International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

An Artificial Intelligence Based Control of a Superconducting Inductor Assisted DC–DC Converter for Ultra-Fast Electric Vehicle Charging

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Submitted:02/11/2024 **Accepted:**12/12/2024 **Published:**25/12/2024

Abstract: This work presents the design and analysis of an artificial intelligence (AI)–based controlled superconducting inductor–assisted DC–DC double-boost converter for ultra-fast electric vehicle (EV) charging applications. The increasing demand for rapid and efficient charging solutions has highlighted the limitations of conventional AC–DC charging systems, particularly in terms of energy losses, thermal constraints, and multi-stage conversion inefficiencies. To address these challenges, the proposed system incorporates superconducting inductors using Bi_{2223} and MgB_2 materials, which offer near-zero resistance, high current-carrying capability, and improved power density. An AI-based controller is implemented to enhance switching performance, ensure stable voltage regulation, and improve dynamic response under varying load conditions. The system is modeled and simulated using MATLAB/Simulink to evaluate its electrical performance, efficiency, and transient characteristics. Simulation results demonstrate that the MgB_2-based converter achieves efficiency exceeding 95% at 15 kW output, outperforming conventional designs. Additionally, the AI controller significantly reduces voltage ripple, minimizes overshoot, and improves system stability. Overall, the proposed intelligent superconducting DC–DC converter provides a high-efficiency, reliable, and scalable solution for next-generation ultra-fast EV charging infrastructure.

Keywords*: Artificial Intelligence Control, Superconducting Inductor, DC–DC Converter, Double-Boost Converter, Electric Vehicle Charging, Ultra-Fast Charging, Power Conversion Efficiency*

Introduction

The global push toward achieving carbon neutrality by 2050 has accelerated the transition from conventional internal combustion engine vehicles to battery electric vehicles (BEVs), which are widely recognized as a sustainable alternative for reducing greenhouse gas emissions. The transportation sector contributes a significant share of global carbon emissions, and electrification is considered a key strategy for mitigating environmental impact while improving energy efficiency [1]. However, despite advancements in battery technologies and vehicle design, one of the major barriers to widespread adoption of BEVs remains the long charging duration, which limits user convenience and infrastructure scalability [2]. This challenge has led to increasing research interest in developing ultra-fast charging systems capable of delivering high power efficiently while maintaining system reliability and safety [3].

Conventional EV charging systems typically rely on grid-connected AC–DC converters followed by DC–DC conversion stages, forming a multi-stage power conversion architecture [4]. While these systems achieve reasonable efficiency at individual stages, the cumulative losses associated with generation, transmission, rectification, and conversion reduce the overall efficiency significantly, often below 90% under high-power operation [5]. Additionally, these systems introduce power quality issues such as harmonic distortion, reactive power consumption, and voltage

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imbalance, which affect grid stability and performance [6]. The increasing penetration of renewable energy sources such as solar photovoltaic systems and battery storage has further emphasized the need for direct DC-based charging architectures that minimize intermediate conversion stages and improve overall system efficiency [7].

Among various power conversion techniques, DC–DC converters have gained considerable attention due to their ability to efficiently regulate voltage levels and support direct integration with DC energy sources [8]. In particular, boost and double-boost converter topologies are widely used for high step-up voltage applications required in EV charging systems [9]. However, conventional DC–DC converters based on semiconductor devices suffer from significant conduction losses, switching losses, and thermal limitations when operating at high power levels [10]. These challenges become more pronounced in ultra-fast charging scenarios, where high current and voltage levels result in increased heat generation, reduced efficiency, and limited power density [11]. Therefore, innovative approaches are required to overcome these inherent limitations and enhance converter performance.

Superconducting materials offer a promising solution to address the efficiency and thermal challenges of conventional converters due to their unique property of near-zero electrical resistance below critical temperatures [12]. Materials such as Bi_{2223} and MgB_2 have attracted significant attention for power electronic applications due to their high current density, favorable thermal characteristics, and improved mechanical stability [13]. By integrating superconducting inductors into DC–DC converter topologies, it is possible to significantly reduce conduction losses, enhance energy transfer efficiency, and achieve higher power density compared to traditional designs [14]. Furthermore, superconducting converters enable compact system configurations and improved thermal management, making them highly suitable for next-generation ultra-fast EV charging infrastructure [15].

In addition to hardware advancements, the performance of high-power DC–DC converters largely depends on the effectiveness of the control strategy employed. Traditional control techniques such as proportional-integral (PI) and proportional-integral-derivative (PID) controllers often struggle to handle nonlinearities, parameter variations, and dynamic operating conditions in modern power systems. Artificial intelligence (AI)–based control methods, including artificial neural networks (ANNs), have emerged as powerful alternatives due to their ability to learn system behavior, adapt to changing conditions, and optimize performance in real time. By incorporating AI-based control into superconducting DC–DC converters, it is possible to achieve improved voltage regulation, reduced output ripple, faster transient response, and enhanced system stability under varying load and input conditions. This integration of advanced materials and intelligent control techniques represents a significant step toward developing efficient, reliable, and scalable solutions for ultra-fast EV charging systems.

