

A Riview Study On Self-Charging In Electric Vehicles Using Wheels

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ABSTRACT

The rapid adoption of electric vehicles (EVs) has intensified research into improving energy efficiency and extending driving range. One emerging area of interest is self-charging mechanisms utilizing wheel-based energy recovery systems. These systems aim to harvest mechanical energy generated during wheel rotation, braking, and vehicle motion, and convert it into electrical energy to support auxiliary loads or partially recharge the onboard battery. This review presents a comprehensive analysis of wheel-based self-charging techniques, including regenerative braking, wheel-mounted generators, hub motor reverse energy flow, and vibration-based energy harvesting methods. The working principles, energy conversion efficiency, and practical feasibility of each approach are critically examined based on existing research. Furthermore, the paper highlights the limitations of current systems such as increased rolling resistance, limited power output, and integration challenges. Key research gaps related to system optimization, real-world validation, and hybrid energy recovery architectures are identified. The review concludes that while wheel-based self-charging systems cannot independently sustain vehicle propulsion, they offer significant potential for enhancing overall energy efficiency and enabling self-powered auxiliary subsystems in future electric vehicles.

Keywords: *Electric vehicles, self-charging systems, wheel-based energy recovery, regenerative braking, energy rvesting, hub motor technology, auxiliary power generation, vehicle energy efficiency, and sustainable transportation.*

1. INTRODUCTION

The global transition toward electric vehicles (EVs) is driven by the urgent need to reduce greenhouse gas emissions, dependence on fossil fuels, and operational costs associated with conventional internal combustion engine vehicles. Despite significant advancements in battery technology and power electronics, limited driving range, long charging durations, and energy inefficiencies remain critical challenges affecting large-scale EV adoption. Consequently, improving onboard energy utilization and recovery has become a key research focus in modern electric mobility systems.

One promising approach to enhance overall vehicle efficiency is the concept of self-charging through wheel-based energy recovery mechanisms. During vehicle operation, a considerable amount of mechanical energy is dissipated through braking, wheel rotation losses, and road-induced vibrations. Wheel-based self-charging systems aim to capture a portion of this otherwise wasted energy and convert it into usable electrical power. Techniques such as regenerative braking, wheel-mounted generators, hub motor reverse energy flow, and vibration-based energy harvesting have been explored to support auxiliary electrical loads and improve energy management within the vehicle.

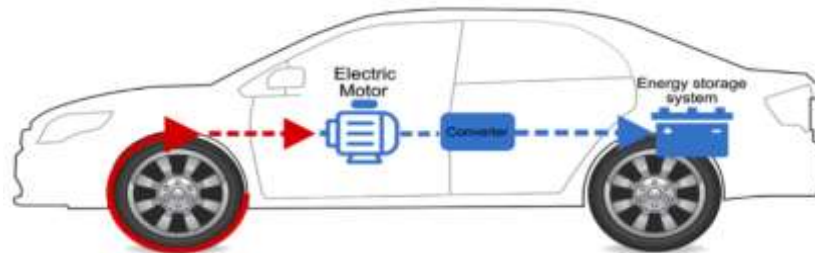
Among these methods, regenerative braking has emerged as the most mature and widely implemented technology, capable of recovering a significant fraction of kinetic energy during deceleration. However, regenerative braking alone is insufficient to address continuous energy losses during steady-state driving conditions. This limitation has encouraged researchers to investigate complementary wheel-based energy harvesting solutions that operate during regular vehicle motion, thereby expanding the scope of energy recovery beyond braking events.

Existing research demonstrates that while wheel-based self-charging systems cannot independently sustain vehicle propulsion, they offer measurable benefits in powering auxiliary systems such as sensors, control units, lighting, and monitoring modules. Nevertheless, challenges including increased rolling resistance, limited power output, system integration complexity, and economic feasibility continue to restrict large-scale implementation. Moreover, inconsistencies in performance evaluation metrics and a lack of real-world experimental validation hinder meaningful comparison across proposed systems.

