DRIVING TOWARDS SUSTAINABILITY: A COMPREHENSIVE REVIEW OF ELECTRIC VEHICLES

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SUMMARY

This research summarizes research on electric vehicles (EVs) and sustainable transit solutions, highlighting advancements in battery technologies, motor efficiency, and vehicle-to-grid (V2G) integration. It explores the conversion of a Rover Mini into the electric E-MINI and discusses the potential of proton exchange membrane (PEM) fuel cells and hybrid electric vehicle (HEV) architectures. The study emphasizes the importance of effective power management and infrastructure upgrades to support EV adoption. Despite inherent complexities, innovative designs offer promising solutions for future transportation sustainability. advanced strategies for optimizing electric powertrains, transit networks, and fast charging systems to enhance sustainability in electromobility. Additionally, analysis is done on how quick charging affects Li-ion battery deterioration, revealing insights into mitigating effects and identifying cost-effective solutions for various battery technologies. Overall, this comprehensive investigation contributes crucial insights for advancing sustainable electric mobility.

KEYWORDS

Electric vehicles (EVs), Vehicle-to-grid (V2G) integration, Hybrid electric vehicle (HEV), EV adoption

1. INTRODUCTION

The rapid change from conventional automobiles with internal combustion engines to electric propulsion systems has necessitated innovative approaches to optimize energy efficiency and sustainability across various facets of electromobility [1-4]. This research addresses this imperative by presenting a comprehensive exploration into the intricacies of electric powertrain optimization, transit network efficiency, and the effect of rapid charging on the degradation of Li-ion batteries (LIBs) [5]. In the pursuit of achieving heightened energy efficiency in electric powertrains, a multifaceted strategy is employed [6-7]. The derived convex models for powertrain components, coupled with a novel two-step optimization algorithm, exemplify an advanced methodology validated through a detailed case study involving a compact family car [8]. Beyond powertrain optimization, the present research presents an innovative design approach for battery-electric light car powertrains [37-38]. This methodology, characterized by rapid brute-force optimization, navigates a complex design space by combining analytical modelling and lookup tables for system components [39]. The efficacy of this approach is demonstrated through its application to real-world scenarios, highlighting its potential impact on the future design of electric light vehicles [40]. Extending the focus to public transit, the study delves into the design of effective transportation networks powered by electric buses that run on batteries [41]. Furthermore, the research scrutinizes the critical aspect of fast charging and its ramifications on LIB degradation [42]. Real-world Battery Electric Bus (BEB) driving profiles form the basis for analysis, investigating the influence of different charger sizes and LIB chemistries [43]. The findings shed light on strategies to mitigate degradation effects and identify cost-effective solutions for a diverse array of battery technologies [44]. By addressing intricacies in powertrain optimization, transit network efficiency, and fast charging dynamics, the study contributes valuable insights to propel the sustainable evolution of urban transportation [45]. The research identifies several research gaps: it lacks detailed exploration of real-time control strategies for electric vehicles, fails to provide comprehensive insights into the thermal behaviour of key components like the inverter and battery, lacks specificity in optimal design for active aerodynamic elements, overlooks cost implications in transit network design, and doesn't offer a comparative analysis of various fast charging strategies [46]. Filling these gaps is essential for a more thorough understanding of practical implementation, system dynamics, economic feasibility, and trade-offs in sustainable electric mobility [47].

2. LITERATURE REVIEW

Some researches proposes a robust methodology for designing transit networks with battery electric buses, presenting a tested model in Guadalajara. The findings underscore the potential of BEBs in achieving significant cost savings and environmental benefits. This research contributes to advancing sustainable transit solutions and offers a foundation for further exploration and refinement in diverse urban contexts [32]. The study offers valuable conclusions for designing fast-charging infrastructure and EV powertrains. LTO emerges as a promising chemistry with minimal degradation, while charger downsizing and battery capacity adjustments prove effective for mitigating degradation in NMC and LTO batteries5 [33].

According to recent studies, AC induction motors for EVs are a better option than DC motors for EVs and internal combustion engines (IC engines) because of their increased efficiency, wider speed range, and better weight-to-power ratio. In order to improve performance, the electric vehicle proposed in this research has an AC induction motor in addition to Sinusoidal Pulse Width Modulation (SPWM) [59].