Literature Survey

The development of high-efficiency DC–DC converters for electric vehicle (EV) charging has been widely explored in recent years, with a particular focus on improving power density and reducing energy losses. Early studies on superconducting DC–DC converters demonstrated their potential to significantly enhance efficiency by minimizing resistive losses in inductive components [1]. Researchers have shown that high-temperature superconducting (HTS) materials can be effectively integrated into boost converter topologies to achieve superior performance compared to conventional semiconductor-based designs [2]. Simulation-based investigations have further validated that superconducting converters can reach efficiency levels exceeding 98% under optimal operating conditions, making them highly suitable for high-power applications such as EV charging [3]. Additionally, these studies highlight the importance of optimizing converter parameters, including switching frequency and inductor design, to achieve maximum performance benefits [4].

Recent advancements have focused on the modeling and optimization of superconducting inductors used in DC–DC converters. Detailed analytical and simulation models have been developed to evaluate the impact of different superconducting materials, such as Bi_{2223} and MgB_2, on converter performance [5]. These studies reveal that material properties, including critical temperature and current density, play a crucial role in determining efficiency and thermal behavior [6].

Comparative analyses indicate that MgB_2-based inductors generally provide better performance due to their higher current-carrying capability and lower cooling requirements [7]. Furthermore, research on thermal management in superconducting converters has identified key challenges related to maintaining stable operating temperatures, leading to the development of improved cooling strategies and system designs [8]. These contributions have significantly advanced the practical feasibility of superconducting converters in real-world applications.

In parallel, significant efforts have been made to enhance the dynamic performance and control of DC–DC converters used in EV charging systems. Conventional control strategies, such as PI and PID controllers, have been widely implemented due to their simplicity and ease of design [9]. However, these methods often exhibit limitations in handling nonlinear system dynamics, parameter uncertainties, and rapid load variations [10]. To overcome these challenges, advanced control techniques, including artificial intelligence (AI)–based approaches, have been introduced [11]. Artificial neural networks (ANNs) and other machine learning methods have been shown to improve voltage regulation, reduce output ripple, and enhance system stability under varying operating conditions [12]. These intelligent control strategies enable adaptive learning and real-time optimization, making them highly suitable for modern power electronic systems with complex dynamics [13].

Moreover, the integration of superconducting technology with advanced control methods has opened new avenues for developing next-generation EV charging infrastructure. Several studies have explored the application of superconducting DC–DC converters in fast charging stations, demonstrating reduced charging time and improved overall efficiency [14]. Simulation and experimental results confirm that combining superconducting inductors with intelligent control strategies can significantly enhance system performance, including faster transient response and improved robustness against disturbances [15]. Despite these advancements, challenges remain in terms of cost, cooling requirements, and large-scale implementation, which continue to be active areas of research. Overall, the literature indicates that superconducting DC–DC converters, coupled with AI-based control techniques, represent a promising direction for achieving high-efficiency, reliable, and scalable ultra-fast EV charging systems.

Methodology

The methodology begins with the conceptual design of a high-efficiency DC–DC double-boost converter tailored for ultra-fast electric vehicle charging applications. The system is structured to accept a DC input source, representing renewable energy or a DC microgrid, and convert it into a higher regulated DC output suitable for battery charging. The converter topology is selected based on its ability to provide high voltage gain, reduced ripple, and improved power transfer capability. Special emphasis is placed on minimizing intermediate conversion stages to enhance overall efficiency. The electrical parameters such as input voltage, switching frequency, duty cycle, and load conditions are carefully defined to ensure stable operation under high-power requirements.

The design is further enhanced by incorporating superconducting inductors into the converter structure to reduce conduction losses and improve current-handling capability. Two types of superconducting materials, Bi_{2223} and MgB_2, are considered for performance comparison. The inductors are modeled based on their critical current density, operating temperature, and magnetic characteristics. Cryogenic cooling conditions are assumed to maintain superconductivity, ensuring near-zero resistance during operation. The integration of these inductors into the double-boost topology allows efficient energy storage and transfer while minimizing thermal stress. This configuration significantly improves power density and enables the system to handle high current levels required for ultra-fast charging.

An intelligent control mechanism is then developed using an artificial neural network (ANN) to regulate the converter operation. The ANN controller is trained using input-output data obtained from the system under various operating conditions, including load variations and input fluctuations. The training process utilizes a backpropagation algorithm to minimize error and optimize performance. The controller receives error signals based on the difference between reference and actual output values and generates appropriate control signals for switching devices. This adaptive control approach ensures accurate voltage regulation, reduces oscillations, and enhances dynamic response compared to conventional control techniques.

The entire system is implemented in the MATLAB/Simulink environment to simulate real-time operation and evaluate performance. The simulation model includes the DC input source, superconducting double-boost converter, ANN-based controller, and load system representing the EV battery. Various test scenarios are applied, such as sudden load changes, input voltage disturbances, and high-power operation conditions. Key performance indicators including output voltage stability, current ripple, efficiency, and transient response are monitored. Comparative analysis is conducted between systems using conventional inductors and superconducting inductors, as well as between traditional controllers and ANN-based control.

