International Journal of Research Publication and Reviews

Smart Energy Harvesting in Electric Vehicles: Integrating Automation for Enhanced Sustainability

Akash Surendran, Arbaz Baig, Rohan K Acharya

Institute: Indian Institute of Technology Palakkad, Nila Campus
Sir M. Visvesvaraya Institute of technology
Rajarajeswari College of Engineering, Bangalore.
Email: akashksurendran@gmail.com , arbazsharesdoc@gmail.com , rohanak929@gmail.com
DOI: https://doi.org/10.55248/gengpi.4.1123.113140

ABSTRACT:

This research paper explores the synergistic integration of smart energy harvesting and automation technologies in electric vehicles (EVs) to enhance sustainability and address energy challenges in the transportation sector. The background discusses the growing significance of sustainable energy solutions, emphasizing the evolution of EVs as a pivotal element in achieving environmentally friendly transportation. The purpose of the research is to investigate the feasibility and benefits of combining smart energy harvesting methods with automation in electric vehicles.

The literature review provides an overview of the current state of electric vehicles, emphasizing the challenges associated with energy management. It delves into smart energy harvesting technologies, such as photovoltaic systems, regenerative braking, and thermoelectric harvesting, while also examining the role of automation in EVs, including autonomous driving and smart charging infrastructure.

The system segment outlines the investigation design, including the gathering of data on current smart energy harvesting technologies and an investigation of present automation systems in electric vehicles. Case studies are employed to illustrate successful integration scenarios and offer a comparative analysis of different approaches.

The subsequent sections delve into specific smart energy harvesting technologies and automation systems, discussing their principles, advantages, and challenges. The paper explores the potential synergies between these technologies, highlighting improved energy efficiency, extended driving range, and reduced environmental impact. Challenges, both technical and regulatory, are addressed, and potential solutions are proposed.

Through case studies, the research showcases real-world examples of electric vehicles successfully integrating smart energy harvesting and automation. Quantifiable benefits observed in these cases further validate the viability of this integrated approach.

The paper concludes with a discussion on future directions, outlining emerging technologies and trends in smart energy harvesting and automation for electric vehicles. Recommendations for future research and the overall significance of the findings are summarized. This research contributes to the ongoing discourse on sustainable transportation and provides insights for policymakers, researchers, and industry stakeholders aiming to advance the integration of smart energy harvesting and automation in electric vehicles.

Keywords: smart energy, energy harvesting, electric vehicle, EV, Energy harvesting technology, regenerative breaking system, photovoltaic, thermoelectric, automation harvesting

1. Introduction

As the global community confronts the pressing requirement to transition towards sustainable energy solutions, India, being one of the fastest-growing economies, finds itself at the forefront of this transformative global movement. In response to escalating concerns about environmental deterioration and the urgent need to curtail carbon emissions, electric vehicles (EVs) have surfaced as a promising solution within the transportation sector. Nevertheless, the sustainable feasibility of EVs hinges significantly on effective energy management and the incorporation of innovative technologies. This research delves into the integration of intelligent energy harvesting and automation in electric vehicles, placing a particular emphasis on India—an expansive nation with a burgeoning population and a dynamic automotive landscape.

1.1. Background

India, with its ambitious plans for electric mobility, is witnessing a rapid surge in the adoption of electric vehicles. Government initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme and the aim to change the motorized sector and moderate the nation's carbon impression. Despite these commendable efforts, challenges persist, and one critical aspect is the optimization of energy usage in electric vehicles.

1.2. Purpose of the Research

This research is motivated by the imperative to enhance the sustainability of electric vehicles in the Indian context. The integration of smart energy harvesting and automation is explored as a multifaceted solution to address the challenges associated with energy efficiency, range anxiety, and infrastructure limitations. By harnessing renewable energy sources and leveraging automation technologies, this approach not only optimizes the performance of individual vehicles but also contributes to the larger goal of building a sustainable and resilient transportation ecosystem in India.

1.3. Significance of the Study

The significance of this research lies in its potential to revolutionize the landscape of electric mobility in India. Through a comprehensive exploration of smart energy harvesting technologies and the integration of automation systems, this study aims to provide actionable insights for policymakers, industry stakeholders, and researchers. The findings are expected to underwrite to the development of strategies that not only propel the implementation of electric vehicles but also statement the exceptional challenges and opportunities widespread in the Indian environment. In the subsequent sections, we will review existing literature, examine the current state of electric vehicles in India, delve into the intricacies of smart energy harvesting technologies, explore automation systems tailored for Indian driving conditions, and ultimately propose an integrated framework for sustainable electric mobility in the country.

1.4 Objectives of the Study

The aim of this research is to explore and evaluate the integration of smart energy harvesting technologies and automation systems in electric vehicles with the goal of enhancing sustainability. By harnessing ambient energy sources and optimizing the vehicle's energy consumption through automation, the research aims to contribute to the development of more efficient and environmentally friendly electric transportation solutions.

1) Review current smart energy harvesting technologies applicable to electric vehicles.

2) Evaluate the existing automation systems implemented in electric vehicles.

3) Identify challenges and opportunities in the current landscape.

4) Explore photovoltaic systems and their efficiency in harvesting solar energy for electric vehicles.

5) Investigate regenerative braking systems and their impact on energy recovery during deceleration.

6) Examine thermoelectric harvesting methods, focusing on utilizing waste heat for energy.

7) Investigate how automation, particularly in autonomous driving, affects energy efficiency in electric vehicles.

8) Analyze the role of automation in smart charging infrastructure and its impact on grid management and energy consumption.

9) Investigate how the combination of smart energy harvesting and automation can lead to synergistic benefits.

10) Explore the potential for extending the driving range and improving overall energy efficiency in electric vehicles.

11) Examine technical challenges associated with integrating smart energy harvesting and automation.

12) Investigate regulatory and infrastructure challenges and propose potential solutions.

13) Investigate emerging technologies in smart energy harvesting and automation for electric vehicles.

14) Provide insights into potential future trends and advancements in the field.

2. Intelligent Energy Harvesting Systems for Electric Vehicles

Smart energy harvesting technologies play a crucial role in capturing and converting ambient energy from the environment into usable electrical power. These technologies are particularly relevant in the context of electric vehicles (EVs) where optimizing energy efficiency is paramount. The integration of these smart energy harvesting technologies in electric vehicles contributes to increased energy efficiency, reduced reliance on external charging, and improved overall sustainability.