The particular project covered in the article is the conversion of a Rover Mini to create the electric car known as E-MINI. This electric car may now drive on public roads after receiving approval to do so. It can travel an astounding 38 kilometres on a single charge. At its maximum, E-MINI's efficiency is stated to be 10.85 km/kWh, albeit this figure may vary according on a number of variables, including driving habits and road conditions [34].

When operating in V2G mode, EV's are essential to the grid's support because they boost reactive power and discharge during periods of high load to improve efficiency, dependability, and a host of ancillary services [48]. The benefits and drawbacks of the V2G technology for grid operators and EV owners are covered in the study. V2G has a number of difficulties, such as battery deterioration, the need to modify the grid's infrastructure, energy losses, and high investment prices [49]. V2G mode has several advantages, such as providing auxiliary services, peak reduction techniques, active-reactive power regulation, load balancing, and grid support during outages [50]. Optimizing advantages requires effective communication and managed charging schemes between car owners or aggregators and the grid operator [35]. Adoption of EVs is greatly influenced by policy, with financial incentives promoting early adoption. To avoid overloading the current grid, infrastructure upgrades, including charging stations, must be in line with EV technology [51].

Proton exchange membrane (PEM) fuel cells have been less expensive over the last ten years, and additional cost reductions are predicted, making this technology more competitively priced going forward. The hybrid electric car described in the paper of Ioan Aschilean, while not cutting edge, demonstrates the technology's potential and provides an idea of what creative and environmentally friendly transportation options might look like [36].

Farshid Naseri suggested a system, which combines zinc-bromine batteries to provide power continuously under typical driving circumstances, and uses ultracapacitors to effectively store regenerative braking energy during deceleration and manage peak power needs during acceleration [56]. High efficiency and cost-effectiveness are ensured by the electric motor in the EV, which operates in constant torque mode at speeds lower than the base speed and transitions to constant power mode at speeds higher [57]. Effective power management is crucial for electric vehicles, as demonstrated by the meter-reading vehicle's real drive cycle study [9].

Because of their numerous subsystems, BEVs, HEVs, and FCEVs are inherently complicated devices; nevertheless, advances in innovative architectures are reducing dependability difficulties [52]. Certain cutting-edge designs can improve fault tolerance and remove or lessen the restrictions connected with ICEs, enabling partial operation in the case of an incident [53]. The CSIM hybrid design has received a lot of interest in recent study due to its appealing advantages, although being immature. Both strategies have obstacles that need to be overcome, but they end up being arrangements with bright futures for hybrid and electric cars [10,54].

Two permanent magnet synchronous motors (PMSMs), power converters, a TMS320F28335 DSP control board, and an energy storage system (ESS) made up of battery cells, a battery management system (BMS), and an ultracapacitor unit are all part of the powertrain implementation [20]. Permanent magnet synchronous motors (PMSMs) are tested in a lab setting at different acceleration rates. The battery pack (BP) effectively provides the energy needed for the EV, and the experiments reach the maximum cruise velocity. Preliminary findings are obtained in the laboratory demonstrating the successful integration of an Ultracapacitor (UC) into the battery pack [11]. Figure 1 depicts a commercial charging station, having various ev vehicles charging at the same time.

Vehicle acceleration, gradeability, and driving distance all significantly improve when EV transmission ratios are optimised, especially when using a two-speed gearbox. The particular results show that during the UDDS cycle, there was a 7.39% rise in vehicle acceleration, a 20% improvement in grade ability, and a 7.02% gain in driving distance. Optimising the process, especially when using a multi-speed transmission system, shows promise for raising the energy economy and dynamic performance of electric vehicles [12].