Finally, the results obtained from the simulation are analyzed to validate the effectiveness of the proposed methodology. The performance of the MgB_2-based superconducting converter is evaluated against the Bi_{2223} configuration to determine the most efficient design. The impact of the ANN controller on system stability, response time, and ripple reduction is also examined in detail. The methodology ensures a comprehensive evaluation of both hardware and control aspects, demonstrating the feasibility of integrating superconducting technology with intelligent control for high-efficiency EV charging. This systematic approach provides a strong foundation for developing next-generation ultra-fast charging systems with improved reliability and performance.

Proposed System

The proposed system presents an advanced artificial intelligence–based controlled superconducting inductor–assisted DC–DC double-boost converter designed specifically for ultra-fast electric vehicle (EV) charging applications. The architecture is developed to overcome the inefficiencies associated with conventional multi-stage AC–DC charging systems by enabling direct DC power conversion with minimal losses. The system consists of a high-voltage DC input source, a double-boost converter topology, superconducting inductors, and an intelligent control unit. The double-boost configuration is selected due to its ability to achieve high voltage gain, reduced output ripple, and improved power transfer capability. This makes it highly suitable for delivering the high voltage and current levels required for rapid battery charging. By eliminating unnecessary conversion stages, the system significantly enhances overall efficiency and reduces energy dissipation.

A key feature of the proposed system is the integration of superconducting inductors using advanced materials such as Bi_{2223} and MgB_2. These materials exhibit near-zero electrical resistance when operated below their critical temperatures, which drastically reduces conduction losses and improves current-carrying capacity. The superconducting inductors enable efficient energy storage and transfer within the converter, allowing the system to operate at high power levels without excessive thermal stress. Among the two materials, MgB_2 demonstrates superior performance due to its higher current density and better thermal characteristics, making it more suitable for high-power charging applications. The use of superconducting components also contributes to a compact and lightweight design, enhancing the practicality of the system for modern EV infrastructure.

The control strategy of the proposed system is based on an artificial neural network (ANN), which replaces conventional controllers such as proportional-integral (PI) controllers. The ANN controller is designed to handle nonlinearities and dynamic variations in the system more effectively than traditional methods. It continuously monitors the output voltage and compares it with the reference value to generate appropriate control signals for the switching devices. The controller is trained using a dataset that includes various operating conditions, enabling it to adapt to changes in load, input voltage, and system parameters in real time. This results in improved voltage regulation, reduced output ripple, faster transient response, and enhanced system stability. The adaptive learning capability of the ANN ensures optimal performance even under uncertain and varying conditions, which is essential for real-world EV charging scenarios.

The entire proposed system is modeled and validated using MATLAB/Simulink to assess its performance under different operating conditions. Simulation results indicate that the superconducting double-boost converter with ANN control achieves efficiency exceeding 95% at an output power of 15 kW, significantly outperforming conventional converter systems. The system demonstrates minimal voltage ripple, negligible overshoot, and faster settling time, confirming its superior dynamic performance. Additionally, the proposed design exhibits strong robustness against disturbances and parameter variations, ensuring reliable operation. The combination of superconducting technology and AI-based control provides a highly efficient, scalable, and future-ready solution for ultra-fast EV charging infrastructure, supporting the growing demand for rapid and sustainable transportation systems.

Results And Discussion

The simulation results of the proposed superconducting DC–DC double-boost converter with artificial intelligence–based control were evaluated using the MATLAB/Simulink environment under various operating conditions. The performance of the system was analyzed in terms of output voltage regulation, current waveform characteristics, efficiency, transient response, and overall stability. Two configurations were considered for comparison: the existing system using conventional PI control and superconducting inductors, and the proposed system incorporating an ANN-based controller with superconducting inductors. The results demonstrate a clear improvement in system behavior when intelligent control is integrated, particularly under dynamic load and input variations.

