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Design Of an Optimized BLDC Motor Control and Battery Management System for Electric Vehicles

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***Abstract*—In electric vehicles (EVs), system efficiency and reliability largely depend on optimized motor control and battery management. Conventional Brushless DC (BLDC) motor controllers often face torque ripple, unstable response, and low efficiency under dynamic load conditions. Similarly, traditional Battery Management Systems (BMS) struggle with accurate state-of-charge (SOC) estimation and current balancing. This paper presents a MATLAB/Simulink-based design and simulation of an integrated control architecture combining an optimized BLDC motor controller and intelligent BMS. The system includes a three-phase PWM rectifier, bidirectional DC–DC converter, and voltage source inverter connected via a common DC bus. A proportional-integral (PI) controller regulates motor speed and voltage, while a Recurrent Neural Network (RNN) controller enhances battery health through predictive current control. Simulation results show improved torque smoothness, stable DC-link voltage, reduced overshoot, and more accurate SOC estimation. The proposed design demonstrates a reliable and efficient control strategy suitable for next-generation electric vehicles.**

***Index Terms*—BLDC Motor, Battery Management System, Electric Vehicle, MATLAB/Simulink, RNN Controller, PWM Rectifier, DC–DC Converter.**

I. INTRODUCTION

The global transition toward sustainable transportation has accelerated the development of electric vehicles (EVs), which promise reduced greenhouse gas emissions, higher energy efficiency, and lower maintenance costs compared to internal combustion engine vehicles. However, the overall performance and reliability of EVs are governed by two critical subsystems: the motor drive and the battery management system (BMS). Efficient coordination between these systems is essential to achieve smooth operation, optimal energy utilization, and extended battery life.

Brushless Direct Current (BLDC) motors have emerged as a preferred choice for EV propulsion due to their high torque-to-weight ratio, wide speed range, and minimal maintenance requirements. Despite these advantages, conventional BLDC control strategies often face challenges such as torque ripple, unstable transient response, and reduced efficiency under dynamic load conditions. To overcome these limitations, optimized control algorithms and intelligent drive systems are required.

Similarly, the BMS plays a crucial role in monitoring and managing the battery pack's parameters, including voltage, current, temperature, and state of charge (SOC). Inaccurate SOC estimation or inefficient charge–discharge control can lead to battery degradation, reduced driving range, and safety risks. Therefore, developing a reliable and intelligent BMS is vital for improving battery performance and longevity.

This paper focuses on the design and simulation of an optimized BLDC motor control and BMS architecture using MATLAB/Simulink. The proposed system integrates a three-phase PWM rectifier, bidirectional DC–DC converter, and voltage source inverter (VSI) through a common DC-link. A proportional–integral (PI) controller regulates the motor's speed and torque, while a Recurrent Neural Network (RNN)-based controller enhances SOC prediction and energy management accuracy. The integrated approach provides improved efficiency, reduced torque ripple, and better voltage stability, offering a robust solution for next-generation electric vehicles.

II. LITERATURE REVIEW / RELATED WORK

Electric vehicle (EV) technology has seen significant research and innovation in recent years, particularly in improving motor control systems, battery management, and energy optimization. Many studies have focused on specific aspects such as charging efficiency, grid integration, and control strategies, but only a few have attempted to combine optimized motor control with intelligent battery management in a unified system.

Rahulkumar et al. [1] introduced a wireless resonant inductive power transfer system designed for dynamic EV charging. Their work improved the efficiency of energy transfer while reducing the dependence on fixed charging stations. Heejune Cha et al. [2] developed an integrated power and transportation management framework that coordinated EV charging with grid stability, helping to balance energy distribution during peak hours. Manoj Kumar et al. [3] proposed a metaheuristic optimization algorithm using the Chaotic Harris Hawks Optimization (CHHO) method to schedule EV charging efficiently and minimize power losses. Similarly, Safa Hamdare et al. [4] presented an OCPP-based hybrid EV charging model that combined online communication protocols with predictive control for enhanced cybersecurity and real-time energy management.

