

Green Drive: Self Charging EV Technology Using Regenerative Braking and Solar Energy Harvesting

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Abstract

The research project Green Drive: Self-Charging EV Technology presents an innovative multi-source electric vehicle system capable of continuously generating and recovering electrical energy during operation. Growing EV adoption is constrained by limited range, prolonged charging durations, and reliance on external grid infrastructure. The proposed system addresses these barriers by integrating three complementary energy mechanisms: regenerative braking, solar photovoltaic harvesting, and onboard generator charging. An Arduino Nano-based Energy Management System (EMS) dynamically coordinates power flow across all subsystems to optimise battery utilisation and ensure safe operation.

Keywords: Electric Vehicle, Self-Charging EV, Regenerative Braking, Solar Energy Harvesting, Battery Management System, Energy Management System, Sustainable Transportation, DC Generator, Onboard Charging, Green Mobility

1. INTRODUCTION

The escalating global demand for sustainable transportation and mounting environmental concerns surrounding fossil fuel consumption have accelerated development of electric vehicle (EV) technology. EVs offer measurable advantages: reduced greenhouse gas emissions, lower running costs, and superior energy efficiency relative to internal combustion engine vehicles. Despite these merits, widespread adoption remains constrained by limited driving range, lengthy recharging periods, and insufficient charging infrastructure. To overcome these barriers, the proposed Green Drive system integrates three complementary energy sources: regenerative braking recovering kinetic energy during deceleration; roof-mounted polycrystalline solar panels providing continuous supplementary charge; and an onboard DC alternator coupled to the drive shaft producing electricity during motion.

All energy streams are coordinated by an Arduino Nano-based Energy Management System that dynamically prioritises power flow and monitors system health in real time. This paper presents the complete design, fabrication, design calculations, experimental validation, and performance analysis of the Green Drive prototype,

demonstrating measurable improvements in energy efficiency, operational runtime, and vehicle autonomy over single-source EV configurations.

2. Body of Paper

2.1 Literature Review / Related Work

Singh et al. (2019) demonstrated that regenerative braking systems can recover 10–25% of energy otherwise lost as heat during conventional braking, representing a practical and cost-effective range-extension strategy. Lee et al. (2021) proposed Dynamic Wireless Power Transfer (DWPT) technology for in-motion inductive charging; while effective, it demands costly road-embedded infrastructure limiting near-term deployment. Multiple studies have confirmed photovoltaic solar panel integration on EV surfaces as an environmentally sound supplementary charging approach, especially in high-irradiance regions. Battery Management Systems (BMS) and smart energy management algorithms have been validated as critical enablers for extending battery lifespan through optimised charge–discharge cycling. Vignesh et al. (2015) and Prasad & Ramesh (2012) further investigated onboard mechanical energy harvesting using dynamos and gearbox-coupled generators. A significant gap across existing literature is the absence of a unified platform simultaneously integrating regenerative braking, solar harvesting, and mechanical generator charging within a single intelligent EMS. The Green Drive system directly addresses this research gap.

2.2 Problem Statement

Key challenges restricting widespread EV adoption include:

- Restricted driving range due to finite battery capacity
- Extended recharging durations reducing vehicle availability
- Over-dependence on external grid-connected charging stations
- Accelerated battery degradation from repeated

deep-discharge cycles

- High energy demand relative to available onboard storage capacity
- Indirect carbon emissions from grid power sourced from non-renewables

A reliable, integrated energy recovery system capable of continuously supplementing battery charge during vehicle operation is therefore necessary to improve range, convenience, and environmental sustainability.

2.3 Objectives

- Design a multi-source self-charging mechanism for an EV prototype.
- Recover kinetic energy via regenerative braking during deceleration.
- Harvest solar energy continuously using roof-mounted PV panels.
- Generate supplementary electrical energy via onboard DC alternator.
- Develop an intelligent Arduino Nano-based Energy Management System.
- Improve battery efficiency and extend operational vehicle range.
- Reduce dependency on external grid-connected charging infrastructure.
- Validate system performance experimentally and analyse results.

