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Optimizing Regeneration and Control of Energy in Pure Electric Vehicle

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ABSTRACT: Electric vehicle range improvement aims to make the electric vehicle more desirable. Enhancing the range of electric vehicles increase their appeal with energy regeneration playing a pivotal role in extending the electric vehicle's range in comparison to non-regenerative counterparts. Regenerating energy is a crucial aspect of optimizing the efficiency and extending the driving range of pure electric vehicles. There are two primary approaches to energy regeneration in these vehicles. The first involves regenerative braking where the kinetic energy of the vehicle is converted into electrical energy and stored in the battery for future use. This not only minimizes wear on traditional brakes but also enhances the overall efficiency of the vehicle's propulsion system. The second method focuses on energy generation from motor propulsion. Electric motors are positioned at each wheel, allowing for precise power distribution control. As the vehicle propels electric motors function as generators, transforming mechanical energy back into electrical energy which is then redirected back into the battery.

KEYWORDS: Pure Electric Vehicle; Battery Management System; Optimization; Regenerative Braking; Motor Propulsion; Vehicle Controller

I. INTRODUCTION

Electric vehicles (EVs) have renovated the automotive industry countering traditional concepts of transportation and sustainability. EVs work on electric propulsion systems drawing power from rechargeable batteries. This offers promising solutions for reducing carbon emissions and dependence on fossil fuels. At the heart of electric vehicles mechanism, the concept of energy regeneration, a process crucial for enhancing efficiency and extending the driving range of EVs is a key method that involves regenerative braking, where the kinetic energy generated during braking is converted back into electrical energy and stored in the vehicle's battery. The extensive use of renewable energy has a significant role in enhancing the environmental friendliness of EVs when compared to conventional Internal Combustion Engine Vehicles (ICEVs) [1]. The electric vehicles need electricity for propulsion, the expense of power generation significantly influences the overall cost of using EVs. Consequently, there is a growing demand for increased generation capacity within the power grid to accommodate the additional load from EVs [2, 3]. Battery management systems (BMS) play an important role in different applications that utilize battery technology including electric vehicles, renewable energy systems, and portable electronic devices [4]. Efficient battery management is essential for maximizing performance, guaranteeing safety and extending the life of batteries. BMS monitors and regulates battery parameters such as voltage, current, temperature, state of health and state of charge. The primary goal of a BMS is to secure the safe and effective functioning of the battery system involving functions like cell balancing, state estimation, fault detection, and thermal management. [5, 6]. This paper aims to provide two approaches for the generation; (a) Control and optimization of energy in pure electric vehicles through regenerative braking and (b) Energy generation through motor propulsion. In regenerative braking, the vehicle's kinetic energy transforms into electrical energy and then stored in the battery. This reduces the strain on conventional brakes and also improves the overall efficiency of the vehicle's propulsion system. In motor propulsion, electric motors are situated at individual wheels enabling precise control over power distribution. As vehicle propels these motors serve as generators converting mechanical energy back into electrical energy and is subsequently fed back to the battery.

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II. PROPOSED METHODOLOGY

The figure 1 represent that the electric vehicle has an electric motor/generator on each wheel, serving dual purposes of propulsion and energy regeneration. These motors are linked to specialized inverters that convert DC power to AC power, facilitating precise control. The inverters are seamlessly integrated into the vehicle's electrical system. The EV incorporates DC choppers to decrease the DC voltage feasible for powering the auxiliary systems to operate at 24 V within the vehicle itself [7]. The energy is supplied to an electric motor which in turn runs the vehicle's wheels. During regenerative braking battery is recharged from the grid [8].

Sensors identify amount of brake application by the driver. These sensors transmit signals to the regenerative braking controllers linked to both wheel speed sensors and brake force sensors, enabling up-to-the-moment data on wheel speed and braking force. The battery management system consistently oversees the battery pack's state of charge, voltage and temperature. Connected to individual battery cells via voltage and temperature sensors, the BMS communicates with the inverter and the energy storage system to regulate the flow of energy [9, 10]. The Energy Storage System (ESS) collects and stores the electrical energy produced during regenerative braking linked to both the inverter and the regenerative braking system. This system comprises a high-capacity battery pack and the corresponding electronics for energy management [11]. Hence, by using a single battery or two separate battery packs we can generate maximum energy where one battery propels the motor and is being discharged whereas the other gets charged by regenerative braking and by motor propulsion. Therefore, utilizing either a single battery or two distinct battery packs enables the generation of maximum energy. In this setup, one battery powers the motor, undergoing discharge, while the other is charged through regenerative braking and motor propulsion.