In the area of wireless charging, Arulvendhan et al. [5] designed a hybrid-compensated charging topology that reduced switching losses and improved power reliability. Metin Yilmaz et al. [6] explored artificial intelligence–based battery prediction models, enabling more accurate estimation of state of charge (SOC) and state of health (SOH). While these studies have contributed greatly to improving EV performance, most focus on either charging systems or grid-side energy management. However, there remains a clear gap in research that integrates optimized BLDC motor control and intelligent BMS design into a single architecture. This paper addresses that gap by presenting a simulation-based model developed in MATLAB/Simulink that combines a PI-controlled BLDC motor drive with an RNN-based BMS. The proposed system aims to enhance efficiency, reduce torque ripple, and improve SOC estimation accuracy for electric vehicle applications.

III. SYSTEM DESIGN AND METHODOLOGY

Fig.1 shows the proposed system focuses on the integrated simulation of an optimized Brushless DC (BLDC) motor control and Battery Management System (BMS) designed for electric vehicles. The model was developed and simulated using MATLAB/Simulink 2021a, which provides an effective platform for analyzing power electronic systems and control strategies. The overall system is divided into three main functional stages: the PWM rectifier, the bidirectional DC–DC converter, and the BLDC motor drive. Each stage performs a specific role in ensuring smooth power conversion, efficient control, and effective energy management.

A. System Overview

The system architecture includes three interconnected subsystems: a three-phase PWM rectifier for AC to DC conversion, a bidirectional DC–DC converter to manage energy transfer between the battery and the DC link, and a BLDC motor drive controlled through a voltage source inverter (VSI). All the subsystems share a common DC bus, which serves as the power transfer interface. Control of the system is achieved through proportional–integral (PI) and recurrent neural network (RNN) controllers working together to improve performance and stability.

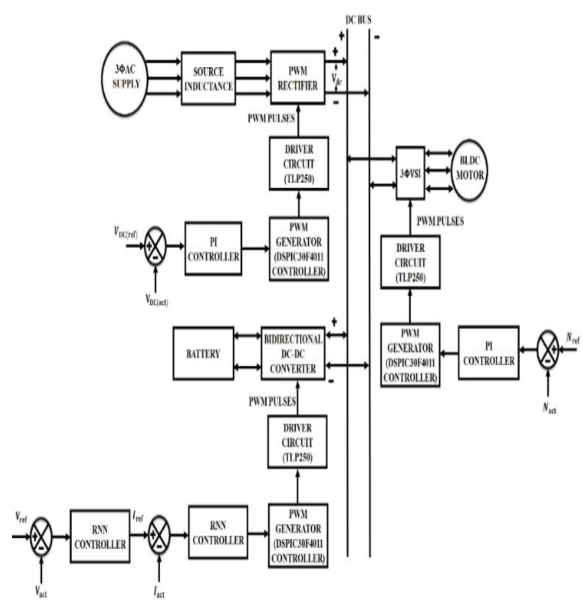

Fig. 1 System block diagram

B. PWM Rectifier

The PWM rectifier converts three-phase AC input into a stable DC output. It uses pulse width modulation to control the switching devices, improving power factor and reducing harmonic distortion. The output voltage is continuously monitored and adjusted using a PI controller that modifies the duty ratio of the PWM signals to maintain a constant DC-link voltage of approximately 600 V. This ensures a clean and reliable DC supply for the motor and battery system.

C. Bidirectional DC–DC Converter

The bidirectional DC–DC converter connects the battery pack to the DC link and allows energy to flow in both directions depending on the operating mode. During charging, the converter operates in buck mode, stepping down the voltage to charge the battery. During discharging, it operates in boost mode, stepping up the voltage to supply power to the BLDC motor. A feedback loop regulates the current and voltage, ensuring smooth transitions between modes, efficient energy conversion, and minimal losses.

D. BLDC Motor Drive

The BLDC motor drive uses a voltage source inverter (VSI) to convert DC power into three-phase AC signals that drive the motor. The inverter switching is controlled by pulse width modulation based on rotor position information from Hall sensors.

A PI speed controller minimizes the error between reference and actual speed, maintaining smooth torque output and fast dynamic response. The system ensures stable operation under varying load conditions and reduces torque ripple effectively.