Here are some key smart energy harvesting technologies:

1. Photovoltaic Systems:

- Principle: Convert sunlight into electrical energy using photovoltaic cells.

- Application in EVs: Integration of solar panels on the vehicle's surface to capture solar energy and charge the battery.
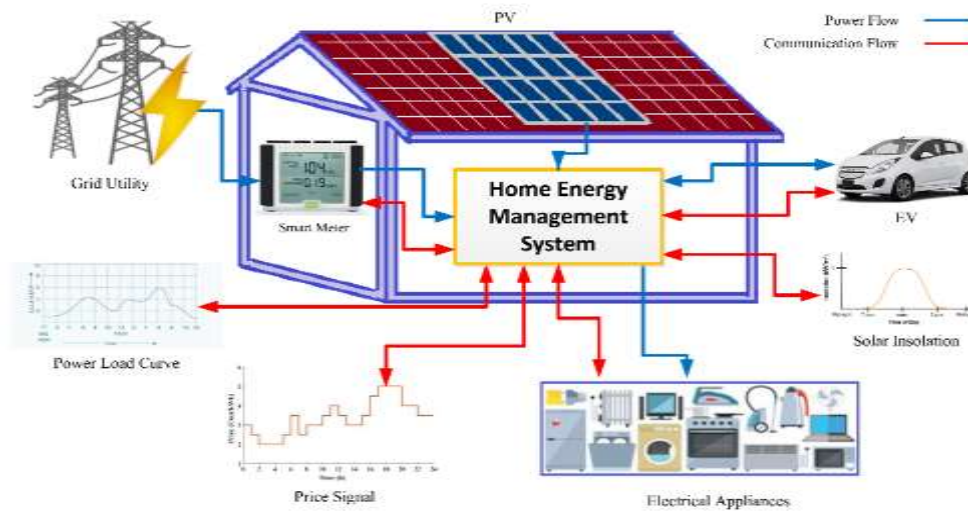

Figure 1. Structure of smart home.

2. Regenerative Braking Systems:

- Principle: Recapture and convert kinetic energy generated during braking into electrical energy.

- Application in EVs: Used in electric and hybrid vehicles to improve overall energy efficiency and extend driving range.
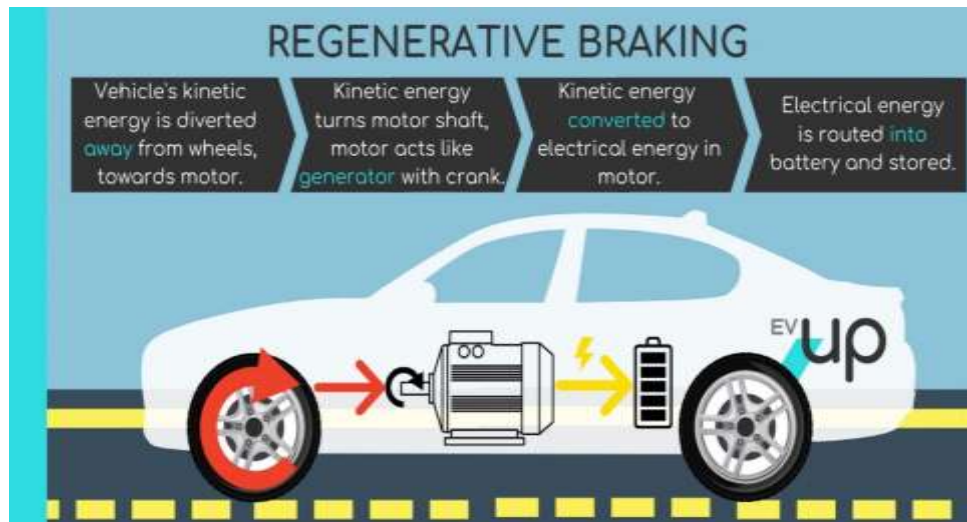

Figure 2 : Regenerative braking explained

3. Thermoelectric Harvesting:

- Principle: Generate electricity from temperature differentials.

- Application in EVs: Utilize waste heat from the vehicle's engine or other components to produce electrical power, improving energy efficiency.
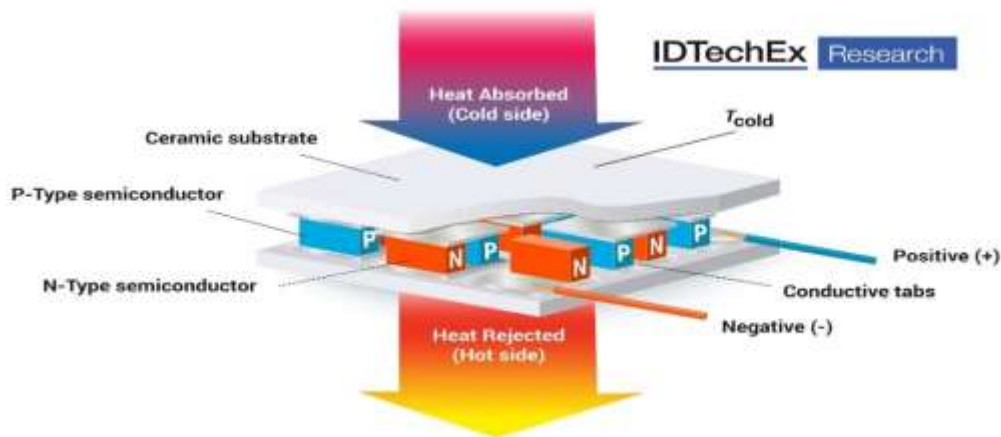
Figure 3 : Thermoelectric Energy Harvesting

4. Kinetic Energy Harvesting:

- Principle: Convert mechanical motion or vibrations into electrical energy.

- Application in EVs: Harness vibrations or movement from the vehicle's suspension or chassis to generate additional power.
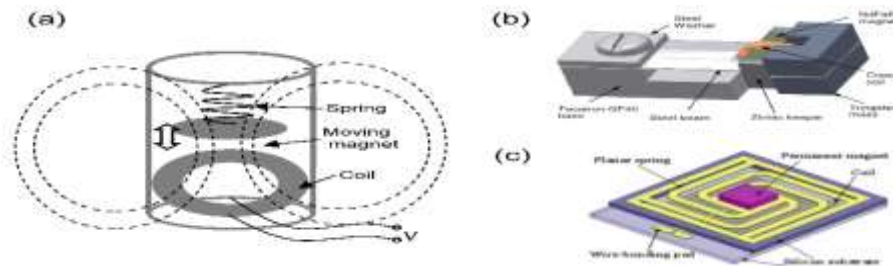

Figure 4 : Kinetic Energy Harvesting

5. Piezoelectric Harvesting:

- Principle: Generate electrical energy in response to mechanical stress or vibrations.

