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ORIGINAL ARTICLE

Enhanced cell balancing strategies for electric vehicles using a modified matrix GaNFET flyback topology with design and simulation analysis

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Abstract

This paper addresses the limitations of existing topologies, such as the dual active bridge (DAB) and half-full bridge (HFB) designs, which are hindered by high complexity, low conversion efficiency, and increased costs due to the necessity for multiple transformers and switches. To overcome these challenges, we introduce a novel active cell balancing topology based on a modified Matrix GaNFET Flyback approach. This new topology improves both balancing speed and conversion efficiency by incorporating various cell balancing methods, including Cell to Cell (C2C), Cell to UV Battery to Cell (CUVC), UV Battery to Cell (UVC), and Cell to UV Battery (C2UV). The design reduces system cost and size by using a single isolation transformer instead of multiple per cell transformers. Furthermore, the integration of a switching matrix and GaNFET devices facilitates efficient energy transfer with fewer switches, allowing for high frequency switching with minimal losses. MATLAB simulation results demonstrate that the proposed topology offers improved energy efficiency and a lower component count compared to traditional methods. The remainder of this paper provides a detailed discussion of the circuit structure, operational principles, and control strategies of the proposed topology, along with an analysis of the balancing principles and simulation results.

Keywords Dual active bridge (DAB) · Half Full bridge (HFB) · Modified matrix GaNFET Flyback topology · Cell to UV pack and Cell (C2UVC) · State of Charge (SOC)

1 Introduction

Amid rising concerns about energy security and environmental impact, plug-in hybrid electric vehicles (PHEVs) and pure electric vehicles (EVs) have garnered significant research attention [1]. In these vehicles, high-power traction batteries are essential. Among the various types of power batteries available—such as lead-acid, nickel-metal hydride (Ni–MH), nickel–cadmium (Ni–Cd), and lithium-ion (Li-ion) batteries, as well as graphene-based and all-solid-state batteries—Li-ion batteries are particularly suitable for these vehicles due to their high energy density, which helps to improve energy efficiency and longer cycle life [2]. Two widely used Li-ion battery types in EVs are Lithium Iron Phosphate (LFP) and Nickel Manganese Cobalt (NMC). NMC batteries generally offer higher energy density compared to LFP batteries, allowing them to provide more power and support a broader range of applications [3]. However, NMC batteries tend to be more expensive and have a shorter lifespan. A typical Li-ion EV battery consists of several components, including a cooling system, battery management system (BMS), high-voltage wiring harness, structural frame, and battery modules. Li-ion batteries are favored in EVs and PHEVs due to their high power and energy density, and they also dominate the consumer electronics market in products like laptops and smartphones. Unlike lead-acid batteries, Li-ion batteries are highly sensitive to overcharging, making safety a critical concern, especially in terms of overcharging, over-discharging, and temperature rise. To ensure safety and performance, a BMS with a balancing function is necessary when connecting a large number of Li-ion battery cells in series for high-power and high-energy

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