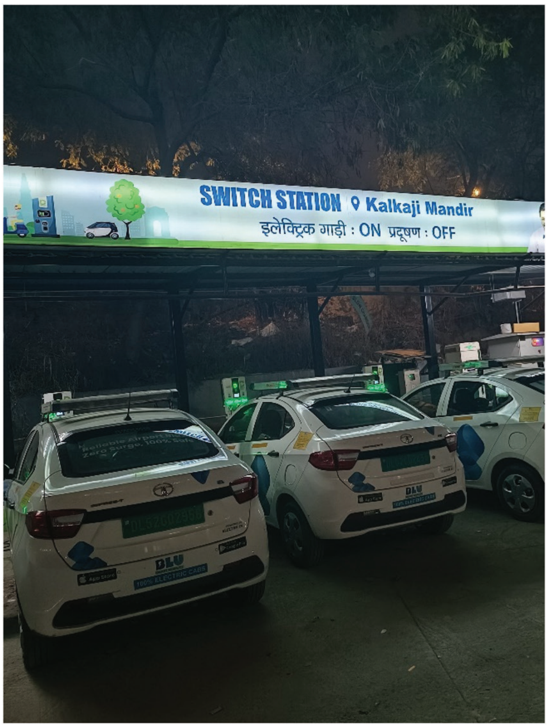

Figure 1. EV vehicles charging at Kalkaji Mandir Metro Station

The prototype's electric powertrain is flexible, which makes it appropriate for testing on-board energy management-related hardware and software. The EV prototype has a brushless AC drive, runs on a 96 V LiFePO4 battery pack, and can support up to two more energy storage systems (ESSs) with various technologies installed. The prototype is noteworthy for having a signal conditioning and measurement system in place to keep an eye on the voltages and currents in the engine [13].

The integration of batteries with uninterruptible capacitors (UC's) in hybrid energy storage systems (HESS) is focused on utilizing UC's for high-frequency, dynamic charge and discharge operations in order to assure quick system response and prolong battery life, in contrast to conventional considerations of power density and energy density. The most widely used HESS arrangement at the moment is the UC/battery topology, which makes full use of ultracapacitors' capabilities while providing a reasonably cheap cost and good efficiency [55]. Certain EMSs have several goals to pursue, necessitating high-fidelity models that could become computationally demanding [14].

The goal of the suggested design approach is to maximize the gearshift strategy in the powertrain systems of electric cars (EVs) that have automated manual transmissions (AMTs) with multiple speeds. Real-time applications are made possible by the solution technique, which combines numerical approaches and Pontryagin's Minimum Principle (PMP). Results from simulations run on a range of drive cycles for a passenger electric vehicle equipped with a four-speed automatic transmission show that the suggested approach can save three to five percent of fuel, and potentially much more when slope and other road factors are taken into consideration [15].

Currently, the emphasis is on optimizing the fuel consumption of Plug-in Hybrid Electric Vehicles (PHEVs) using a driver-centric approach [21]. This study places emphasis on enabling drivers to choose suitable drive modes, in contrast to conventional techniques that mainly take internal optimization processes into account [22]. Drive modes, such as Electric Vehicle (EV) mode or Charge Sustaining (CS) mode, are preset profiles of the vehicle's powertrain and settings. An empirical evaluation of the system's implementation on a Chevrolet Volt shows a notable increase in fuel efficiency [16].

When an electric vehicle (EV) has a range extender installed, there is an issue with the Energy Management Strategy (EMS) (REX). The purpose of the REX is to extend the battery's All Electric Range (AER), and it can be selectively enabled or deactivated in accordance with operational needs. Power generation and heat dynamics are taken into account when modelling the powertrain with an emphasis on the REX [17].

For electric vehicles (EVs), there is a preliminary powertrain design approach that concentrates on performance-enhancing the motor torque–speed curve and gear ratio. Utilizing the Nelder-Mead (Simplex) optimization technique, a less complex substitute for the genetic algorithms frequently utilized in this domain, is offered. The longitudinal vehicle model is taken into consideration, and a two-zone mechanical characteristic of a Permanent Magnet Synchronous Motor (PMSM) traction motor is used in the study [18]. Figure 2, depicts Tata Motors' star bus which has the maximum power of 328 hp.

Figure 2. Commercial EV vehicle Tata Starbus used for public transport

For two-wheeled electric vehicles (EVs), a dual-motor powertrain arrangement is available to improve overall efficiency. A front motor installed on the hub and a rear motor connected to the rear wheel via a two-stage gearbox with a 1:10 gear ratio make up the suggested dual-motor configuration. The World Motorcycle Test Cycle (WMTC) Part 1 - Reduced driving cycle is used to calculate energy consumption across a driving cycle in order to assess and compare the efficiency of this dual-motor configuration with a single-motor setup. The outcomes show that the Dual-motor topology outperforms the Single-motor topology in terms of how well it uses the energy that is available. When compared to a single motor powertrain, the vehicle's torque requirement is effectively split between the two motors, resulting in a 23.8% reduction in energy usage [19].