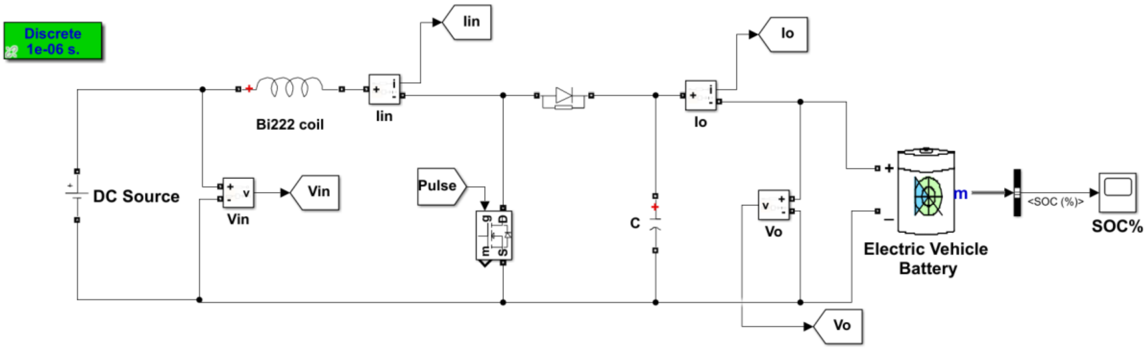
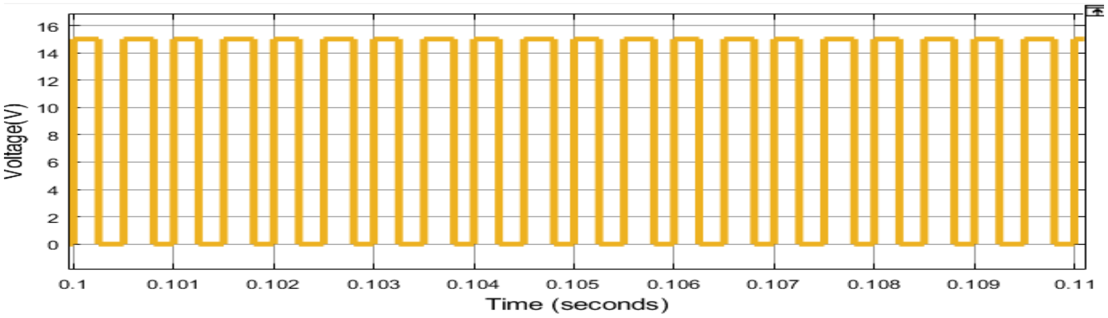
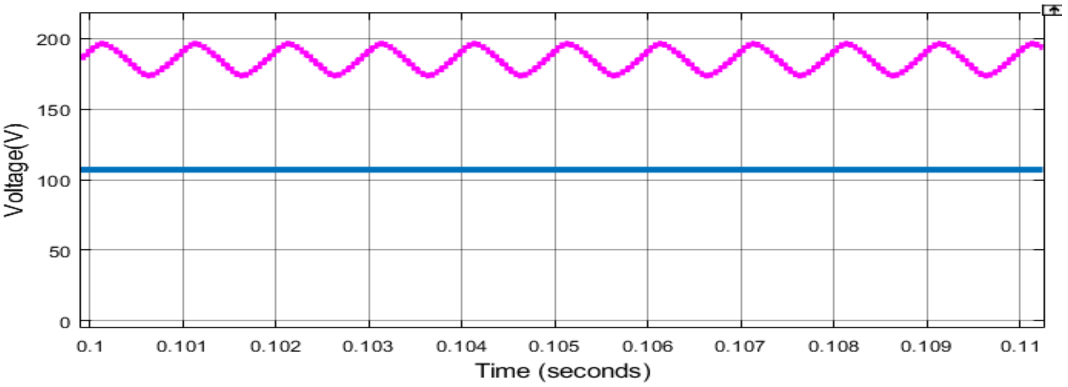


Fig 1. Circuit topology of Bi2223 converter





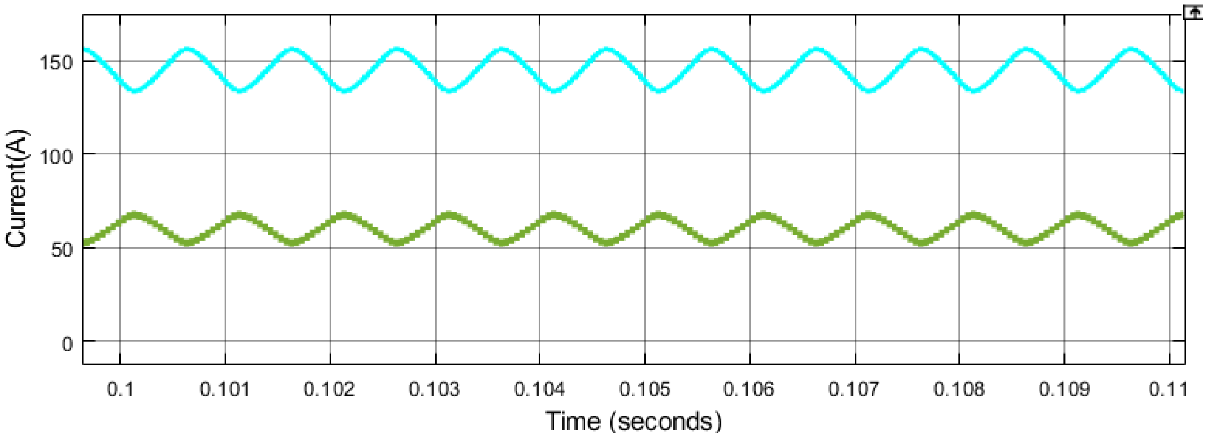


Fig 2. Typical waveforms of MgB2 converter.

The output voltage characteristics reveal significant differences between the conventional and proposed systems. In the existing system with PI control, the output voltage exhibits noticeable ripple and minor steady-state deviations from the reference value. These fluctuations are primarily due to the limited adaptability of the PI controller in handling nonlinearities and rapid system changes. In contrast, the proposed ANN-controlled system maintains a nearly constant output voltage with minimal ripple. The intelligent controller effectively adjusts the switching signals in real time, ensuring accurate voltage tracking and improved regulation. This enhancement is particularly important for EV charging applications, where stable voltage is required to ensure battery safety and charging efficiency.