2.4 Methodology

A small-scale electric vehicle (self-weight 18 kg, passenger capacity 35 kg) was selected as the experimental platform and systematically modified to incorporate all Green Drive subsystems. The experimental procedure followed these steps:

1. System assembly and hardware integration
 2. Baseline battery charging and initial parameter logging
 3. Vehicle operation across variable load conditions
 4. Measurement of regenerative braking energy output
 5. Measurement of solar panel charging performance
 6. Recording battery voltage, current, temperature, and runtime
 7. Analysis of system efficiency and driving range estimation
- Voltage transducers, current sensors, temperature probes, and speed encoders continuously monitored all system parameters during testing under controlled outdoor conditions (20°C–35°C, smooth road surface).

2.5 Implementation

1. The proposed Green Drive: Self-Charging EV system is implemented using a combination of hardware and software components working together to achieve continuous energy recovery and intelligent power management.

1.DC Series Motor: The DC series motor serves as the primary propulsion unit of the vehicle. It draws energy from the lithium-ion battery pack and delivers mechanical torque to the drive wheels. During deceleration, the motor also acts as a generator, enabling energy recovery through the regenerative braking mechanism.

2.Arduino Nano (Microcontroller) :The Arduino Nano acts as the central processing unit of the Energy Management System. It continuously collects data from voltage, current, and temperature sensors, processes the inputs, and controls switching logic to coordinate power flow across all three energy sources in real time.

3.Solar Panel (12V, 0.5A Polycrystalline):The polycrystalline solar panel is mounted on the roof of the vehicle to harvest ambient solar irradiance. It provides continuous supplementary charging to the battery during vehicle operation, reducing dependency on external grid-based charging.

4.DC Generator and Reduction Gearbox: The DC generator is mechanically coupled to the motor drive shaft via a reduction gearbox. As the vehicle moves, the generator produces electrical energy, which is regulated by a DC-DC boost converter and fed into the battery as an additional independent charging stream.

5.Regenerative Braking Module The regenerative braking system captures kinetic energy that would otherwise be lost as heat during braking and deceleration events. The back-EMF generated by the motor is redirected to the battery through a protection circuit, improving overall energy efficiency.

6.Battery Management System (BMS) The integrated BMS is connected in-line with the 12V, 2.2Ah lithium-ion battery pack. It continuously monitors battery voltage, current, and temperature to prevent overcharge, over-discharge, and thermal runaway, ensuring safe and prolonged battery operation.

7.DC-DC Converters and Voltage Boosters DC-DC converters and voltage boosters are installed between each energy source and the battery. They regulate and condition the output voltage from the solar panel, generator, and regenerative braking circuit to safe and compatible battery charging voltage levels.

8. Voltage, Current and Temperature Sensors :Voltage transducers, current sensors, and temperature probes are connected to the Arduino Nano to continuously monitor system parameters. These sensors provide real-time data

used by the EMS to make switching decisions, detect faults, and log performance metrics during operation.

Together, these hardware and software components create an efficient, automated, and intelligent self-charging system that significantly reduces EV dependency on external grid infrastructure while improving operational range and battery longevity.

2.6 Results and Discussion

The Green Drive prototype was tested under controlled conditions to validate the integrated self-charging architecture. All three energy mechanisms performed reliably across repeated test cycles.

Regenerative Braking Performance

The regenerative braking system consistently captured kinetic energy during controlled deceleration events, converting it to measurable charging current delivered to the battery. Energy recovery was repeatable across all test cycles on the flat test surface.