The study assesses industry costs, uncertainties, and CO2 emissions under several scenarios, taking into account managed and uncontrolled EV charging, using a Monte Carlo-based portfolio modelling technique. The findings emphasize cost and emission reduction benefits, especially with larger EV fleet sizes and low carbon prices, and indicate possible synergies between PV generation and managed EV charging. The research assesses industry costs, uncertainties, and CO2 emissions under several scenarios, taking into account managed and uncontrolled EV charging, using a Monte Carlo-based portfolio modelling technique. The significance of controlled daytime charging and the role that carbon pricing plays in augmenting the economic feasibility of photovoltaics are also underscored, with consequences for the best generating portfolios in the context of changing energy environments [23-24]. Figure 3 depicts a charging station used for fast charging of electric cars.

Figure 3. Charging point at Kalkaji Mandir Metro Station

Furthermore, a revolutionary method of EV charging is suggested, introducing a brand-new class of on-board chargers that make use of already-existing EV parts—more precisely, the machine and inverter—when the charger is in the charging mode [25]. A five-phase inverter/five-phase machine setup is used to demonstrate the idea of hardware reconfiguration with just two switches. In both the charging and vehicle-to-grid (V2G) modes, torque-free operation and unity power factor are confirmed through experimental testing [26].

Key findings include the environmental impact of electricity production for externally chargeable vehicles and the potential of electric vehicles in mitigating global warming if powered by low-emission electricity. The model suggests that this system, transferring range risk to station operators, can enhance electric vehicle adoption but may encourage more driving compared to conventional systems [27-29].

In order to minimize energy usage in a fully electric powertrain, this research proposes a thorough modelling and optimization approach. The text discusses design and control tactics, taking into account the electric motor's (EM) thermal behaviour. The significance of thermal concerns is highlighted by powertrains including a continuously variable gearbox (CVT), which exhibit reduced energy usage and EM temperatures. Incorporating thermal dynamics for extra components and investigating real-time control of electric cars are two proposals for future research [30].

The presented design methodology showcases the potential for rapid and exhaustive comparison of BEV powertrain designs. Future work can focus on incorporating additional optimization criteria and refining models to enhance the predictivity of the proposed methodology, contributing to the ongoing evolution of optimal BEV powertrain design practices [31].

3. CONCLUSIONS

In conclusion, the presented research encompasses a broad spectrum of innovative approaches and methodologies aimed at optimising various aspects of electric powertrains and sustainable transit solutions. The utilisation of convex models and the incorporation of continuously variable gearboxes (CVTs) emerge as key strategies to enhance energy efficiency and mitigate electromagnetic cooling challenges. The significance of thermal considerations is underscored, especially in the context of extended driving periods, and the potential benefits of CVTs, particularly in downsizing, are highlighted.

The research also extends its scope to the design of transit networks with battery electric buses (BEBs), offering valuable insights into cost savings and environmental benefits. The findings contribute to the ongoing evolution of optimal BEV powertrain design practices and emphasise the importance of tailored design approaches for charging stations and battery systems.

The exploration of fast-charging infrastructure and its impact on lithium-ion battery degradation in electric vehicles adds another layer of complexity to the research. The identification of Lithium Titanate (LTO) as a promising chemistry with minimal degradation and the consideration of charger downsizing and battery capacity adjustments contribute to the essential knowledge base for sustainable EV adoption.

Moreover, the integration of Vehicle-to-Grid (V2G) technology is discussed, acknowledging its potential benefits for grid support and various ancillary services. However, challenges such as battery deterioration, infrastructure modifications, and investment costs are recognised, highlighting the need for effective communication and managed charging schemes between stakeholders.

The adoption of innovative technologies, such as AC induction motors, and the exploration of hybrid energy storage systems demonstrate a commitment to addressing the multifaceted challenges in the electric mobility landscape. The research not only contributes to the current understanding of electric vehicle technologies but also provides a foundation for further advancements and refinement in the pursuit of sustainable and efficient transportation solutions.

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