This review paper presents a comprehensive and critical analysis of wheel-based self-charging technologies for electric vehicles. It systematically examines working principles, energy conversion efficiency, and practical limitations of existing approaches while identifying key research gaps and future directions. By clearly distinguishing between auxiliary energy support and primary propulsion charging, this study aims to provide a realistic and technically sound perspective on the role of wheel-based self-charging systems in advancing next-generation electric vehicle efficiency and sustainability.

2. LITERATURE SURVEY

Early research on self-charging mechanisms in electric vehicles predominantly focused on regenerative braking systems, which remain the most practically successful form of wheel-based energy recovery. Pioneering work by C. C. Chan emphasized regenerative braking as a critical technology for improving EV efficiency by converting kinetic energy during deceleration into electrical energy stored in the battery. Subsequent studies demonstrated that regenerative braking can recover approximately 10–30% of the vehicle's kinetic energy under urban driving conditions. However, these studies also highlighted a fundamental limitation: energy recovery is restricted to braking events, leaving continuous rotational energy during cruising largely unutilized.



To address this limitation, researchers began exploring wheel-mounted generator systems capable of harvesting energy during normal vehicle motion. S. Lukic and colleagues investigated auxiliary energy generation systems integrated with vehicle wheels to supply power for onboard electronics and monitoring systems. Their findings confirmed that while wheel-mounted generators can produce usable electrical power, the additional mechanical load introduces rolling resistance, which must be carefully optimized to prevent net energy loss. These studies marked an important shift from propulsion-focused recovery to auxiliary power generation, reinforcing the realistic scope of wheel-based self-charging systems.

Parallel to electromagnetic generation methods, vibration-based energy harvesting attracted attention as a non-intrusive approach to wheel energy recovery. Research conducted by S. Priya demonstrated the feasibility of piezoelectric materials in harvesting energy from road-induced vibrations and wheel deformation. Although the power output was limited to milliwatt levels, these systems proved suitable for self-powered sensors and wireless monitoring devices. Such contributions established vibration-based harvesting as a complementary rather than primary charging solution, particularly for intelligent and connected vehicle applications.

With the rise of hub motor-based electric vehicles, researchers explored bidirectional energy flow within traction motors. Mehrdad Ehsani presented extensive work on motor control strategies enabling traction motors to operate as generators under specific operating conditions. These studies highlighted the advantage of eliminating additional mechanical components while achieving energy recovery through advanced power electronics and control algorithms. Nevertheless, challenges related to thermal management, system complexity, and control stability were identified as barriers to widespread adoption.

Flywheel-based energy storage systems were also investigated as a means of temporarily storing wheel-generated mechanical energy. J. M. Miller analyzed flywheel integration in electric and hybrid vehicles, demonstrating high energy efficiency and rapid charge–discharge capability. Despite their technical advantages, issues such as high cost, safety concerns, and packaging constraints limited their commercial feasibility, confining their application mainly to experimental and high-performance vehicles.

More recent studies emphasize hybrid energy recovery architectures that combine regenerative braking with auxiliary wheel-based harvesting systems. Researchers increasingly argue that the true value of wheel-based self-charging lies not in fully recharging the traction battery, but in reducing auxiliary load dependency on the main energy source. Simulation-based investigations reveal that intelligent control strategies and lightweight system design can achieve marginal yet meaningful improvements in overall vehicle efficiency. However, a lack of standardized evaluation metrics and real-world experimental validation remains a significant gap in existing literature.

Overall, the reviewed literature clearly indicates that wheel-based self-charging systems are technically feasible within defined limits and application scopes. While no existing approach enables complete self-sustained vehicle propulsion, substantial research supports their role in enhancing energy utilization, powering auxiliary systems, and contributing to sustainable EV design. These findings underscore the need for further integrated studies focusing on system optimization, durability, and real-world performance assessment to fully realize the potential of wheel-based energy recovery technologies.