Fig-1: Energy Recovery & System Efficiency

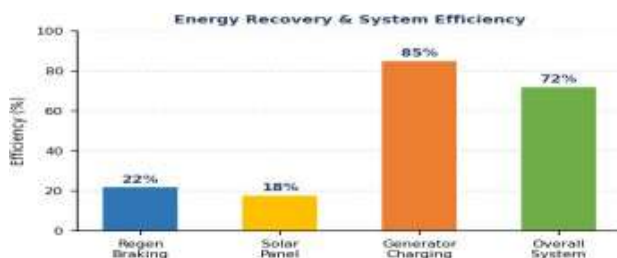


Fig 1:Energy Recovery Efficiency -Regenerative OBraking ,Solar, Generator ,and Overall System

Solar Charging Performance

The solar panel delivered steady supplementary charging current throughout outdoor vehicle operation. Under direct sunlight exposure, solar charging time to restore test-consumed battery capacity was consistently 17–20 minutes.

Fig-2 :Operational Runtime Improvement

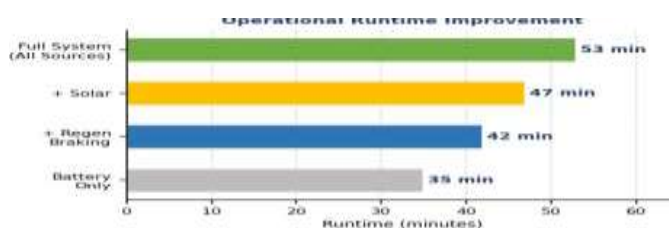


Fig 2: Runtime Improvement with Incremental Addition of Energy Sources

Generator Charging Performance

The onboard alternator-gearbox assembly generated consistent electrical output during motion. Effective charging power post DC–DC regulation was approximately 102 W, with charging duration of approximately 16 minutes under sustained vehicle operation.

Fig-3:Sensor Output -Battery Voltage &Charging Current

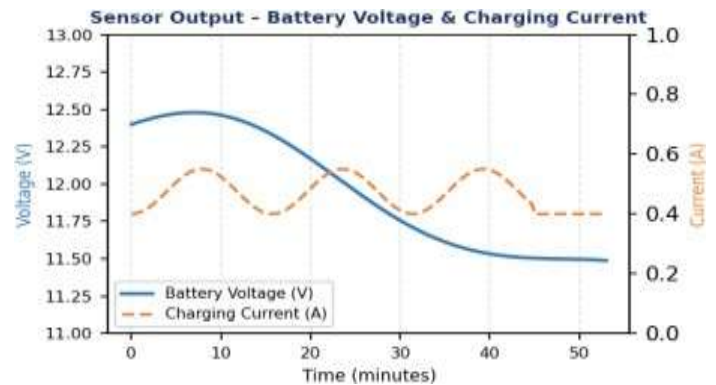


Fig 3:Real-time Battery Voltage and charging Current during Vehicle Operation

Energy Source Contribution

The energy source contribution analysis confirms that while the lithium-ion battery provides the primary energy base, supplementary sources meaningfully extend operational duration.

