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ARTIFICIAL NEURAL NETWORK-BASED BATTERY MANAGEMENT AND POWER CONTROL IN A BIDIRECTIONAL MULTI-LEVEL CONVERTER FOR ELECTRIC VEHICLE

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ABSTRACT: Electric Vehicles (EVs) have emerged as a sustainable alternative to conventional transportation, necessitating advanced energy management strategies for effective battery utilization. This project presents the modeling, simulation, and performance analysis of a smart Battery Management System (BMS) integrated with a Bidirectional DC-DC Converter, controlled using an Artificial Neural Network (ANN). The proposed system demonstrates intelligent battery selection, accurate SoC estimation, and stable voltage regulation. It was developed in MATLAB/Simulink and validated by dynamic simulation scenarios. The initiative aims to contribute to the design of intelligent EV charging infrastructure in order to guarantee battery longevity and enhanced system performance.

Suggested system, which is created in MATLAB/Simulink and verified by dynamic simulation scenarios, exhibits intelligent battery selection, precise SoC estimation, and stable voltage regulation. In order to ensure battery longevity and improved system performance, the effort intends to contribute to the design of intelligent EV charging infrastructure.

Keywords: Electric Vehicles (EVS), Battery Management System (BMS), State Of Charge (SOC). Artificial Neural Network (ANN)

I. INTRODUCTION

The use of electric vehicles (EVs) as a greener substitute for cars with internal combustion engines has increased due to the worldwide movement toward decarbonization and sustainable transportation. However, the effectiveness of EVs' energy storage and management systems has a significant impact on their performance, dependability, and user uptake. Battery Management Systems (BMS) are pivotal in ensuring the safety, reliability, and longevity of EV batteries by monitoring critical parameters such as State of Charge (SoC), State of Health (SoH), voltage, current, and temperature. Traditional BMS implementations rely on model-based methods like the Extended Kalman Filter (EKF), Coulomb Counting, or voltage estimation. While widely used, these techniques often lack adaptability under dynamic and nonlinear battery behavior, particularly during rapid charging, load variation, or regenerative braking scenarios.

In recent years, Artificial Neural Networks (ANNs) have emerged as a robust and flexible alternative for modeling complex, nonlinear systems due to their capacity to learn data driven correlations without requiring explicit physical modeling.

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The use of ANN in BMS applications has shown significant improvement in real-time SoC estimation, fault diagnosis, and adaptive control. Unlike rule-based systems, ANNs can generalize across operating conditions and enhance the predictive accuracy of SoC and SoH under various load and environmental conditions.

This project introduces the following advancements in battery management and EV charging technology

- Development of a MATLAB/Simulink-based simulation framework for a multi battery EV charging system.
- Implementation of a feed forward ANN model for SoC prediction using voltage, current, and temperature as input features.
- Integration of ANN outputs with switching logic for dynamic battery selection and converter mode control.

Performance validation through simulation results under various charging and discharging scenarios. This project aims to offer a cost-effective, intelligent, and adaptable solution for EV battery management and charging infrastructure, contributing to the future of smart mobility systems.

II. METHODOLOGY

The ANN model is trained offline using supervised learning techniques with battery data collected from simulations and empirical data. The ANN is structured as follows:

- Inputs: Battery voltage, current, temperature
- Hidden Layer: 1 hidden layer with 10 neurons
- Output: Estimated SoC

Levenberg-Marquardt back propagation is used to train the neural network with a Mean Squared Error (MSE) target of less than 0.001. After training, MATLAB's Neural Network Toolbox (gensim or genFunction) is used to embed the ANN into the Simulink model, enabling real-time estimation during simulation. In this research, the integration of an Artificial Neural Network (ANN) is central to developing an intelligent control framework for electric vehicle (EV) charging using a bidirectional DC-DC converter. Based on real-time inputs like voltage, current, temperature, and past charging patterns, the ANN is intended to forecast and optimize important charging parameters, such as battery state-of-charge (SOC), power flow direction, and control mode selection. The ANN is developed using supervised learning techniques and is implemented as a feedforward neural network design with one or more hidden layers. Control Strategy for Bidirectional Converter

The bidirectional converter is controlled through a closed-loop control system that adjusts the PWM duty cycle in real time based on:

- Desired load voltage/current
- Battery SoC status
- Mode of operation (charging or discharging)

The converter operates under the supervision of the ANN, which continuously monitors system variables to decide whether to:

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• Charge a selected battery

• Discharge to the EV load

• **Idle (no energy exchange)**

An essential component of intelligent, dependable, and effective electric vehicle (EV) charging is the bidirectional DC-DC converter control approach. In order to govern the converter's operation in both buck (charging) and boost (discharging) modes based on the battery's state-of-charge (SOC), system voltage levels, and power flow requirements, this study uses a hierarchical, dual-mode control architecture.An essential component of intelligent, dependable, and effective electric vehicle (EV) charging is the bidirectional DC-DC converter control approach. In order to govern the converter's operation in both buck (charging) and boost (discharging) modes based on the battery's state-of-charge (SOC), system voltage levels, and power flow requirements, this study uses a hierarchical, dual-mode control architecture.

