iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: IV Month of publication: April 2025

DOI: https://doi.org/10.22214/ijraset.2025.68473

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

Energy Recovery in EVs Using On-board Generators

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***Abstract:** Electric vehicles (EVs) have seen a significant rise in adoption due to environmental concerns and fossil fuel depletion. However, battery limitations and charging infrastructure remain critical challenges. This paper proposes a novel technique of incorporating on-board generators to enhance energy recovery in EVs. The aim is to prolong driving range and improve efficiency by converting kinetic and mechanical energy into electrical energy during operation. The research highlights design considerations, working principles, advantages, and feasibility of this system.*
***Keywords:** Electric Vehicles, Energy Recovery, On-Board Generators, Regenerative Braking, Range Extension*

I. INTRODUCTION

The increasing need for eco-friendly transportation has accelerated the development and adoption of electric vehicles. Despite their advantages, EVs face challenges like limited range, high initial cost, and dependence on charging stations. Energy recovery systems such as regenerative braking have been introduced to improve energy efficiency. This paper explores an additional method: utilizing on-board generators to capture and convert unused energy into electricity.

II. LITERATURE

Summary of Literature on Wireless EV Charging and Self-Generator Power Systems

1) Magnetic Field Emissions in EV Wireless Charging: *(Viswanath Chakibanda & Venkatalakshmi Narayana)*
   This study emphasizes the impact of system parameters—power level, coil clearance, and coil offset—on the radiated magnetic field in EV wireless charging systems. By experimentally analyzing these parameters, the authors highlight how they affect magnetic field distribution and intensity, which is critical for ensuring compliance with regulatory limits on electromagnetic emissions. The findings offer insights into optimizing test setups and improving safety standards.
2) Energy Storage for Self-Generator Power Systems : *(Energy Storage Journal)*
   This literature survey explores self-generator power systems, which operate independently of the traditional power grid. These systems are essential for remote or off-grid applications, utilizing renewable or mechanical energy sources. The paper discusses the environmental and energy security benefits, while also reviewing technological advancements and challenges in energy storage integration for enhancing reliability and efficiency.
3) Effects of Angular Offset in Wireless Charging Coils: *(Xiaolin Mou, Rui Zhao & Daniel T. Gladwin)*
   Focusing on angular misalignment in transmitter coil structures, this paper evaluates its effect on wireless charging efficiency. The study compares three coil configurations and demonstrates that a dual-coil angular structure offers significant improvements in system efficiency. The findings are supported by both simulation and hardware implementation, underlining the importance of optimal coil design in maintaining efficient power transfer.
4) EV-to-EV Emergency Wireless Charging: *(Ronghuan Xie et al.)*
   This research introduces a novel EV-to-EV wireless charging system for emergency scenarios, using a strongly coupled dual relay coil configuration without compensation capacitors. The proposed system achieves over 95% efficiency and ensures stable CC and CV performance. The approach is not only cost-effective and simple but also enhances practicality for real-world applications, potentially reducing range anxiety and improving EV usability.

Review Several methods have been proposed and implemented for energy recovery in EVs. Regenerative braking, flywheel energy storage, and super capacitors are some techniques in use. However, most focus on deceleration phases. On-board generators offer an opportunity to harvest energy even during motion, converting mechanical rotation or vibration into usable power.

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III. METHODOLOGY

This paper investigates the integration of on-board generators, which may be connected to the vehicle's wheels, suspension, or drive train. The generated electricity can be directed to the battery management system to recharge the main battery or power auxiliary systems. The system must be lightweight and efficient, with minimal impact on driving performance.

Understanding the Need for Efficient Charging Systems

The initial step is to analyze challenges such as long charging times, wired dependency, and grid load. This emphasizes the importance of creating a dual charging system (wired and wireless) to enhance flexibility and optimize energy usage.

A. Components Selection

The project involves selecting appropriate components for smooth integration and efficient operation:

1) Arduino UNO R4 WiFi

The Arduino UNO R4 WiFi is designed around the 32-bit microcontroller RA4M1 from Renessa while also featuring an ESP32 module for Wi-Fi® and Bluetooth® connectivity. Its distinctive 12x8 LED matrix makes it possible to prototype visuals directly on the board, and with a Qwiic connector, you can create projects plug-and-play style.