Battery Management System: A crucial element in electric vehicles, the battery management system is integral for overseeing and enhancing the efficiency of the vehicle's battery pack. It is responsible for monitoring and regulating individual cells within the battery pack to maintain their operation within predetermined voltage and temperature thresholds. The BMS also keeps track of the state of charge and state of health of each cell providing insights into their performance and degradation over time [12]. Variations can occur among individual cells in a battery pack, leading to imbalances in voltage and capacity. The BMS performs balancing by redistributing energy between cells to ensure that all cells are charged and discharged equally by maximizing the overall pack performance and lifespan. Maintaining an optimal temperature range is crucial for the performance and lifespan of lithium-ion batteries. It monitors and controls the temperature of individual cells, ensuring they operate within a safe range. This involves cooling or heating the battery as needed. It regulates the charging process to prevent overcharging which can damage cells and reduce their lifespan. It also manages the charging rate to optimize charging efficiency and prevent overheating during fast charging. To prevent damage due to excessive discharging, the BMS manages the discharge process, ensuring that the battery pack is not depleted beyond safe limits. They estimate the SOC of the battery based on various factors including voltage, current, and temperature. This information is crucial for providing accurate range estimates to the driver. Continuous monitoring of cell voltages and currents helps the BMS identify any abnormal conditions or faults in the battery pack. The BMS is equipped with various sensors and algorithms to detect faults, such as cell failures or abnormalities in temperature and voltage. It provides diagnostic information to the vehicle's onboard computer to alert the driver or initiate corrective actions. BMS often includes communication interfaces to allow it to communicate with other vehicle systems, charging stations and devices [13,14].

Vehicle Controller: The central electronic unit that is vehicle controller in a pure electric vehicle plays a crucial role in overseeing and coordinating diverse subsystems to ensure the effective functioning of the vehicle. Specifically, it takes charge of regulating the electric motor propelling the vehicle overseeing power distribution to the motor and adjusting speed, torque and direction in accordance with both driver commands and system specifications [15]. The vehicle controller interacts with the battery management system to gather data about the battery's status, encompassing metrics such as SOC, SOH and the condition of individual cells. This data is essential for optimizing the vehicle's performance and range ensuring the battery's safety. Additionally, the vehicle controller supervises regenerative braking a functionality that captures and transforms kinetic energy from braking into electrical energy to recharge the battery. It effectively handles the shift between regenerative and friction braking to maximize the recovery of energy [16]. Electric vehicles commonly incorporate a thermal management system to regulate the temperature of crucial components like the battery and motor. The vehicle controller collaborates with this system to maintain ideal operating temperatures promoting efficiency and extending the lifespan of these components. Moreover, the vehicle controller offers diverse drive modes (e.g., Eco, Sport) that present different levels of performance and energy efficiency. It fine-tunes variables such as throttle response, power delivery, and energy consumption to align with the driver's preferences

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and enhance overall efficiency. In electric vehicles featuring multi-speed transmissions, the vehicle controller takes charge of optimizing efficiency and performance by adjusting gear ratios as required [17]. The vehicle controller enables communication with external charging stations and oversees the charging process. It monitors the battery's charging status regulates charging power and ensures the safety of the entire charging procedure. Furthermore, the vehicle controller interfaces with safety systems like the Anti-lock Braking System (ABS), Electronic Stability Control (ESC) and traction control to enhance overall vehicle safety. The vehicle controller may interact with the vehicle's user interface providing real-time information to the driver regarding the vehicle's status, range and charging status. It may also facilitate driver assistance features such as lane-keeping assistance and adaptive cruise control [18]. In terms of diagnostics the vehicle controller scrutinizes the health and performance of various vehicle systems identifying faults and reporting diagnostic information to either the driver or service technicians.