The ability to smoothly transition between these two operating modes while preserving peak performance and battery health is the basis of the control strategy. Feedback loops, logical switching conditions, and real-time voltage, current, and SOC measurements are used in MATLAB/Simulink to create the control method.

Design of a Bidirectional DC-DC Converter The bidirectional DC-DC converter plays a pivotal role in modern electric vehicle (EV) charging infrastructure, enabling dynamic energy transfer between the battery pack and the power source

Mathematical modeling is a crucial component of this research, forming the foundation for control development. The bidirectional DC-DC converter is analyzed in continuous conduction mode (CCM), and the corresponding differential equations governing inductor current (i_L) and capacitor voltage (v_C) are derived. These equations are linearized and expressed in the statespace format for both buck and boost operations. The generalized state-space equations are given as

$$dx/dt = Ax + Bu \quad \text{and}$$

$$y = Cx + Du$$

where A, B, C, and D are the system matrices representing dynamics. This modeling approach facilitates the application of classical and modern control techniques.

In the buck mode (charging operation), the inductor current increases when the switch is ON and energy is stored in the inductor. When the switch turns OFF, this energy is transferred to the battery through the freewheeling diode.

The dynamic behavior is captured by the equations: $di_L/dt = (V_{in} - V_{bat})/L$ and $dv_{bat}/dt = i_L/C$.

In boost mode (discharging operation), the battery provides energy to the load through the inductor. The switching strategy ensures that the inductor charges when the switch is closed and discharges through the load when the switch is open. The corresponding equations are:

$$di_L/dt = (V_{bat})/L \text{ and}$$

$$dv_{out}/dt = (i_L - i_{load})/C.$$

These equations are used to derive transfer functions and design the control loops.

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Battery Modeling

Each battery module is modeled using a second-order equivalent circuit model (ECM), capturing key dynamics including:

• Open Circuit Voltage (OCV)

• Internal resistance (Rint)

• Temperature-dependent behavior

Each battery is initialized with a distinct SoC to test the system's ability to select and charge/discharge based on the ANN's decisions. Battery capacity, nominal voltage, and discharge curves are set based on lithium-ion chemistry commonly used in EVs. Battery modeling is a fundamental aspect of the research methodology in the development of intelligent EV charging systems.

III SIMULATION DIAGRAM

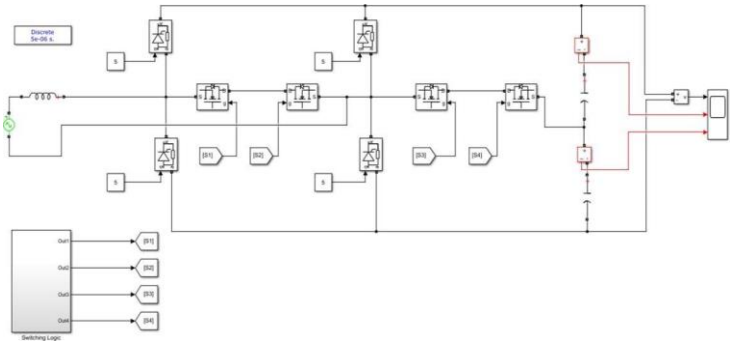
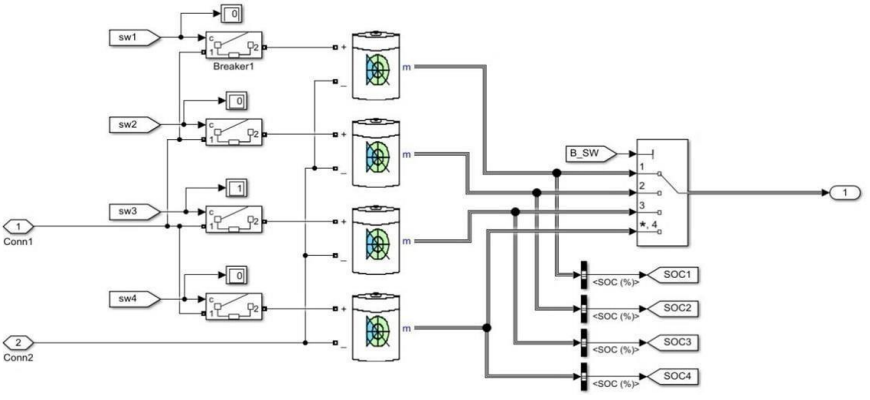