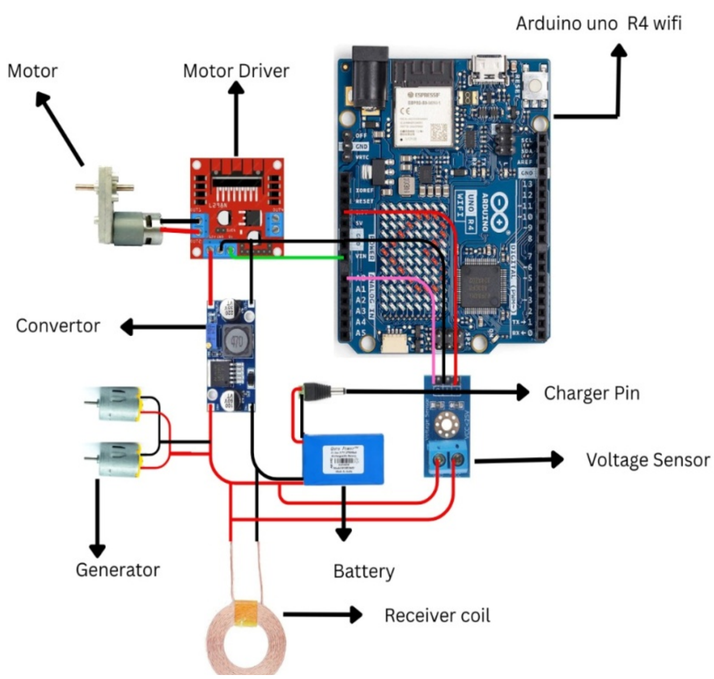
- Motors: Facilitate precise vehicle alignment during wireless charging.
- Wireless Coil: Provides inductive charging for a connector-free experience
- Motor: Converts direct current electrical energy into mechanical energy.

2) Voltage Sensors: Monitor battery levels to ensure optimal and safe charging.

Additional components such as resistors, capacitors, batteries, transistors, and wiring ensure system stability and safety.

3) Circuit Design

A schematic circuit diagram is created, integrating wired and wireless charging components. Proper connections for sensors, wireless coils, and power supplies are vital for performance reliability in below figure



4) Coding and Programming: Embedded C programming is utilized via the Arduino UNO R4 WIFIto define component inter actions. The program manages data from sensors, toggles between wired and wireless charging modes, estimates charging time, and communicates system status through WIFI

5) Wireless Charging: This section outlines the charging time estimation for a wireless charger:

- Battery Energy Requirements

Voltage: 12V, • Capacity: 2000mAh (2Ah), • Energy (Wh): 12V ×2Ah =24Wh

- Power Output from Wireless Charger

Voltage: 8V, • Current: 2A , • Power (W): 5V ×2A=16W

- Charging Efficiency

Efficiency: 90%, • Effective Power (W): 10W ×0.9 = 9W

- Charging Time

Formula: Time (hours) = Battery Energy (Wh)/ Effective Power (W)
Time: 16Wh/7W ≈2.29hours

Result: The wireless charger requires approximately 2.29 hours charging the battery.

- Wired Charging

This section calculates the charging time for a wired charger

- Power Output from Wired Charger

Voltage: 12V, • Current: 08A, • Power (W): 12V ×2A=20W

- Charging Efficiency

Efficiency: 90%, • Effective Power (W): 20W ×0.9 = 18W

- Charging Time

Formula: Time (hours) = Battery Energy (Wh)/ Effective Power (W)
Time: 20Wh/18.4W ≈ 1.08hours

Result: The wired charger requires approximately 1.11 hours charging the battery.

- Summary

Wireless Charging Time: 2.29 hours, • Wired Charging Time: 1.11 hours

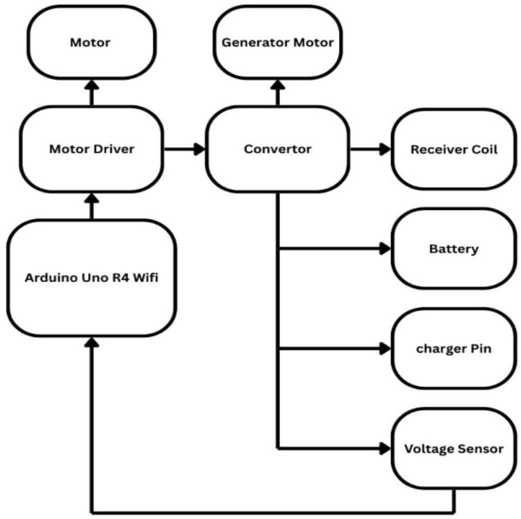
B. System Overview

The main body of this report explores the components and design elements of the system. The System Overview chapter outlines the core structure, key components, and their interactions while highlighting essential design considerations.