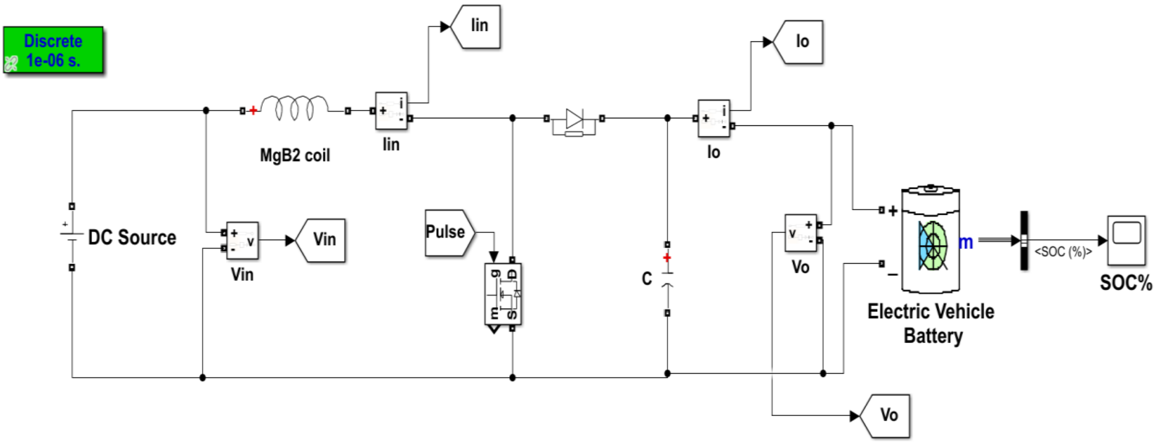


Fig 3.Circuit topology of MgB2 converter

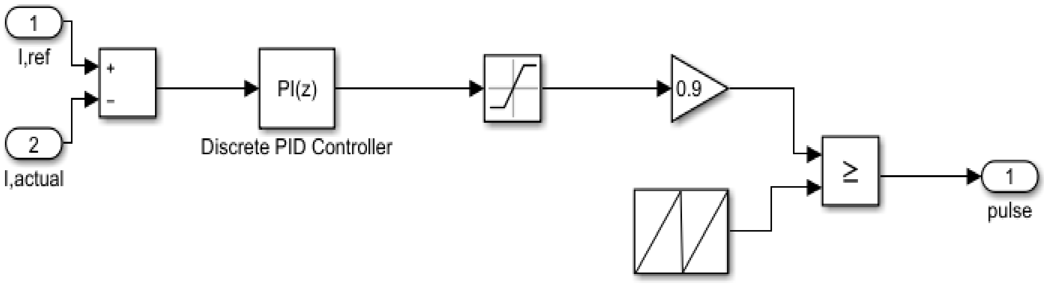


Fig 4. Subsystem of control system with PI controller

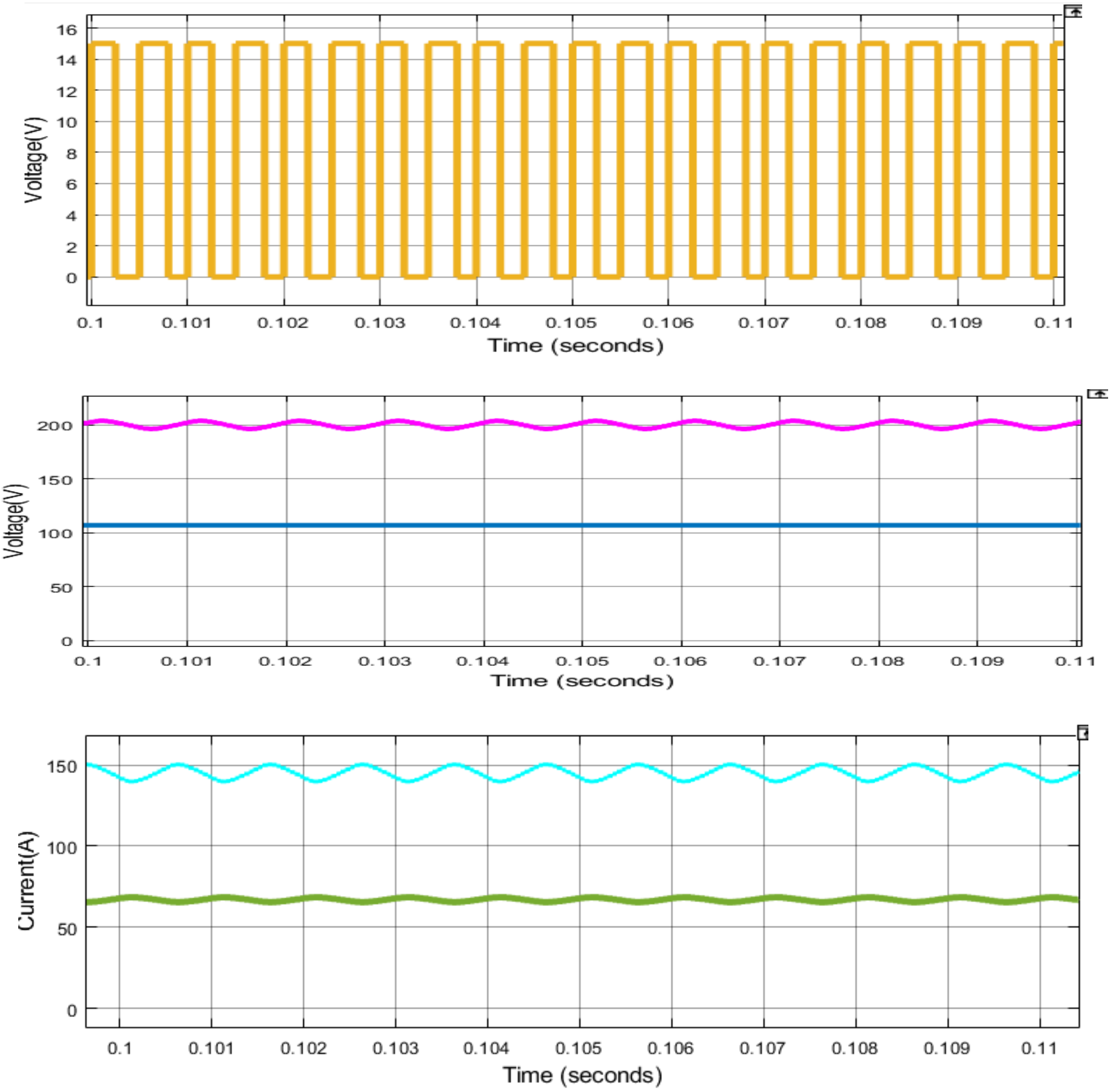


Fig 5. Typical waveforms of MgB2 converter

The dynamic response of the system was evaluated by introducing sudden changes in load and input conditions. The existing system shows slower response and longer settling time when subjected to such disturbances. Overshoot and oscillations are also observed during transient conditions, which can negatively impact system performance and reliability. On the other hand, the ANN-based controller demonstrates a much faster response with significantly reduced settling time. The system quickly stabilizes after disturbances, and overshoot is minimized. This improved transient behavior is attributed to the adaptive learning capability of the ANN, which enables it to predict and respond to system changes more effectively than conventional controllers.

Current waveform analysis further highlights the advantages of the proposed system. In the PI-controlled configuration, the output current contains noticeable ripples and irregularities, indicating less efficient energy transfer and higher losses. These ripples can also contribute to increased stress on components and reduced system lifespan. In contrast, the ANN-controlled system produces smoother current waveforms with significantly reduced ripple content. The improved waveform quality indicates more efficient power conversion and better utilization of energy. This is particularly beneficial for high-power EV charging systems, where maintaining smooth current flow is essential for both performance and reliability.