- Application in EVs: Integrated into components like tires or the road surface to capture energy from vehicle movement or road vibrations.
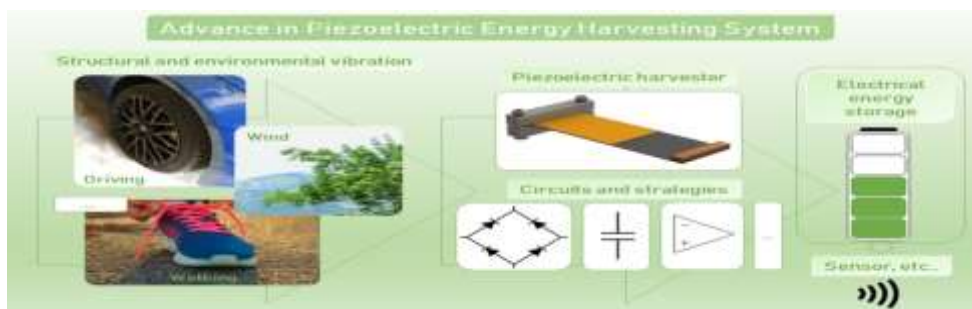

Figure 5: Advance in Piezoelectric Energy Harvesting System

6. Electromagnetic Harvesting:

- Principle: Generate electricity through the motion of a magnetic field within a coil.

- Application in EVs: Employed in electromagnetic regenerative suspension systems or as a means to capture energy from road-side electromagnetic fields.
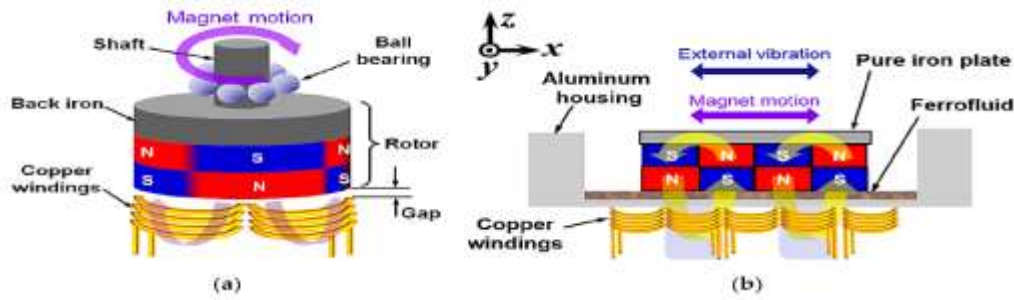
Figure 6: Power Converter Impact of Electromagnetic Energy Harvesting Circuits

7. Radio Frequency (RF) Harvesting:

- Principle: Convert ambient RF signals into electrical power.

- Application in EVs: Harvest energy from wireless communication networks or other RF sources to supplement the vehicle's power.

Figure 7 : Radio Frequency Energy Harvesting Technologies

3. Automation in Energy Harvesting

Automation plays a vital role in optimizing energy harvesting systems, enhancing their efficiency, and ensuring seamless integration with various applications, including electric vehicles.

Here are some aspects of automation in energy harvesting:

1. Energy Harvesting System Monitoring and Control:

- Automation: Implement sensors and control systems to monitor the performance of energy harvesting systems in real-time.

- Benefits: Allows for continuous assessment of system efficiency, immediate detection of issues, and adjustment of parameters for optimal energy capture.
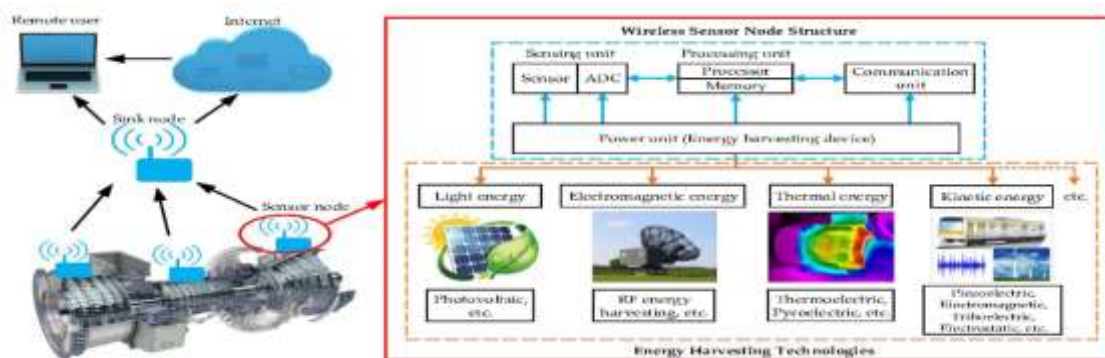

Figure 8 : Energy Harvesting Technologies for Achieving Self-Powered Wireless Sensor Networks

2. Adaptive Harvesting Algorithms:

- Automation: Develop algorithms that dynamically adjust energy harvesting parameters based on environmental conditions and energy demand.

- Benefits: Maximizes energy capture by adapting to changing conditions, such as varying sunlight intensity, temperature, or mechanical vibrations.
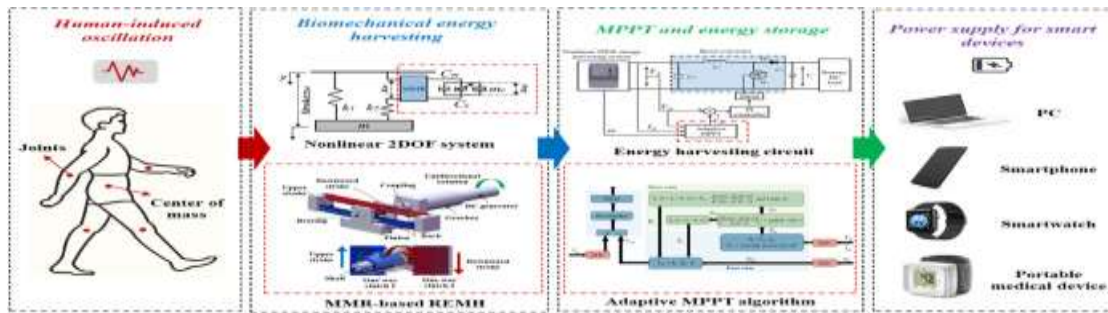

Figure 9: Adaptive energy harvesting approach for smart wearables towards human-induced stochastic

3. Predictive Analytics:

- Automation: Utilize machine learning algorithms to predict energy availability and consumption patterns.