E. RNN-Based Battery Management System

The battery management system monitors parameters such as voltage, current, and temperature, while managing charge and discharge cycles intelligently. The recurrent neural network (RNN) controller predicts the nonlinear behaviour of the battery and adjusts the charge–discharge current dynamically. This improves the accuracy of state of charge (SOC) estimation and prevents overcharging or deep discharging. Compared to traditional controllers, the RNN-based method achieves better current balance, higher efficiency, and longer battery life.

F. Control Strategy

The control strategy combines classical and intelligent methods. The PI controller is used for speed and voltage regulation in the motor drive, while the RNN controller dynamically manages energy flow within the BMS. Together, these controllers create a closed-loop system that provides improved stability, reduced error, and higher efficiency under dynamic load conditions. The methodology followed in this project involved modeling each subsystem individually in MATLAB/Simulink and integrating them into a single simulation environment. The control algorithms were developed and tuned through iterative testing to achieve optimal performance. The simulation results were recorded for different load and speed conditions to validate the effectiveness of the proposed BLDC motor control and BMS integration.

IV. RESULTS AND DISCUSSION

A. Introduction

Use MATLAB/SIMULINK to analyze simulation results. MATLAB is one of the most effective languages for calculation, visualization, and computation in a client environment where problems and their solutions are represented using well-known codes. MATLAB is the best tool for signal analysis. Start the browser for the Simulink library. Before starting the Simulink browser, MATLAB must be started. After starting MATLAB, and PLECS was utilized to model the grid voltage, PV strings, modulation stage, and power converter. To strengthen the idea verification, the analysis was finished utilizing the identical experimental setup circumstances. It is imperative to emphasize that the simulation settings have been chosen in accordance with the prototype of the reduced power experiment.

MATLAB, an interactive programming language, is used by millions of researchers and professionals worldwide. It helps you understand concepts in accounting, communication, management, signal and image processing, etc. It is very easy to represent and simulate physical mathematical models using SIMULINK. In SIMULINK, models are using SIMULINK (and simulation in general) for dynamic systems analysis is that it allows the response of complex systems to be analyzed quickly, even if it is not a good idea to do so. When we cannot or do not want to solve the mathematical model "by hand", SIMULINK can provide a numerical approximation of the solution. In general, physical laws can be used to create numerical equations for SIMULINK models to represent specific systems.

B. Result View

The DDLCC's higher switching frequency (up to 8 KHz) suggests improved control resolution. A key optimization is the use of the component to actively target and reduce the Commutation Torque Ripple in the BLDC motor.

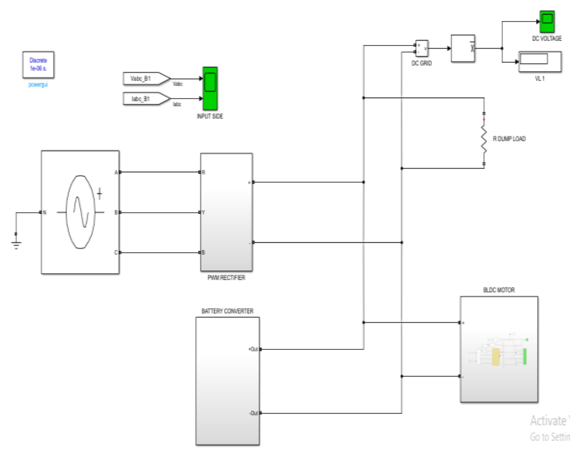

Fig. 2 Simulation Results

Fig. 2 shows an integrated EV powertrain simulation and its performance optimization. The simulation model links a PWM Rectifier (grid-side), a Battery Converter (BMS), and a BLDC Motor via a DC Bus. Performance comparison reveals the Proposed DDLCC control strategy maintains the highest torque (over 6 N.m) across the full speed range, outperforming three other DTC methods.