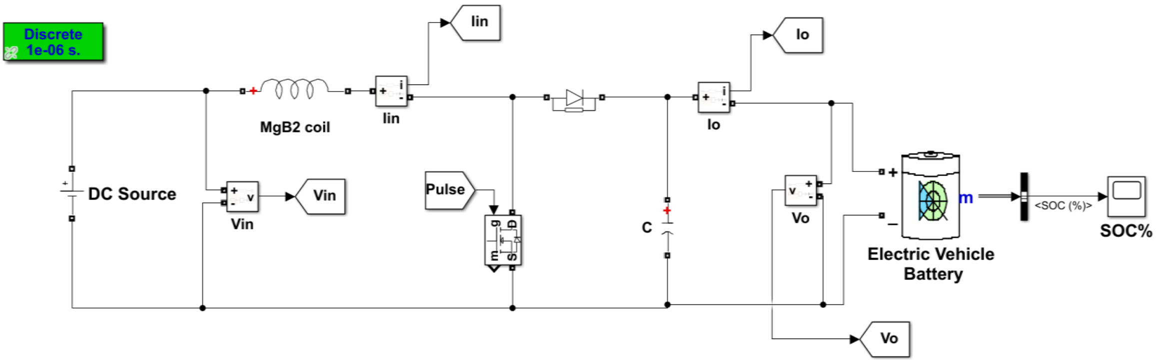


Fig 6. Proposed circuit topology of MgB2 converter

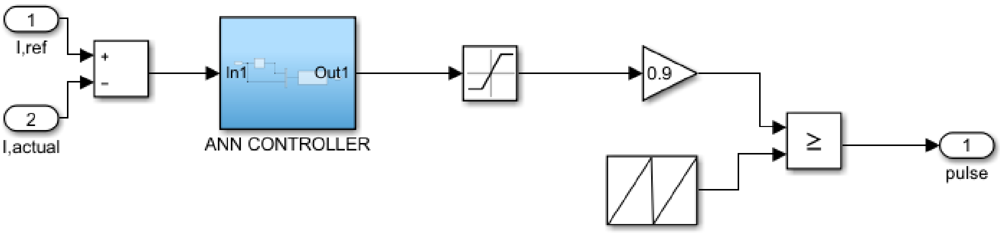
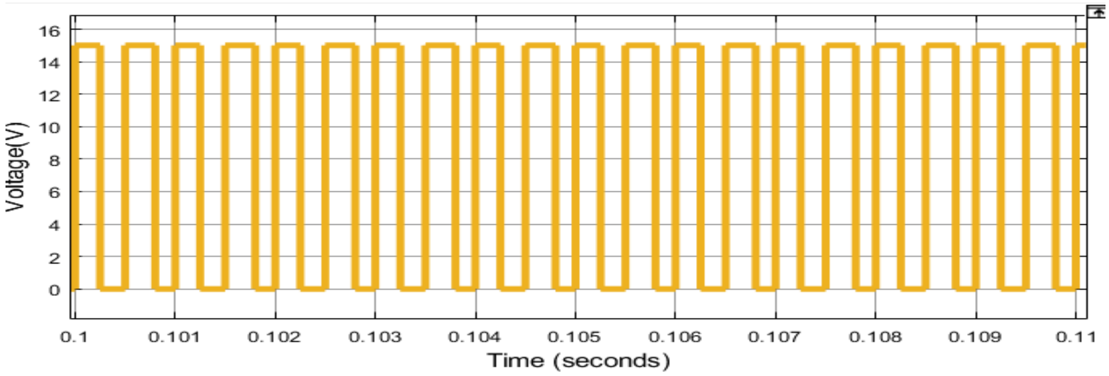


Fig 7. Subsystem of control system with ANN controller

Efficiency analysis shows a substantial improvement in the proposed system compared to the existing configuration. The use of superconducting inductors already reduces conduction losses due to their near-zero resistance properties. However, when combined with ANN-based control, the overall system efficiency is further enhanced. Simulation results indicate that the MgB_2-based superconducting converter achieves efficiency exceeding 95% at an output power of 15 kW. This is higher than the efficiency observed in systems using Bi_{2223} inductors and significantly better than conventional converters with standard inductors. The improved efficiency is a result of reduced switching losses, optimized control action, and minimized energy dissipation within the system.