Electronic Power Converter: In a pure electric vehicle, the electronic power converter holds a vital function in overseeing the transmission of electrical energy between the vehicle's power sources and diverse electrical components. While electric vehicles generally utilize high-voltage DC (direct current) batteries for energy storage, certain components like the electric motor and specific auxiliary systems may necessitate AC (alternating current). The electronic power converter is tasked with converting DC power sourced from the battery into AC power whenever necessary. Several electrical elements within the vehicle including lights, sensors and the 12V battery system often function at a lower voltage level typically around 12V. The vehicle is powered by the fuel cell and surplus energy generated is employed to recharge the battery. Operating in a regenerative mode, the traction motor serves to replenish the battery. [19]. The electronic power converter serves to reduce the high-voltage DC power from the primary traction battery to the lower voltage necessary for these components. Particularly in electric vehicles featuring AC electric motors, the electronic power converter frequently incorporates an inverter. This inverter is responsible for transforming DC power from the battery into three-phase AC power to propel the electric motor. It regulates the frequency, voltage and phase of AC power to control the speed and torque of the motor. In electric vehicles, regenerative braking enables the restoration of energy during deceleration. The electronic power converter oversees the conversion of kinetic energy into electrical energy during braking by channelling it back to the battery for storage. Given the substantial power levels involved in electric vehicle operations the electronic power converter often incorporates a cooling system to disperse heat generated during the conversion process. This helps maintain optimal operating temperatures by ensuring the durability of the converter components. The electronic power converter communicates with the vehicle's control system such as the battery management system and vehicle controller to receive instructions and furnish real-time information regarding power flow, voltage and current. Power electronic converters (PECs) are extensively employed to control the power distribution in electric vehicles, uninterruptible power supplies (UPS), renewable energy sources (RESs), and energy storage systems such as solar photovoltaic (PV) systems, fuel cells (FCs), and wind energy conversion systems. [20-23]. The converter is equipped with safety features to identify faults and safeguard the electrical components from overcurrent, overvoltage and other irregular conditions. In case of malfunction, the converter might disengage or restrict power to prevent potential damage. The primary goal of the electronic power converter is to optimize the efficiency of energy conversion, thereby minimizing losses during the conversion of power across various forms (from DC to AC, high voltage to low voltage, etc.).

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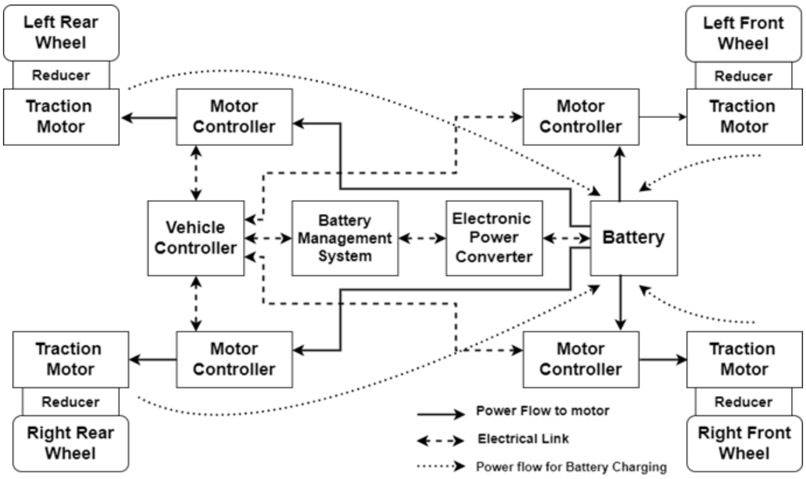

Fig.1. EV integrated with BMS and Power converter

Additionally, the electronic power converter may integrate power factor correction (PFC) to enhance the effectiveness of power transfer between the vehicle and the charging station. PFC plays a role in ensuring that the power sourced from the grid is utilized more efficiently leading to decreased losses and an overall improvement in efficiency.

III. CONCLUSION

Electric vehicles offer various advantages by contributing to their growing popularity and adoption of low carbon footprints - the overall carbon footprint of an EV depends on the source of electricity used for charging. However, even when charged with electricity from conventional power grids, EVs often have a lower carbon footprint than traditional vehicles. But there is still some presence of carbon footprints. The EVs use electricity for charging, where electricity is generated by coal in majority of our country. Hence the carbon footprints can further be reduced by regeneration of energy within the vehicle. This also results in regenerative braking systems that capture and convert kinetic energy, that would otherwise be lost as heat during traditional braking. This process improves the overall energy efficiency by allowing the vehicle to recapture and reuse some of the energy expended during acceleration. By recovering and storing energy during braking and deceleration, regenerative braking helps to extend the driving range of electric vehicles. This is particularly valuable in addressing the range anxiety concerns and improving the sensibleness of electric vehicles for daily use.