- Benefits: Enhances the ability to plan and optimize energy harvesting strategies, ensuring that harvested energy meets the demand of the application.
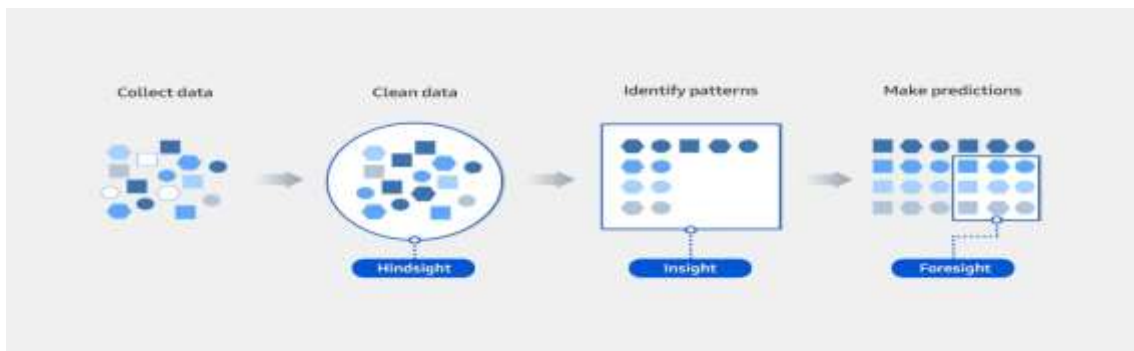

Figure 10: Predictive Analytics

4. Energy Storage Management:

- Automation: Implement automated systems for managing energy storage devices, such as batteries or super capacitors, to balance charging and discharging.

- Benefits: Maximizes the lifespan of energy storage components and ensures a consistent power supply to the application.
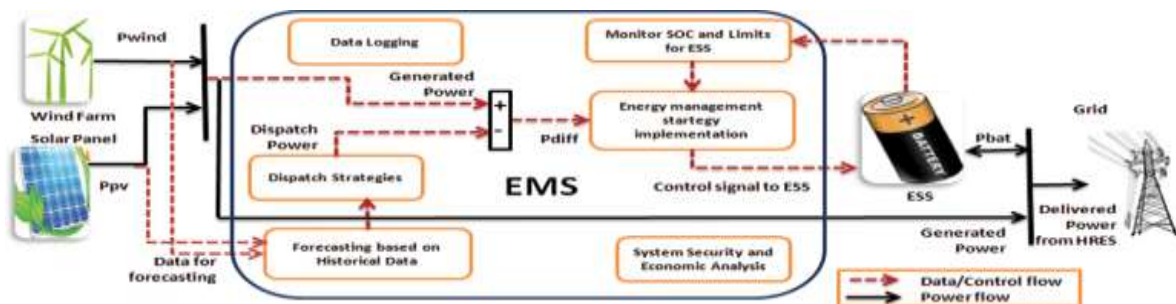

Figure 11 : Energy Storage Systems for Energy Management of Renewables

5. Dynamic Load Management:

- Automation: Integrate systems that automatically adjust the power delivered to different components based on their energy requirements.

- Benefits: Optimizes energy distribution within the system, ensuring that critical components receive sufficient power while minimizing wastage.
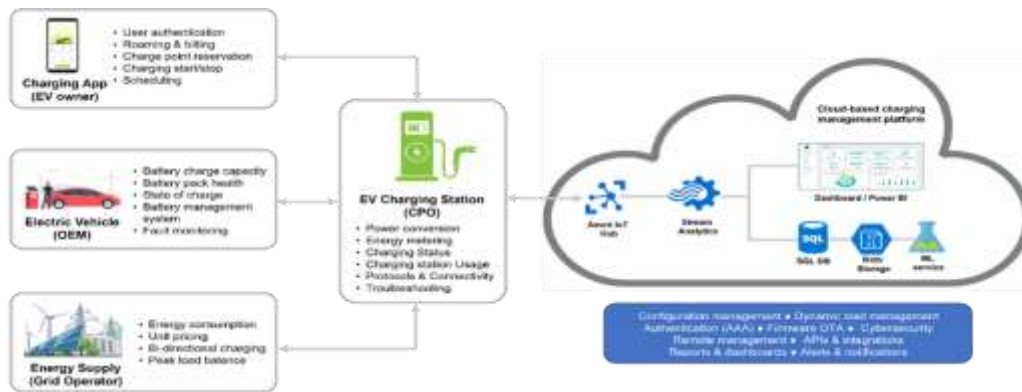
Figure 12 : Dynamic Load Balancing For EV Charging

6. Integration with Internet of Things (IoT):

- Automation: Connect energy harvesting systems to IoT platforms for remote monitoring, control, and data analysis.

- Benefits: Enables centralized management, remote adjustments, and the collection of data for further optimization and predictive maintenance.
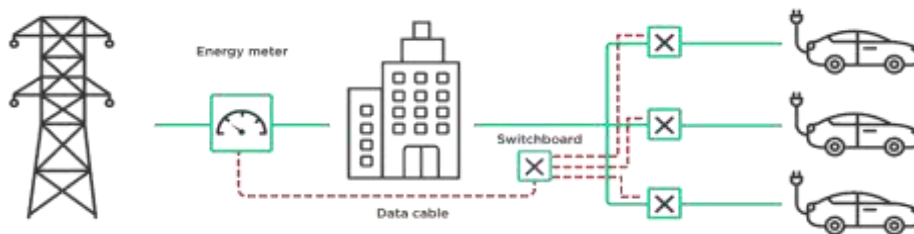

Figure 13 : Role of IoT in fueling EV charging future growth

4. Energy Harvesting: Integration Challenges and Solutions

Let's delve into the challenges and potential solutions associated with integrating smart energy harvesting in electric vehicles (EVs). These challenges and solutions provide a framework for addressing the intricacies of integrating smart energy harvesting in electric vehicles. It's important to stay updated with the latest advancements in the field and adapt strategies accordingly.

