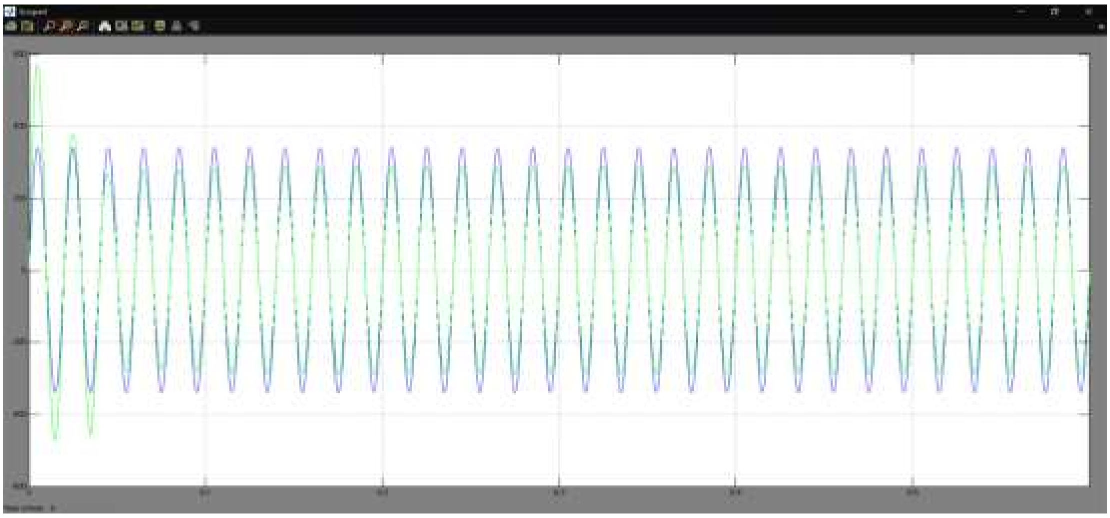


(a)



(b)

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

IV. Conclusion

The bidirectional power converter that employs Artificial Neural Networks (ANNs) is a dependable choice for enhancing EV charging control networks. By enabling real-time power management, the adaptive features of the ANN controller guarantee efficient and reliable energy transmission regardless of the charging state. The technology outperforms conventional control methods in terms of power quality, response time, and charging efficiency as a whole. With this technology, we may potentially improve charging speed, make high-power EV chargers that are compatible with a wider range of batteries, and make them smaller, lighter, and cheaper. Advertised as both scalable and forward-compatible, the ANN-based bidirectional converter can adjust to the evolving needs of EV infrastructure. Future research on the ANN model may aim to improve the model's accuracy and efficiency in high-capacity electric vehicle charging applications.

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