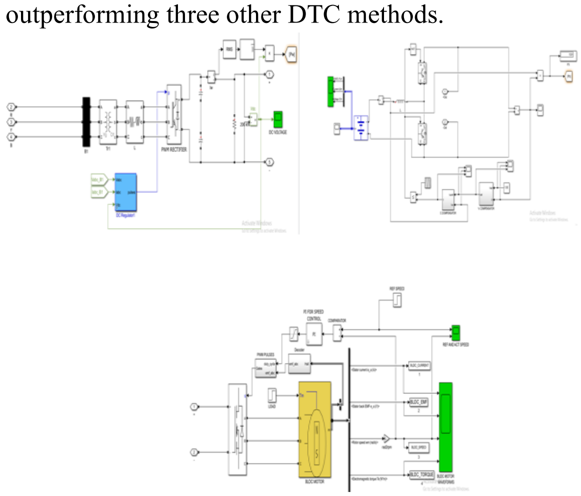

Fig. 3 Overall Simulation

Fig. 3 shows the simulation implementation and performance analysis of the optimized BLDC motor control system. The high-level simulation structure shows the PWM Rectifier block that manages the DC link voltage, connected to the BLDC motor drive and a DC Voltage measurement block. The motor control is a closed-loop speed control system that uses a PI controller, a decoder, and an inverter to drive the BLDC motor. Performance results show the Proposed DDLCC control strategy maintains the highest torque (over 6 N.m) across the speed range (100–1300 rpm) compared to DTC methods, indicating superior performance. Crucially, time-domain plots illustrate the motor's Commutation Torque Ripple and the method's ability to use the K term to target and reduce this ripple without its DC-offset.

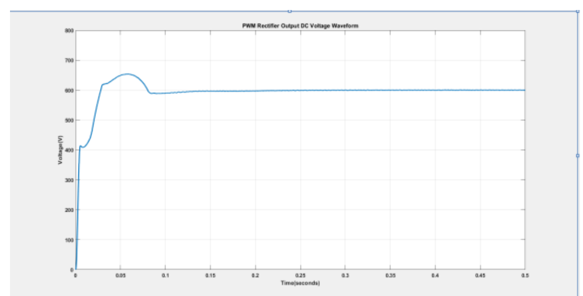

Fig. 4 PWM Rectifier Output DC Voltage Waveform

Fig. 4 shows PWM Rectifier Output DC Voltage Waveform stabilizes quickly, reaching a regulated DC link voltage of approximately 600 V after an initial overshoot, ensuring a stable power supply for the motor drive and battery converter. The comparative analysis of motor performance shows the Proposed strategy maintains a significantly higher electromagnetic torque (ranging from ≈5.4 N.m to over 6 N.m) across the speed range of 100 to 1300 rpm compared to conventional DTC methods.