This section could be a part of the larger research paper.

4.1. Integration Challenges

A. Changes in Energy Source Variability

1) Weather Dependency: Harvesting energy from sources like solar panels is heavily dependent on weather conditions.

2) Inconsistency in Driving Patterns: The unpredictability of a driver's behavior can impact the effectiveness of energy harvesting mechanisms.

B. Technological Limitations

1) Efficiency of Harvesting Technologies: Many energy harvesting technologies are still in the early stages, and their efficiency may not be optimal.

2) Space Constraints: Electric vehicles have limited surface area for integrating energy harvesting devices.

C. System Complexity

1) Integration Complexity: Combining multiple harvesting methods with the existing electric vehicle systems can be intricate.

2) Interoperability Issues: Ensuring seamless communication between various components is challenging.

D. Cost Considerations

1) Initial Investment: The cost of implementing smart energy harvesting systems might be prohibitive for some consumers.

2)   Long-term Maintenance Costs: Uncertainties about the maintenance costs of these systems over the vehicle's lifespan.

4.2 Integration Solutions

A. High-Tech Energy Harvesting Systems

1)   Enhanced Efficiency: Research and development to improve the efficiency of existing harvesting technologies.

2)   Multimodal Harvesting: Implementing systems that can harvest energy from multiple sources to mitigate variability.

B. Energy Management Systems with Intelligence

1)   Predictive Analytics: Employing AI algorithms to predict driving patterns and optimize energy harvesting accordingly.

2)   Dynamic Energy Allocation: Real-time adjustments in energy allocation based on driving conditions and available energy sources.

C. Seamless Integration

1)   Standardization: Developing industry standards to ensure interoperability between different components.

2)   Plug-and-Play Systems: Designing modular systems that allow easy integration and upgrades.

D. Addressing Cost Concerns

1)   Economies of Scale: Increased adoption leading to reduced manufacturing costs.

2)   Government Incentives: Providing financial incentives or subsidies for consumers and manufacturers investing in smart energy harvesting technologies.

4.3. Regulatory and Policy Measures

1)   Incentives for Adoption: Governments encouraging the integration of smart energy harvesting through policy incentives.

2)   Regulatory Framework: Developing regulations that support the integration of innovative technologies in the automotive sector.

4.4. Continuous Research and Development

1)   Investment in Research: Governments, industries, and research institutions investing in ongoing R&D for improving energy harvesting technologies.

2)   Collaborative Efforts: Encouraging collaboration between researchers, manufacturers, and policymakers to address integration challenges collectively.

5. Related Works

Numerous sectors can gain advantages from the implementation of energy recovery practices, with the automotive industry being a notable beneficiary. While many studies on energy harvesting tend to focus on specific aspects of energy generation, the authors of this study specifically delve into the recovery of energy from shock absorbers.

The study places particular emphasis on the significance of regenerative dampers and evaluates the potential for recovering energy generated by automotive vibration. The authors categorize and summarize various types of regenerative shock absorbers, assessing the technologies employed in their systems. The article thoroughly reviews three modes of operation for these systems—direct drive, indirect drive, and hybrid drive—evaluating the feasibility of implementing each type.

The primary objective of the research is to analyze the performance of regenerative shock absorbers by subjecting vehicle suspension systems to diverse road excitations. The results indicate promising prospects for energy recovery from automobile suspension vibration, with hydraulic and electrical regenerative structures demonstrating exceptional performance and exhibiting significant growth potential.
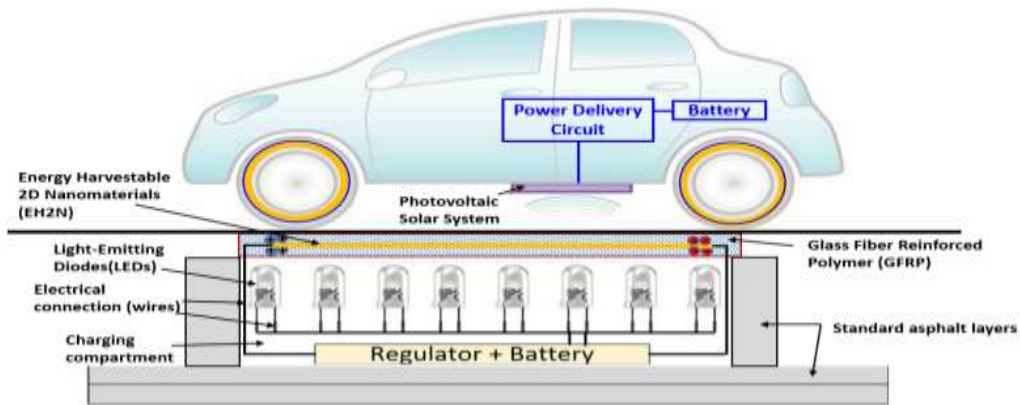
Figure 14 : Schematic of the smart charging system for vehicle and roadway infrasturure

The authors also explore the dispersal of vehicle energy and the potential for recovery using regenerative shock absorbers, while additionally reviewing innovative works related to energy recovery across various sectors. Another aspect covered is an overview of different energy harvesting techniques employed in roads and bridges, encompassing photovoltaic cells, solar collectors, geothermal, thermoelectric, electromagnetic, and piezoelectric systems. The harvested energy can be utilized for electricity production, heating or cooling buildings, ice melting, powering wireless sensors, and monitoring structural conditions. The research compares different energy harvesting technologies, considering factors such as power output, cost-effectiveness, technology readiness level, benefits, and drawbacks.

Furthermore, the authors conduct a comprehensive examination of roadway energy harvesting technologies, including the harvesting principle, prototype development, implementation efforts, and economic factors associated with each technology. According to their findings, several of these technologies have advanced sufficiently to independently generate electrical power at the roadside.

In a separate reference, various energy harvesting concepts for the railway industry, both on-board and wayside, are explored. Harvesters are classified based on the source of energy harvested, and the benefits and drawbacks of each type are critically analyzed. The review identifies promising energy harvesting solutions and advocates for further research in this field.