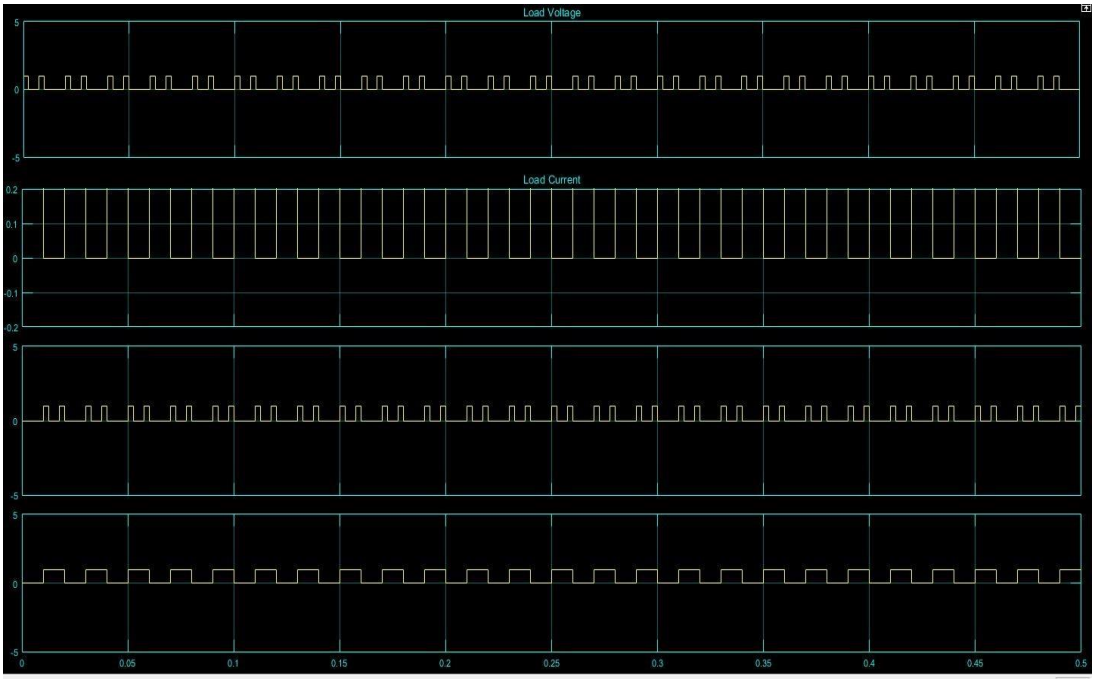
Fig.1 Battery Bank and Switching Logic

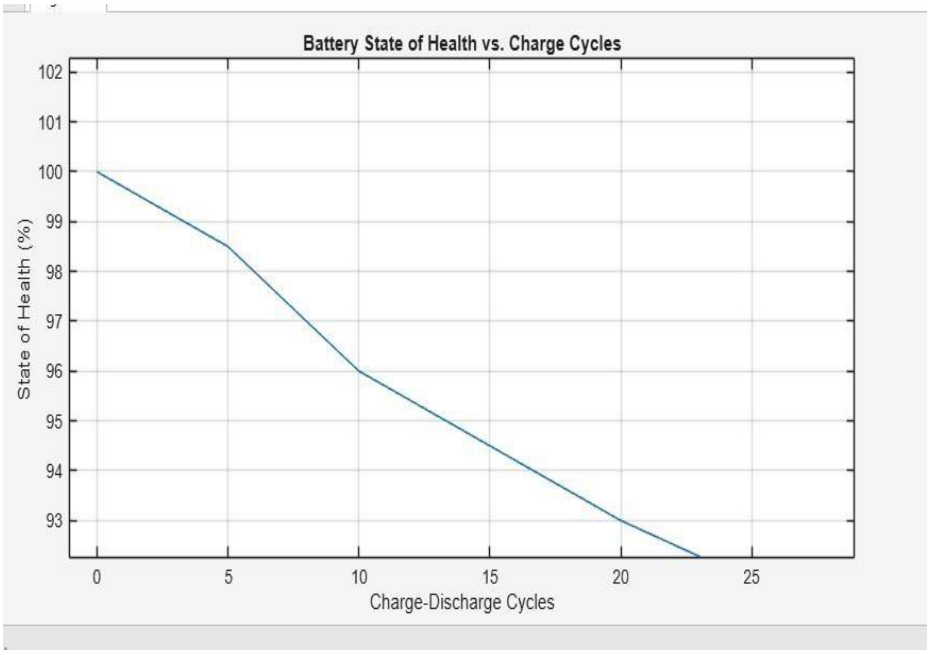
The battery management subsystem allows selective connection of battery units using breakers. Each battery is monitored for SoC, and a multiplexer is used to route the active battery's output. This setup enables efficient energy management and avoids overcharging/discharging individual batteries.