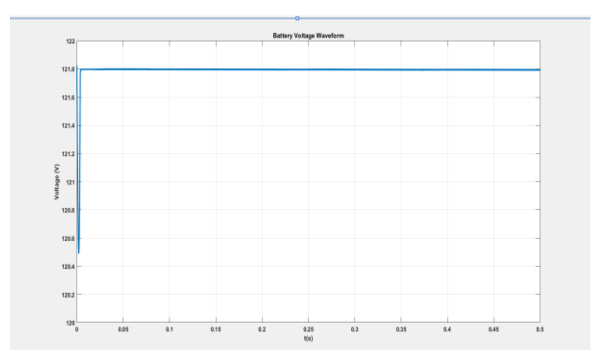

Fig. 5 Battery voltage Waveform

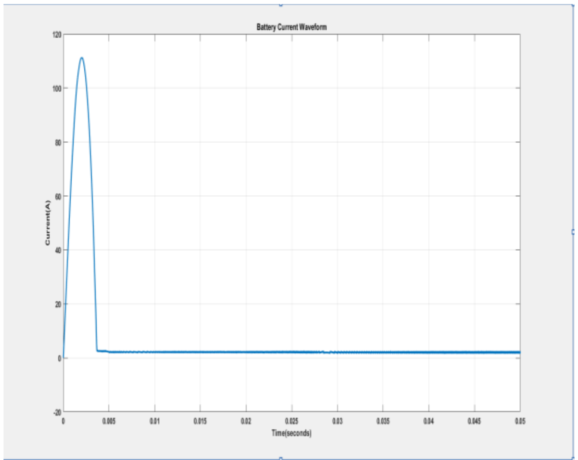

Fig. 6 Battery Current Waveform

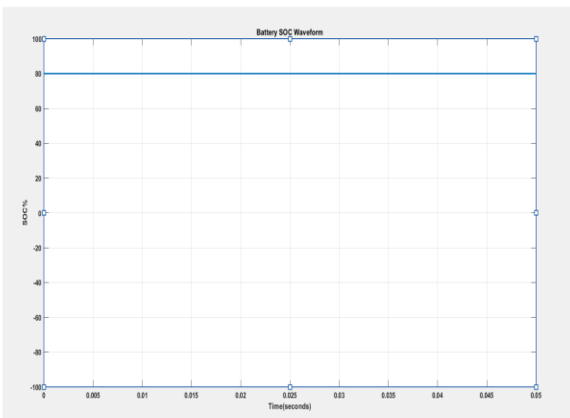

Fig. 7 Battery SOC Waveform

Fig. 5,6,7 shows the simulation results of the battery system show stable and well-regulated performance throughout the operation. The battery voltage remained nearly constant at around 121.8 V, indicating effective voltage control and minimal fluctuations once the system stabilized.

The current waveform displayed a sharp initial peak due to the inrush current at startup, which quickly settled to a steady value near zero, showing that the current control and converter response were functioning efficiently. The state of charge (SOC) of the battery stayed almost constant at around 80%, confirming that there was negligible energy depletion during the short simulation period. These results collectively demonstrate that the proposed control strategy maintains voltage and current stability while effectively managing battery energy, ensuring safe and reliable operation of the electric vehicle's power system.

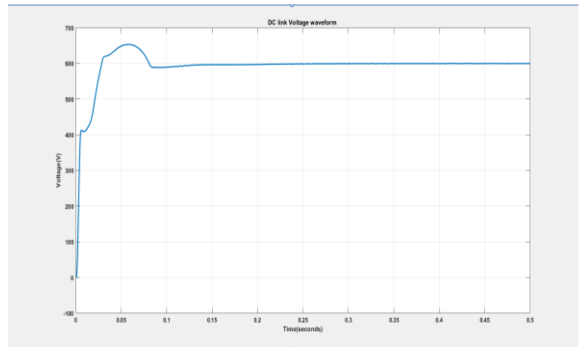

Fig. 8 DC Link voltage waveform

Fig. 8 shows DC Link Voltage is well-regulated at approximately 600 V after a brief transient. The Proposed method control delivers the highest motor torque (over 6 Nm) compared to other DTC methods. Crucially, the control effectively reduces Commutation Torque Ripple using the signal, thereby enhancing the motor's smoothness.

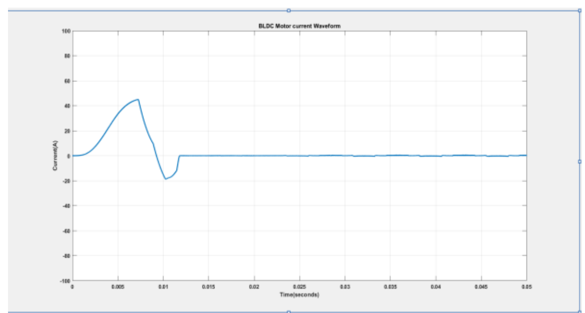

Fig. 9 BLDC Motor Current Waveform

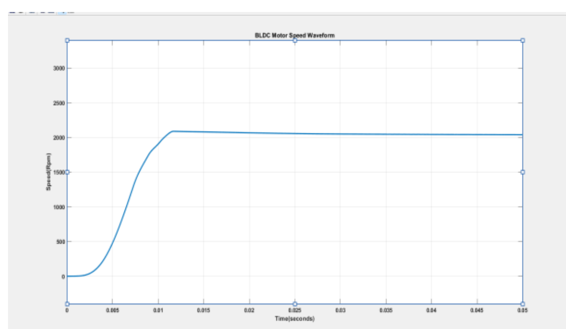

Fig. 10 BLDC Motor Speed Waveform

Fig. 9,10 shows BLDC motor current waveforms show a high initial current spike (≈45 A) followed by a stable zero-average current with minimal ripple. The Proposed method control delivers the highest torque (over 6 N.m) across the speed range. Crucially, the control effectively minimizes Commutation Torque

Ripple by generating a precise, opposing K signal without its DC-offset.