4 LIMITATIONS OF EXISTING SYSTEMS

Despite extensive research on wheel-based self-charging and energy recovery systems in electric vehicles, several critical limitations continue to restrict their practical effectiveness and large-scale adoption. The most fundamental limitation is the inherently low energy output of wheel-based harvesting mechanisms when compared to the energy demands of vehicle propulsion. Existing systems primarily generate power in the range of milliwatts to a few watts, which is insufficient for direct traction battery charging and confines their application to auxiliary loads. This gap between harvested energy and propulsion requirements highlights the need for realistic system objectives rather than exaggerated self-charging claims.

Another significant limitation arises from increased mechanical losses associated with additional energy harvesting components. Wheel-mounted generators and suspension-integrated harvesters introduce extra mass, friction, and rolling resistance, which can negatively impact vehicle efficiency if not properly optimized. Several studies report that poorly designed systems may consume more energy than they recover, resulting in a net efficiency loss. This trade-off between energy recovery and mechanical efficiency remains inadequately addressed in existing designs, particularly under real-world driving conditions.

System integration and control complexity further limit the performance of current wheel-based self-charging solutions. Effective energy harvesting requires precise coordination between mechanical components, power electronics, and battery management systems. Many existing studies rely on simulation-based models with ideal assumptions, while practical implementation faces challenges such as variable road conditions, thermal stress, and fluctuating electrical loads. The absence of adaptive control strategies capable of responding to dynamic vehicle behavior reduces the reliability and consistency of harvested energy.

Durability and long-term reliability also pose major concerns. Components such as magnets, coils, dampers, and piezoelectric materials are subjected to continuous mechanical vibrations, temperature variations, and environmental exposure. However, most published research focuses on short-term experimental validation, with limited investigation into fatigue life, wear characteristics, and maintenance requirements. This lack of long-term performance data creates uncertainty regarding the commercial viability of these systems.

Additionally, there is a lack of standardized performance evaluation metrics across existing research. Studies often report energy harvesting efficiency under different operating conditions, vehicle models, and testing methodologies, making meaningful comparison difficult. The absence of universally accepted benchmarks hinders objective assessment of system effectiveness and slows technological convergence within the research community.

Finally, economic feasibility remains a critical limitation. The added cost of harvesting components, control electronics, and system integration is often not justified by the relatively small energy gains achieved. Without cost-effective designs and scalable manufacturing approaches, wheel-based self-charging systems struggle to transition from experimental prototypes to commercially viable solutions.

5 RESEARCH GAP

Although significant research has been conducted on wheel-based energy recovery and self-charging mechanisms in electric vehicles, existing studies remain fragmented and limited in scope. Most prior work focuses on individual techniques such as regenerative braking, suspension-based electromagnetic harvesters, or vibration-based energy harvesting, without presenting an integrated framework that combines multiple wheel-related energy recovery sources into a unified system. This lack of holistic system-level design prevents effective utilization of available mechanical energy during diverse driving conditions.

A critical research gap exists in the optimization of energy harvesting systems to minimize mechanical and rolling losses. While several studies demonstrate the feasibility of wheel-mounted generators and suspension-integrated harvesters, limited attention has been given to quantifying the net energy balance under real-world operating conditions. The absence of experimental validation addressing long-term efficiency trade-offs, especially across varying road profiles, vehicle speeds, and load conditions, restricts confidence in the practical benefits of these systems.

Another major gap lies in adaptive control and power management strategies. Most existing research relies on static or rule-based control schemes that fail to respond dynamically to changing vehicle states and environmental factors. Intelligent control algorithms capable of regulating energy capture, storage, and distribution in real time remain largely unexplored, despite their potential to significantly improve system efficiency and reliability.

Durability and lifecycle performance of wheel-based self-charging systems represent an under-investigated area. Current literature predominantly emphasizes short-term simulations and laboratory-scale experiments, with minimal focus on component degradation, fatigue behavior, and maintenance implications over extended vehicle operation. This lack of long-term reliability assessment hinders the transition of proposed systems from experimental prototypes to commercially viable technologies.