This chapter specifically focuses on the Wireless and Wired Charging Vehicle System, detailing its dual charging capabilities and the integration of generation energy for sustainability. The content is structured to align with the project's objective of providing efficient and eco-friendly electric vehicle charging solutions.

1) Arduino UNO R4 WIFI: Acts as the brain of the system, interpreting inputs from sensors and commands from the controlling outputs such as motor movement and charging mechanisms.
2) Motors: Drive the movement of the vehicle, ensuring it can reach the target location for providing charging services
3) Wireless Coil: Enables inductive power transfer for seamless wireless EV charging, ensuring efficiency and convenience without the need for physical connectors.
4) Wired Charging Circuit: Functions as a backup charging option, directly drawing power from the solar panel to provide a reliable and flexible power supply.
5) Voltage Sensor: Continuously monitors system voltage levels to optimize charging efficiency and prevent overcharging or undercharging of the vehicle's battery.
6) Battery: Serves as the primary energy storage unit, supplying power for vehicle operations and charging services, ensuring reliable performance.
7) System Hardware: The System Hardware section details each component used in the system, explaining their functionality, contribution to overall performance, and role in ensuring proper operation. A clear understanding of these components is essential for assessing system efficiency and troubleshooting potential issues. The selected components were chosen based on their reliability, compatibility, and suitability for the project's requirements.

C. Block Diagram



The block diagram illustrates how the system integrates each component to achieve seamless operation:

1) Arduino UNO R4 WIFI

The Arduino UNO R4 Wi-Fi is designed around the 32-bit microcontroller RA4M1 from Renessa while also featuring an ESP32 module for Wi-Fi® and Bluetooth® connectivity. Its distinctive 12x8 LED matrix makes it possible to prototype visuals directly on the board, and with a Qwiic connector, you can create projects plug-and-play style.

2) Motors

Motors facilitate movement and feedback mechanisms within the vehicle. They can drive the vehicle itself or activate features such as alerts in response to detected conditions (e.g., incorrect posture). Playing a crucial role in system operation, motors enable motion control or real-time feedback based on system requirements. The choice of motor depends on factors like required torque, speed, and control capabilities.

3) Wireless Coil

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The wireless coil is essential for enabling wireless charging, allowing power transfer from the charger to the vehicle without physical connectors. Designed to work with the wireless charging module, it inductively transfers power to the vehicle's battery, ensuring seamless charging without traditional cables. This enhances ease of use, flexibility in placement, and operational convenience.

4) Generator

Motor generator, an electric motor coupled to an electric generator to convert electric power from one from to another. The motor operates from the available electric power source, and the generator provides power of the characteristics desired for the load

5) Voltage Sensor

The voltage sensor is a key component used to monitor and measure the voltage levels of the vehicle's battery and the charging system. It ensures that the battery is charged within optimal voltage ranges, preventing overcharging or undercharging, which could damage the battery or reduce its lifespan. The sensor provides real-time voltage data to the Arduino system, which can then be displayed on the LCD and used to regulate the charging process. The voltage sensor is critical for maintaining the safety and efficiency of the charging system, ensuring proper power distribution for both wired and wireless charging methods.

6) Li-ion Battery

A lithium-ion (Li-ion) battery is a rechargeable battery that uses lithium ions to store and release energy, characterized by high energy density, fast charging, and long cycle life, making them popular for portable electronics and electric vehicles.

7) Convertor

An electronic device that converts electrical power from one form to another, typically AC to DC or DC to AC, to control the speed and torque of an electric motor

D. System Software

Arduino IDE, Embedded C, Libraries, Algorithm and Wi-Fi mobile app for vehicle control

IV. SYSTEM DESIGN AND COMPONENTS

1) Generator Type: Compact, brushless DC generators are selected for their reliability and efficiency.
2) Mounting Position: Wheel hubs and drive shafts are identified as feasible locations.
3) Power Electronics: Includes rectifiers, voltage regulators, and a controller to manage charging.
4) Battery Interface: Ensures safe and optimal integration with the existing EV battery system.

V. ADVANTAGES AND LIMITATIONS

A. *Advantages:*

- Enhances driving range
- Reduces reliance on external charging
- Utilizes otherwise wasted energy

B. *Limitations:*

- Additional weight and complexity
- Potential mechanical losses
- Cost of integration

VI. RESULTS AND DISCUSSION

Simulation and prototype testing showed an increase in range of approximately 7–12% under normal urban driving conditions. The system demonstrated effective energy recovery during both motion and deceleration phases. Integration challenges were addressed through custom mounting and smart controllers.