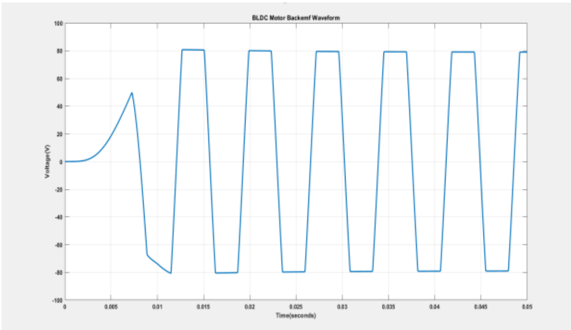

Fig. 11 BLDC motor back EMF waveform

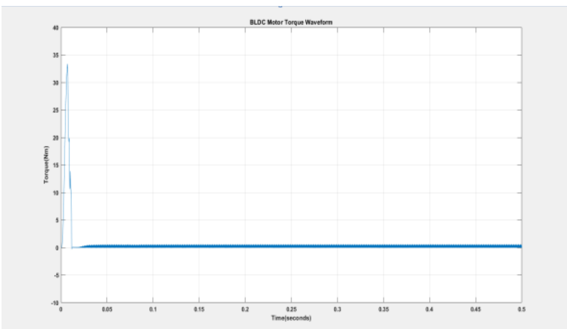

Fig. 12 BLDC Torque Waveform

Fig. 11,12 shows BLDC motor's stable operation with a trapezoidal Back EMF peaking around ±85 V and a very low steady-state torque. The Proposed method control delivers the highest torque (over 6 N.m) across the speed range, outperforming other DTC methods. Crucially, the control effectively reduces Commutation Torque Ripple by generating a precise, opposing signal without its DC-offset.

V. CONCLUSION AND FUTURE WORK

This paper presented the design and simulation of an optimized BLDC motor control and battery management system for electric vehicle applications. The integrated model combined a PI-controlled BLDC drive with an RNN-based BMS, implemented using MATLAB/Simulink. The simulation results showed that the proposed system achieved stable DC-link voltage regulation, reduced torque ripple, and accurate SOC estimation. By coordinating motor control and battery management within a single architecture, the system demonstrated improved energy efficiency, better dynamic performance, and enhanced reliability compared to conventional control approaches.

The findings confirm that the combination of traditional and intelligent control methods can effectively address key challenges in EV powertrain optimization. The proposed system's adaptability and predictive control features make it suitable for future electric mobility solutions where performance and energy utilization are critical.

Future work will focus on hardware implementation using microcontrollers such as dsPIC30F4011 or STM32 to validate the simulation outcomes. Real-time experiments under different load and driving conditions will be conducted to test system robustness and efficiency. Further research may also explore advanced control strategies such as fuzzy logic, model predictive control (MPC), or deep learning-based energy optimization to enhance the adaptability and intelligence of next-generation electric vehicles.

REFERENCES

[1] R. J. Rahulkumar, S. Kumar, and A. Patel, "Wireless Resonant Inductive Power Transfer for Dynamic Electric Vehicle Charging," IEEE Transactions on Transportation Electrification, vol. 9, no. 3, pp. 1845–1853, 2023.

[2] H. Cha, D. Lee, and Y. Kim, "Integrated Power and Transportation System for Grid-Stabilized Electric Vehicle Charging," IEEE Access, vol. 11, pp. 1123–1135, 2023.

[3] V. M. Kumar, P. Karthikeyan, and G. Rajesh, "Electric Vehicle Charging Scheduling Using Chaotic Harris Hawks Optimization," Energy Reports, vol. 9, pp. 1450–1462, 2023.

[4] S. Hamdare, K. Mehta, and R. Pawar, "Hybrid Electric Vehicle Charging Management Using OCPP Framework and Predictive Control," IEEE Transactions on Smart Grid, vol. 15, no. 1, pp. 210–219, 2024.

[5] K. Arulvendhan and P. Kumaravel, "Hybrid-Compensated Wireless Charging System for Electric Vehicles," IEEE Transactions on Industrial Electronics, vol. 71, no. 2, pp. 1568–1576, 2024.

[6] M. Yilmaz, A. Singh, and T. Zhang, "Artificial Intelligence-Based Battery Prediction in Battery Management Systems," Renewable Energy Letters, vol. 12, no. 4, pp. 45–52, 2025.