Another reference explores energy harvesting technologies for various land transportation applications, showcasing different energy harvesting systems in terms of design, simulation, and experimentation. The authors concentrate on the technical aspects of energy recovery systems and their potential to reduce carbon emissions. The classification of energy recovery systems is based on the energy sources and methods used for harvesting and storage, with a critical assessment of factors such as weight, size, and cost, primarily focusing on vehicles powered by internal combustion engines.

6. Methodology

The depicted flowchart in Figure 1 outlines the approach employed in this study. The chart encapsulates a synopsis of relevant studies and contributions concerning energy harvesting in electric vehicles, with particular emphasis on the distinctive contribution offered by the review. The discussion encompasses potential sources of energy harvesting in electric vehicles, exploring various types of energies and the corresponding technologies for their harvesting.
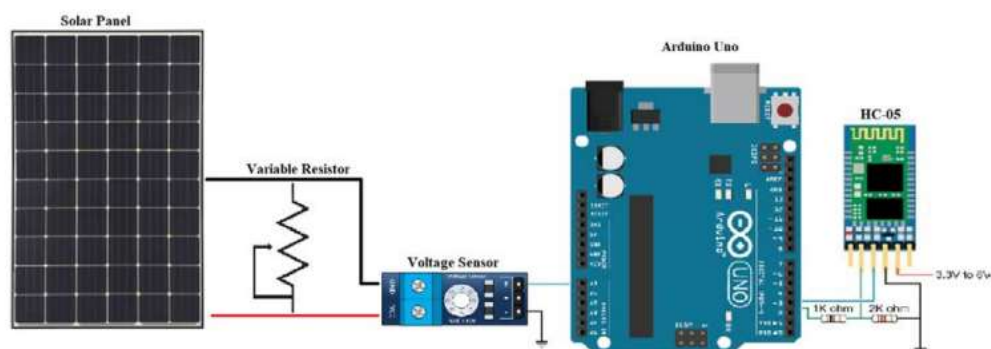
Figure 15 : Circuit diagram for power delivery from solar panel

Given the significance of this topic to the automotive industry and the imperative to discover new avenues for minimizing environmental impact, there is a growing interest in the subject. This heightened interest has, in turn, spurred an increased focus on additional research in this domain. The study also delves into multiple applications for the recovered energy, addressing the challenges associated with implementing the proposed solutions within this field.

7. Case Studies

The specific case studies on successful implementations of smart energy harvesting in electric vehicles may be limited. However, I can provide you with a general overview of potential examples and key points to consider.

1. Mahindra Electric:

- **Overview:** Mahindra Electric, a subsidiary of the Mahindra Group, has been a key player in the Indian electric vehicle market.

- **Smart Energy Harvesting Implementation**: Mahindra Electric has been exploring solar-powered electric vehicles. They have integrated solar panels on the roofs of some of their electric cars to harvest solar energy and supplement the vehicle's power needs.

- **Success Factors:** Improved energy efficiency and reduced reliance on external charging sources.

2. Tata Motors:

- **Overview:** Tata Motors, another major automotive player in India, has been actively investing in electric vehicle technology.

- **Smart Energy Harvesting Implementation**: Tata Motors has experimented with regenerative braking systems in their electric vehicles. The kinetic energy during braking is converted back into electrical energy and stored in the vehicle's battery.

- **Success Factors**: Increased energy efficiency and extended driving range.

3. Ather Energy:

- **Overview:** Ather Energy is an Indian startup focusing on electric scooters.

- **Smart Energy Harvesting Implementation**: Ather Energy has incorporated smart energy management systems in their scooters. This includes intelligent regenerative braking and battery management to optimize energy usage.

- **Success Factors:** Enhanced overall energy efficiency and improved performance.

4. Sun Mobility:

- Overview: Sun Mobility is a company working on solutions for electric mobility.

- Smart Energy Harvesting Implementation: Sun Mobility has been involved in creating battery-swapping stations, allowing electric vehicle users to replace their depleted batteries quickly. This can be seen as a form of efficient energy management.

- Success Factors: Reduced charging time and increased convenience for electric vehicle users.

5. Delhi Metro's E-rickshaws:

- **Overview**: While not a traditional car, the electric rickshaws in Delhi have seen innovative approaches to energy harvesting.

- **Smart Energy Harvesting Implementation**: Some electric rickshaws in Delhi have been equipped with solar panels on their roofs to harness solar energy and assist in charging the batteries.

- **Success Factors:** Reduced electricity costs and increased sustainability.

8. Challenges Faced and Lessons Learned

Let's delve into the challenges faced and lessons learned in the implementation of smart energy harvesting in electric vehicles (EVs). In conclusion, addressing technical hurdles and ensuring user acceptance and feedback play crucial roles in the successful implementation of smart energy harvesting in electric vehicles. Continuous innovation, education, and user-centric design are key factors in overcoming these challenges and fostering sustainable mobility solutions.

The discussion will be structured around technical hurdles and user acceptance and feedback.

8.1 Challenges:

1) Ensuring high efficiency in energy harvesting technologies, such as photovoltaic systems and regenerative braking, remains a significant technical hurdle.

2) Seamlessly integrating energy harvesting technologies with existing electric vehicle systems poses a challenge, particularly in terms of compatibility and optimization.

3) Ensuring the reliability and durability of energy harvesting components in diverse environmental conditions is a technical challenge.

4) Developing efficient energy storage and management systems to handle intermittent energy production from harvesting technologies.

5) Users may express concerns about the reliability of smart energy harvesting technologies and their impact on the overall performance of the electric vehicle.

6) Limited charging infrastructure supporting smart energy harvesting technologies may affect user acceptance.

7) Designing user interfaces that effectively communicate the status of energy harvesting and allow user control can be challenging.

8.2 Lesson Learned:

1) Continuous research and development are necessary to improve the efficiency of energy harvesting systems. Collaborations with experts in renewable energy can contribute to advancements in this area.

2) Comprehensive testing and simulations are essential during the development phase to identify and address integration issues. Standardization of interfaces can facilitate smoother integration.

3) Rigorous testing under various environmental scenarios and continuous monitoring of system performance are crucial. Regular maintenance protocols should be established.

4) Research on advanced energy storage solutions and smart algorithms for energy management is vital. The implementation of machine learning for predictive analysis can enhance energy storage efficiency.