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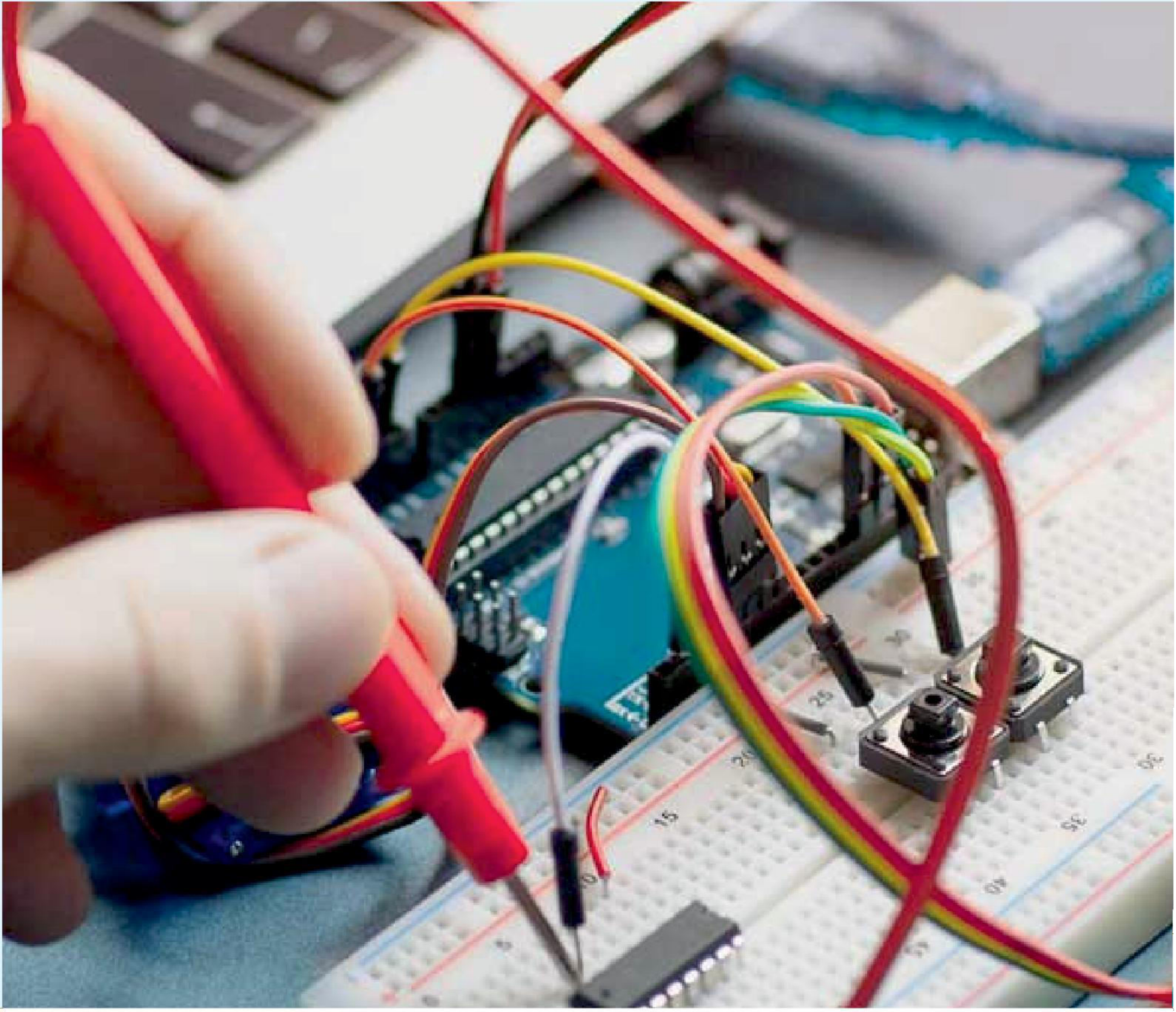

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