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IV. RESULT AND DISCUSSION





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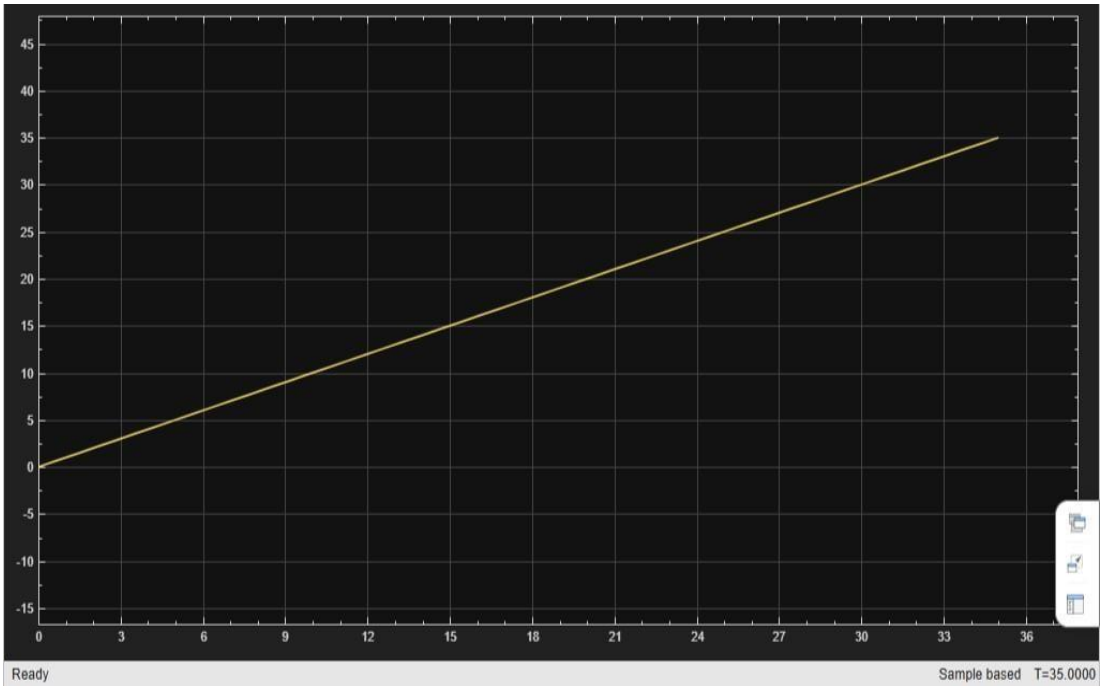


Fig.2 Simulation Results

The following findings were noted after the simulation ran for 20 seconds:Stable charging is shown by the battery's SoC progressively rising from 60% to 60.07%. With very little ripple, the battery voltage stabilizes at about 25.98V.The battery continues to charge steadily, with a current of about -6A.

The load voltage is well regulated around 48V, suitable for DC applications.The simulation results obtained from the proposed ANN-based Battery Management System (BMS) integrated with a bidirectional DC-DC converter clearly demonstrate the effectiveness of the system in achieving reliable energy management for electric vehicle (EV) charging applications. The Artificial Neural Network (ANN) was trained using synthetic battery data that included voltage, current, and temperature parameters under dynamic load conditions. It effectively predicted the State of Charge (SoC) in real time with minimal estimation error, allowing for intelligent switching among multiple battery modules to optimize load sharing and battery utilization.

During the simulation, the SoC of the selected battery module increased gradually from an initial value of 60% to 60.07% within a 20-second interval, indicating a wellregulated charging process. The ANN successfully identified the battery with the lowest SoC for charging and made switching decisions without delay or overlap, demonstrating high adaptability and responsiveness to changing conditions

V. CONCLUSION

The design and simulation of an Artificial Neural Network (ANN)-based battery management and power control strategy for electric vehicle (EV) charging applications using a bidirectional DC-DC converter has been thoroughly examined in this thesis. To ensure effective energy flow during both charging (buck) and discharging (boost) operations, the suggested system combines precise State of Charge (SoC) estimate, intelligent battery selection, and dynamic management of a bidirectional converter. Implemented within the MATLAB/Simulink environment, the system was rigorously tested under varying load and battery conditions. Simulation results validated the effectiveness of the ANN in enhancing SoC tracking accuracy, maintaining voltage stability, and enabling fast, adaptive switching

decisions among battery modules. Compared to traditional rule-based control approaches, the ANN-driven method demonstrated superior adaptability, responsiveness, and energy efficiency. Overall, the research confirms the potential of ANN-integrated systems to significantly improve the performance, safety, and scalability of modern EV charging architectures.

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