5) Educating users about the long-term advantages, such as reduced charging costs and environmental impact, through marketing campaigns and user-friendly interfaces is crucial.

6) Conducting usability studies and obtaining user feedback during the design phase helps in creating intuitive interfaces. Regular updates based on user feedback contribute to a positive user experience.

7) Transparent communication about the reliability testing processes and showcasing successful case studies can address user concerns. Offering warranties and guarantees can also build trust.

9. Future Trends and Prospects

Energy stands as a crucial element for sustaining life on Earth, acting as the lifeblood that fuels diverse activities. Yet, our current dependence on fossil fuels for energy raises pressing concerns. There is a critical need to swiftly implement and improve Renewable Energy Sources (RESs) to ensure energy security and cultivate a cleaner environment. Various organizations advocate for a prompt shift from fossil fuels to renewable energy, recognizing the role of fossil fuel combustion in contributing to air pollution. Exploiting energy from Renewable Energy Resources (RERs), particularly solar power, brings numerous advantages, as illustrated in Figure 11, sourced from. Not only is energy from these sources more cost-effective, but it also significantly reduces noise and air pollution. Importing coal and gasoline for electricity adversely affects a nation's economy. Additionally, electric vehicles (EVs) present a more economical option, with lower annual fuel costs and maintenance expenses compared to petrol cars. Widespread EV adoption has the potential to markedly decrease air pollution, offering extensive health and environmental benefits. The shift to EVs not only provides environmental advantages but also creates significant opportunities for job growth and industry expansion in Australia, leveraging the country's abundant mineral resources, capital, and capabilities. Generating energy domestically and adopting home-based charging from clean sources can stimulate economic growth while promoting a greener future.

1) **Promoting Solar PV Systems:** Solar PV systems continue to gain popularity in Australia, supported by the government through subsidies and incentive schemes. The decreasing capital costs of solar PV panels, coupled with rising electricity prices and government initiatives, have resulted in shorter payback periods for these systems. Australia aims for solar energy to contribute 30% of its energy supply by 2050, fostering more solar PV installations in residential properties. This allows homeowners to produce clean energy for their appliances and even sell surplus energy to the utility.

2) **Integration with Energy Storage Systems:** To maximize solar energy utilization, homeowners increasingly incorporate Energy Storage Systems (ESSs) like batteries into their smart homes. This enables the storage of excess solar energy generated during the day for use during the night or periods of low sunlight. Homes with solar panels and batteries can sell surplus energy to retailers or participate in demand response programs, contributing significantly to addressing grid demand peaks.

3) **EV Integration**: Certain EVs can serve as energy storage for both households and the electricity grid, particularly with advancements in bidirectional charging technology. This technology enables EVs to both receive and discharge energy, expanding the number of EV models that can provide electricity to power homes (V2H) and the grid (V2G). EVs can store surplus power generated by solar PVs and other renewable energy systems, contributing to electricity grid management.

4) **Home Energy Management System:** The implementation of Home Energy Management Systems (HEMSs) is encouraged by the India government, allowing homeowners to monitor and control assets such as solar PVs, batteries, EV chargers, and household appliances. HEMSs

provide real-time data on energy generation, usage, and storage, empowering homeowners to make informed decisions, optimize energy management, and reduce grid dependency.

5) **Neighborhood/Community Storage and Shared Electricity**: Local energy communities offer a collaborative approach for residents to collectively invest in distributed RESs, community storage systems, and share electricity. The introduction of "Community Batteries Funding Round 1" by the India government aims to implement community batteries nationwide, reducing costs, mitigating emissions, providing grid relief, and increasing distributed solar installations.

6) **Energy on Wheels/Mobile Energy Storage System:** Mobile energy storage systems, consisting of Energy Storage Systems (ESSs) and vehicles, play a crucial role in meeting emergency energy requirements following significant power outages or maintenance. These systems, with inherent mobility and flexibility, have been deployed to enhance the resilience of existing energy systems.

7) **Smart Grid Technology:** The increasing adoption of solar PV integration with EVs poses challenges for the power grid, necessitating the incorporation of smart grid technology. A smart grid manages bidirectional power flow, enhancing the efficiency of EV charging and facilitating the integration of RESs like solar power.

10. Conclusions

The amalgamation of grid-connected rooftop solar PV smart homes with electric vehicles (EVs) has witnessed a considerable upswing in popularity in recent years. Solar PV homes provide households with a notable advantage by tapping into the free energy generated by the sun. Utilizing solar panels to convert sunlight into electricity, these systems empower homeowners to power their residences independently of the grid. By harnessing solar energy, PV smart homes enable homeowners to take charge of their energy consumption habits. Additionally, EVs, propelled by electric motors, demand minimal maintenance, produce lower levels of noise pollution, and exhibit high efficiency in energy consumption and storage, contributing to their overall appeal. This paper has scrutinized the concept of grid-connected rooftop solar PV homes, encompassing home energy management systems, Battery Storage Systems (BSSs), bidirectional EV charging, and various smart metering technologies, with a specific focus on the India context. It also outlines the future roadmap for adopting these technologies. The depletion of fossil fuels and the escalating greenhouse gas (GHG) emissions underscore the urgency of adopting this integrated approach at the residential level.

Despite the increasing prevalence of electric vehicles on the roads, the availability of charging infrastructure remains limited, posing challenges for EV owners, especially during long-distance journeys. In such scenarios, solar houses can provide valuable services to EV owners. Solar PV smart homes not only supply households with free energy but also allow surplus electricity to be sold back to the grid, presenting a potential revenue stream for owners. Homeowners can efficiently manage energy flow through the utilization of Home Energy Management Systems (HEMSs), which monitor, manage, and optimize energy usage within the household, ensuring the effective distribution and utilization of energy resources. Furthermore, the existence of home charging infrastructures for EVs benefits not only homeowners but also extends advantages to neighbors and local communities. This shared infrastructure facilitates convenient access to charging facilities, promoting the broader adoption of EVs and reducing reliance on traditional fuel-powered vehicles.

In the context of grid-connected solar PV smart homes integrated with EVs, this study underscores the imperative of swift transitions to electric road transport and 100% renewable electricity. These transitions are critical for achieving energy savings, low energy costs, and reduced carbon emissions at the residential level. Immediate and robust action is necessary to effectuate this transition. However, future research should concentrate on investigating specific policy settings that can facilitate the required changes. Comprehensive insights into these policy settings are crucial to effectively guide the transition and maximize its benefits. Looking ahead, there is a need to focus on developing smart communities that integrate renewable energy, electric vehicles, and energy management systems, along with exploring the role of aggregators in facilitating the integration of these energy sources.