Furthermore, there is no standardized performance evaluation framework for comparing different wheel-based energy harvesting approaches. Variations in test methodologies, efficiency metrics, and reporting standards make it difficult to benchmark systems objectively or identify optimal design configurations. Establishing uniform evaluation criteria remains a significant unmet need in this research domain.

Finally, economic viability and scalability are insufficiently addressed in existing studies. Few researchers evaluate cost-to-benefit ratios or manufacturing feasibility alongside technical performance. Without cost-optimized designs and scalable implementation strategies, wheel-based self-charging systems are unlikely to gain acceptance in mass-market electric vehicles.

6. EXPECTED OUTCOME

The proposed research on wheel-based self-charging mechanisms in electric vehicles is expected to provide a comprehensive and realistic understanding of how auxiliary energy recovery can be effectively integrated into modern EV architectures. By addressing the limitations of existing systems, the study aims to demonstrate that wheel-based energy harvesting, when properly optimized, can contribute measurable improvements to overall vehicle energy efficiency without introducing significant mechanical losses.

A key expected outcome is the development of an optimized energy recovery framework that minimizes rolling resistance and mechanical degradation while maximizing usable electrical output. Through improved system design and intelligent power management strategies, the proposed approach is anticipated to achieve a positive net energy balance under real-world driving conditions, particularly for powering auxiliary loads such as sensors, monitoring units, and control electronics.

The research is also expected to deliver enhanced adaptability and reliability through advanced control strategies capable of responding dynamically to variations in road conditions, vehicle speed, and load fluctuations. This adaptability is anticipated to improve consistency in energy harvesting performance compared to static or rule-based systems reported in existing literature. Another important outcome is the generation of meaningful experimental and simulation data addressing durability and long-term performance. By evaluating system behavior over extended operating cycles, the study aims to provide insights into component wear, fatigue resistance, and maintenance requirements, thereby strengthening confidence in the practical feasibility of wheel-based self-charging systems.

Furthermore, the research is expected to establish standardized performance metrics and evaluation methodologies that enable objective comparison with existing approaches. Such benchmarking is anticipated to support future research and accelerate technological convergence within this domain. Overall, the anticipated outcomes of this study are expected to contribute toward the development of efficient, reliable, and economically viable wheel-based energy recovery systems, positioning them as a complementary solution for enhancing sustainability and energy utilization in next-generation electric vehicles.

7. CONCLUSION

This review comprehensively examined wheel-based self-charging mechanisms in electric vehicles with the objective of assessing their feasibility, effectiveness, and practical limitations. Through a detailed analysis of existing research, it is evident that significant mechanical energy generated during wheel rotation, braking, and suspension movement remains underutilized in current electric vehicle architectures. Technologies such as regenerative braking, wheel-mounted generators, hub motor energy recovery, and suspension-based energy harvesting have demonstrated measurable potential for improving overall vehicle energy utilization when applied within realistic operational boundaries.

The literature review highlighted that regenerative braking remains the most mature and effective wheel-related energy recovery technique, while auxiliary harvesting approaches contribute primarily to powering low-energy subsystems. However, existing systems are constrained by low power output, increased mechanical losses, system integration complexity, and limited long-term reliability assessment. These challenges underscore the necessity of reframing wheel-based self-charging systems as complementary energy-support mechanisms rather than standalone propulsion charging solutions.

The identified research gaps reveal a clear need for integrated system architectures, optimized mechanical-electrical design, adaptive control strategies, standardized evaluation metrics, and durability-focused validation. Addressing these gaps is essential for transitioning wheel-based energy recovery technologies from experimental prototypes to practically deployable solutions. Furthermore, economic feasibility and scalability must be considered alongside technical performance to ensure real-world relevance.

Overall, this review concludes that while wheel-based self-charging systems cannot independently sustain electric vehicle propulsion, they play a valuable role in enhancing energy efficiency, reducing auxiliary load dependency on the main battery, and supporting sustainable vehicle operation. Future research focused on intelligent integration, lightweight design, and real-world performance validation is expected to significantly strengthen the contribution of wheel-based energy recovery systems to next-generation electric vehicles.

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