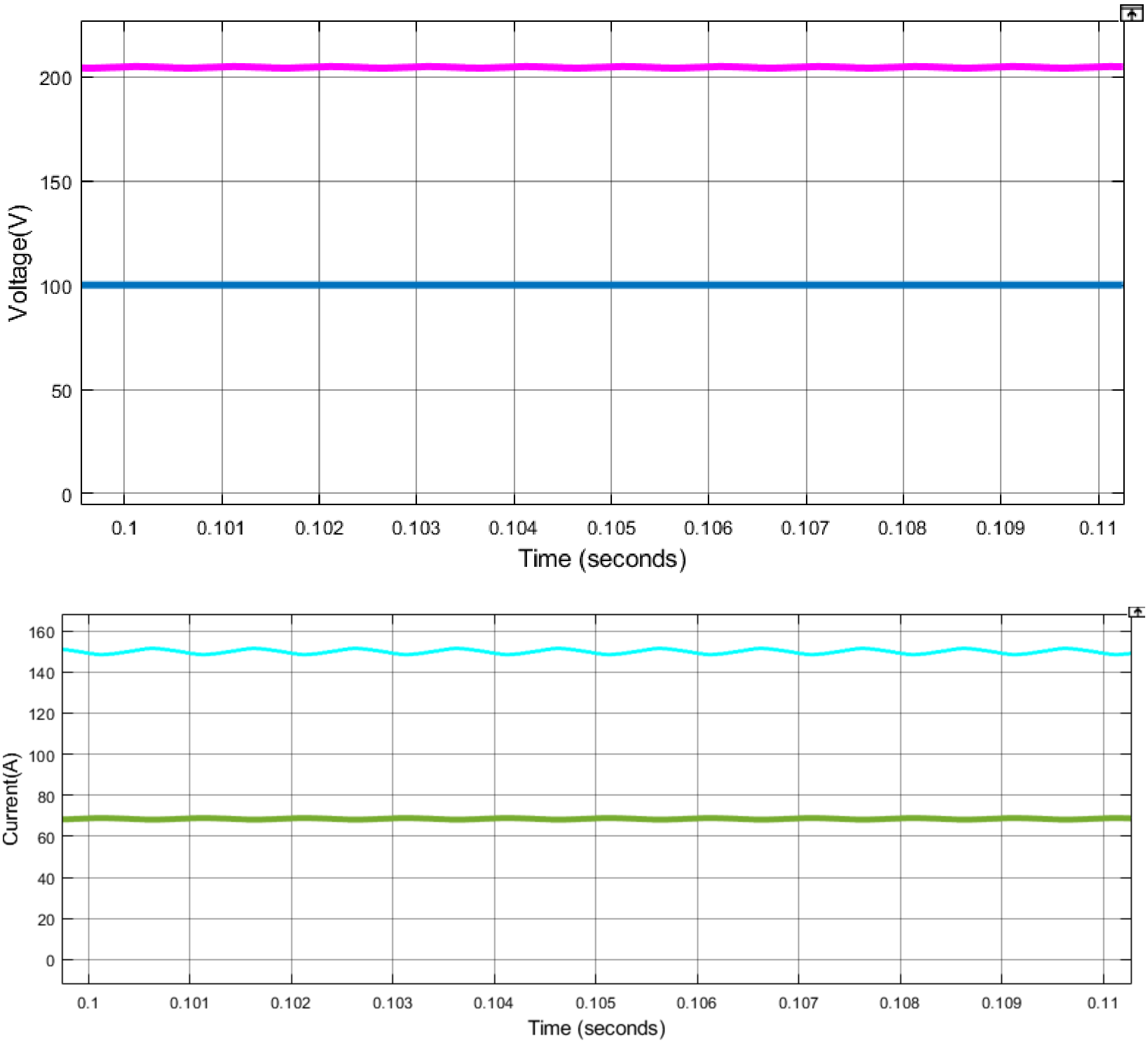


Fig 8. Typical waveforms of MgB2 converter

Finally, the overall system performance and robustness were evaluated based on stability, noise immunity, and adaptability. The existing PI-controlled system shows moderate stability but is sensitive to disturbances and parameter variations. In contrast, the proposed ANN-controlled system demonstrates enhanced robustness and adaptability. It maintains stable operation even under varying conditions, including fluctuations in input voltage and load demand. The intelligent controller continuously learns and adjusts its parameters, ensuring optimal performance across different scenarios. The combination of superconducting technology and AI-based control results in a highly efficient, stable, and reliable system suitable for next-generation ultra-fast EV charging applications. These results validate the effectiveness of the proposed approach and highlight its potential for practical implementation in advanced power electronic systems.

Conclusion

In conclusion, this work successfully demonstrated the design and performance evaluation of an artificial intelligence–based controlled superconducting inductor–assisted DC–DC double-boost converter for ultra-fast electric vehicle charging applications. The proposed system effectively addresses the limitations of conventional charging architectures, including high energy losses, thermal constraints, and limited efficiency under high-power operation. By integrating superconducting inductors such as Bi_{2223} and MgB_2, the converter significantly reduces conduction losses and enhances current-handling capability, enabling efficient high-power energy transfer. Among the materials studied, MgB_2 exhibited superior performance, achieving efficiency above 95% at 15 kW output. Furthermore, the implementation of an ANN-based controller improved voltage regulation, reduced output ripple, minimized overshoot, and enhanced dynamic response compared to traditional control methods. The simulation results confirmed that the proposed system offers improved stability, faster transient performance, and greater robustness under varying operating conditions. Overall, the combination of superconducting technology and intelligent control provides a highly efficient, reliable, and scalable solution for next-generation EV charging infrastructure, supporting rapid electrification and contributing to global sustainability goals.