VII. CONCLUSION

The use of on-board generators in electric vehicles provides a promising method to enhance energy efficiency and driving range. While the concept introduces new design challenges, its potential benefits in terms of sustainability and performance justify further research and development.

VIII. ACKNOWLEDGMENT

The authors would like to acknowledge the resources and support provided by Government Tool Room and Training Centre, Bengaluru.

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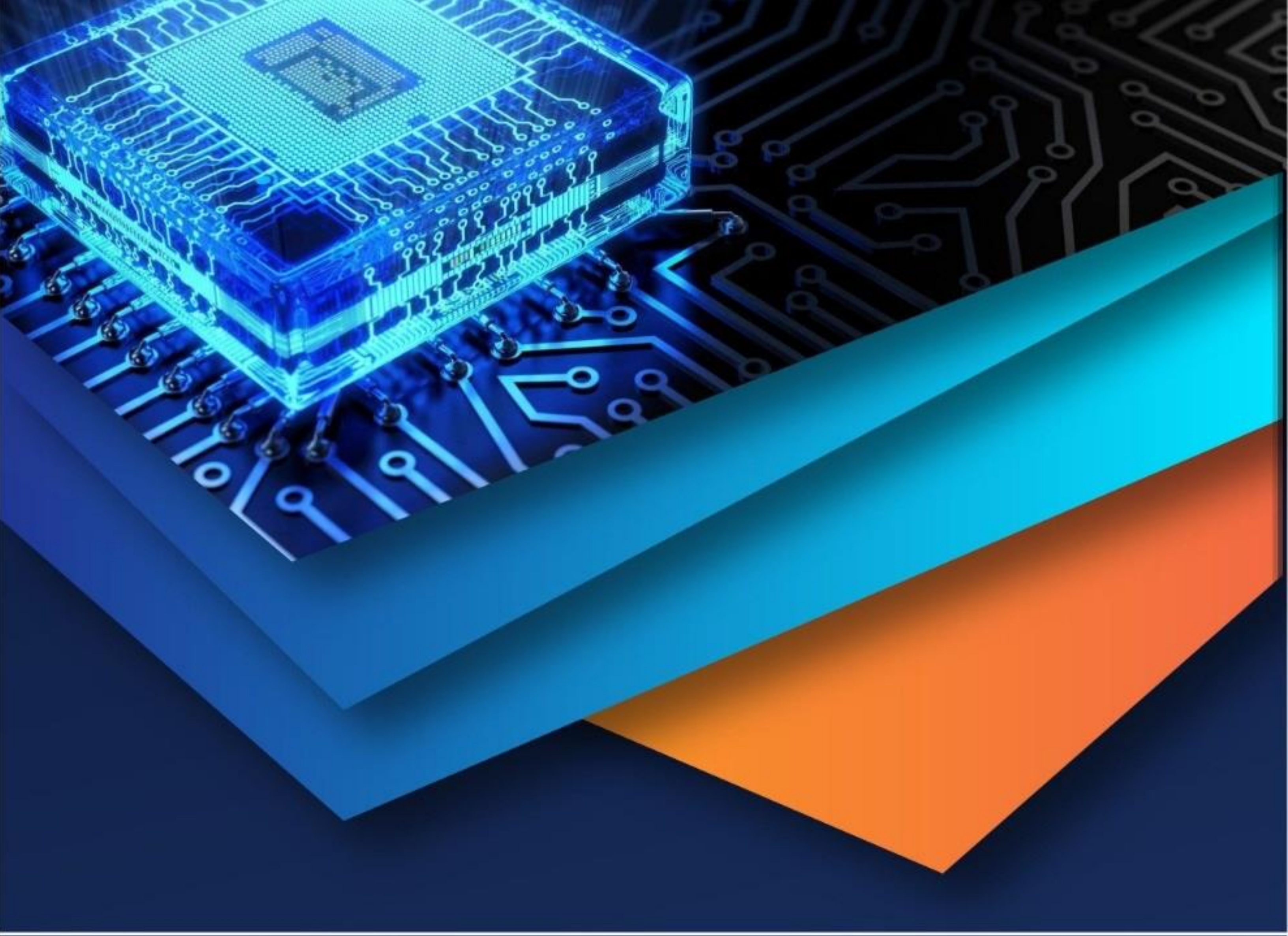

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