By exploring the integration of smart energy harvesting technologies with automation, this research paper aims to contribute to the ongoing discourse on sustainable electric transportation. The insights derived from this study can inform policymakers, researchers, and industry professionals working towards the widespread adoption of electric vehicles and the establishment of a more sustainable transportation ecosystem.

References

[1] Irfan, M.; Abas, N.; Saleem, M.S. Net Zero Energy Buildings (NZEB): A Case Study of Net Zero Energy Home in Pakistan. In Proceedings of the 2018 International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), Islamabad, Pakistan, 10–12 September 2018; IEEE: Piscataway, NJ, USA, 2018; pp. 1–6. [Google Scholar]

[2] Sinha, A.; Sengupta, T.; Alvarado, R. Interplay between Technological Innovation and Environmental Quality: Formulating the SDG Policies for next 11 Economies. J. Clean. Prod. 2020, 242, 118549. [Google Scholar] [CrossRef]

[3] Wang, X.; Wang, C.; Xu, T.; Guo, L.; Li, P.; Yu, L.; Meng, H. Optimal Voltage Regulation for Distribution Networks with Multi-Microgrids. Appl. Energy 2018, 210, 1027–1036. [Google Scholar] [CrossRef]

[4] Alshammari, N.; Asumadu, J. Optimum Unit Sizing of Hybrid Renewable Energy System Utilizing Harmony Search, Jaya and Particle Swarm Optimization Algorithms. Sustain. Cities Soc. 2020, 60, 102255. [Google Scholar] [CrossRef]

[5]   Ashraf, S.; Saleem, S.; Chohan, A.H.; Aslam, Z.; Raza, A. Challenging Strategic Trends in Green Supply Chain Management. J. Res. Eng. Appl. Sci. 2020, 5, 71–74. [Google Scholar] [CrossRef]

[6]   Greenhouse Gases Continued to Increase Rapidly in 2022. Available online: https://www.noaa.gov/news-release/greenhouse-gases-continued-to-increase-rapidly-in-2022 (accessed on 25 August 2023).

[7]   Orbiting Carbon Observatory (Science Writers' Guide). Available online: https://eospso.gsfc.nasa.gov/missions/orbiting-carbon-observatory (accessed on 24 August 2023).

[8]   IEA. CO2 Emissions from Fuel Combustion: Highlights—2020 Edition; International Energy Agency: Paris, France, 2020. Available online: https://www.soe.epa.nsw.gov.au/all-themes/climate-and-air/greenhouse-gas-emissions (accessed on 24 August 2023).

[9]   Ritchie, H.; Roser, M.; Rosado, P. CO2 and Greenhouse Gas Emissions. 2020. Available online: https://ourworldindata.org/co2-and-greenhouse-gas-emissions (accessed on 24 August 2023).

[10] Wu, W.; Skye, H.M. Residential Net-Zero Energy Buildings: Review and Perspective. Renew. Sustain. Energy Rev. 2021, 142, 110859. [Google Scholar] [CrossRef] [PubMed]

[11] Nejat, P.; Jomehzadeh, F.; Taheri, M.M.; Gohari, M.; Majid, M.Z.A. A Global Review of Energy Consumption, CO2 Emissions and Policy in the Residential Sector (with an Overview of the Top Ten CO2 Emitting Countries). Renew. Sustain. Energy Rev. 2015, 43, 843–862. [Google Scholar] [CrossRef]

[12] Li, L.; Wang, Z.; Gao, F.; Wang, S.; Deng, J. A Family of Compensation Topologies for Capacitive Power Transfer Converters for Wireless Electric Vehicle Charger. Appl. Energy 2020, 260, 114156. [Google Scholar] [CrossRef]

[13] Distribution of Carbon Dioxide Emissions Produced by the Transportation Sector Worldwide in 2021, by Subsector. Available online: https://www.statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown/ (accessed on 18 December 2022).

[14] Department of Climate Change, Energy, the Environment and Water. India Energy Statistics. 2022. Available online: https://www.energy.gov.au/sites/default/files/India%20Energy%20Statistics%202022%20Energy%20Update%20Report.pdf (accessed on 12 November 2022).

[15] Yousaf, I.; Nekhili, R.; Umar, M. Extreme Connectedness between Renewable Energy Tokens and Fossil Fuel Markets. Energy Econ. 2022, 114, 106305. [Google Scholar] [CrossRef]

[16] Klinlampu, C.; Chimprang, N.; Sirisrisakulchai, J. The Sufficient Level of Growth in Renewable Energy Generation for Coal Demand Reduction. Energy Rep. 2023, 9, 843–849. [Google Scholar] [CrossRef]

[17] Chittur Ramaswamy, P.; Chardonnet, C.; Rapoport, S.; Czajkowski, C.; Rodríguez Sanchez, R.; Gomez Arriola, I.; Bulto, G.O. Impact of Electric Vehicles on Distribution Network Operation: Real World Case Studies. In Proceedings of the CIRED Workshop 2016, Helsinki, Finland, 14–15 June 2016; IEEE: Piscataway, NJ, USA, 2016; pp. 1–4. [Google Scholar]

[18] Sheng, M.S.; Sreenivasan, A.V.; Sharp, B.; Du, B. Well-to-Wheel Analysis of Greenhouse Gas Emissions and Energy Consumption for Electric Vehicles: A Comparative Study in Oceania. Energy Policy 2021, 158, 112552. [Google Scholar] [CrossRef]

[19] Ben Arab, M.; Rekik, M.; Krichen, L. Suitable Various-Goal Energy Management System for Smart Home Based on Photovoltaic Generator and Electric Vehicles. J. Build. Eng. 2022, 52, 104430. [Google Scholar] [CrossRef]

[20] Javadi, M.S.; Firuzi, K.; Rezanejad, M.; Lotfi, M.; Gough, M.; Catalao, J.P.S. Optimal Sizing and Siting of Electrical Energy Storage Devices for Smart Grids Considering Time-of-Use Programs. In Proceedings of the IECON 2019—45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 14–17 October 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 4157–4162. [Google Scholar]