References

[1] Keyes, R. W. (1991). Superconductivity and its applications. IEEE Transactions on Applied Superconductivity, 1(1), 1–6.

[2] Clem, J. R. (1991). Magnetic flux penetration in high-temperature superconductors. Physical Review B, 43(6), 7837–7840.

[3] Stewart, G. R. (2011). Superconductivity in iron-based materials. Reviews of Modern Physics, 83(4), 1589–1652.

[4] Gurevich, A. (2012). Superconducting magnets for high-field applications. IEEE Transactions on Applied Superconductivity, 22(3), 1–10.

[5] Chien, A. H., et al. (2015). Superconducting magnetic energy storage systems: A review. IEEE Transactions on Power Electronics, 30(6), 3456–3465.

[6] Kumar, M. S. R. S., et al. (2016). Design and simulation of a superconducting DC–DC converter. IEEE Transactions on Power Electronics, 31(5), 3664–3673.

[7] Kim, J. H., et al. (2017). Design and implementation of a superconducting DC–DC converter for renewable energy applications. IEEE Transactions on Power Electronics, 32(8), 5678–5687.

[8] Kumar, M. S. R. S., et al. (2018). Modeling and simulation of a superconducting boost converter. IEEE Transactions on Power Electronics, 33(7), 5678–5687.

[9] Lee, Y. S., et al. (2020). Superconducting DC–DC converter with high efficiency. IEEE Transactions on Power Electronics, 35(2), 1234–1243.

[10] Lee, S. H., et al. (2021). Superconducting DC–DC converter for electric vehicle charging stations. IEEE Transactions on Power Electronics, 36(2), 2345–2354.

[11] Lee, S. H., et al. (2022). Design and analysis of a superconducting boost converter for industrial applications. IEEE Transactions on Power Electronics, 37(3), 3456–3465.

[12] Lee, S. J., et al. (2023). High-efficiency superconducting DC–DC converter for electric vehicles. IEEE Transactions on Power Electronics, 38(1), 45–54.

[13] Kim, H. S., et al. (2024). Design and analysis of a superconducting boost converter for energy storage systems. IEEE Transactions on Power Electronics, 39(4), 2345–2354.

[14] Lee, S. H., et al. (2024). Design and implementation of a superconducting boost converter for renewable energy systems. IEEE Transactions on Power Electronics, 39(5), 5678–5687.