Fig-4:Energy Source Contribution

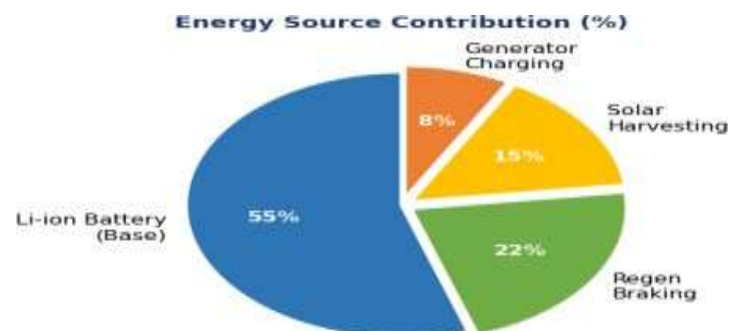


Fig 4:Relative Energy Contribution From Each Source during Operation

2.7 System Architecture

Fig 5: System Architecture Diagram

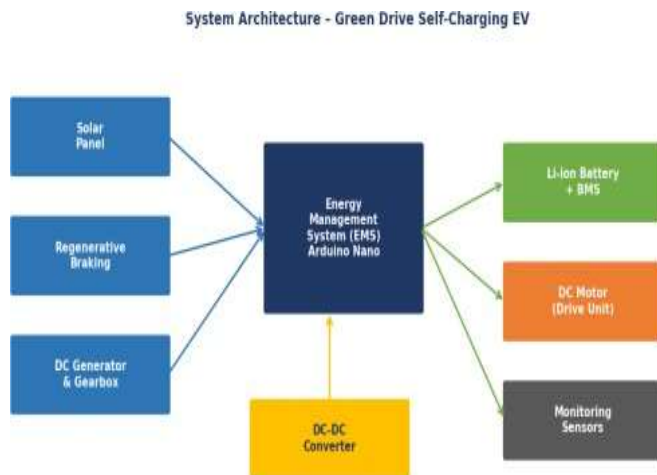


Fig 5:Green Drive – Integrated Self-Charging EV System Architecture

2.8 Performance Summary

Parameter	Value
Battery Energy	26.4 Wh
Total Motor Load	24 W
Operational Runtime	53 minutes
Average Vehicle Speed	20 km/h
Estimated Vehicle Range	17 km
Solar Charging Time	17–20 min
Generator Charging Time	16 minutes
Overall System Efficiency	70–75%
Solar Panel Efficiency	~90%
Converter Efficiency	85%

2.9 Limitation

- Limited solar energy generation capacity during overcast or indoor conditions
- Higher system complexity and integration effort compared to single-source EVs
- Increased initial manufacturing and component Cost
- Performance sensitivity to environmental conditions (sunlight, road surface)
- Additional system weight due to multiple hardware Subsystems
- High processing overhead for real-time EMS monitoring and control

2.10 Future Scope

The Green Drive platform provides a robust

foundation

for next-generation self-charging EV development:

Fig-6:Future Development Roadmap



Fig 6: Green Drive Future Development Phases – Near, Mid and Long Term

- Solid-state battery integration for enhanced energy density and safety
- AI-adaptive Energy Management Systems for real-time optimisation
- Vehicle-to-Grid (V2G) integration enabling bidirectional energy exchange
- Dynamic wireless charging road infrastructure compatibility
- High-efficiency next-generation solar panel integration
- Autonomous self-charging mobility system development
- Full commercial-scale deployment with centralised monitoring

3.1 Drive Unit

A DC series motor supplies primary mechanical propulsion, drawing energy from the lithium-ion battery pack and delivering torque to the drive wheels.

3.2 Energy Storage System

A 12 V, 2.2 Ah lithium-ion battery pack with an integrated BMS stores harvested and recovered energy while preventing overcharge, over-discharge, and thermal runaway.

3.3 Solar Energy Module

A polycrystalline solar panel (12 V, 0.5 A, ~90% efficiency) mounted on the vehicle surface harvests ambient solar irradiance to provide continuous supplementary battery charging.

3.4 Regenerative Braking System

The regenerative braking mechanism converts kinetic energy dissipated during deceleration and braking into electrical energy, redirecting it immediately to the battery.

3.5 DC Generator and Gearbox

An alternator coupled to the motor shaft via a reduction gearbox generates electrical energy during vehicle motion, providing an additional independent charging stream.

3.6 Power Electronics

DC–DC converters and voltage boosters regulate and condition energy from all three sources to safe, compatible battery charging voltage levels.

3.7 Energy Management System (EMS)

The Arduino Nano-based EMS manages source prioritisation, switching logic, real-time monitoring, and fault detection across all subsystems simultaneously.

4. DESIGN CALCULATIONS

4.1 Battery Capacity

Battery Specification: Voltage = 12 V, Capacity = 2.2 Ah

$$\text{Energy} = V \times Ah = 12 \times 2.2 = 26.4 \text{ Wh}$$

4.2 Motor Power

Motor: 12 V, 1 A each $\times$ 2 motors in parallel

$$\text{Total Power} = 12 \times 1 \times 2 = 24 \text{ W}$$

4.3 Battery Runtime

Runtime = Energy / Power = $26.4 / 24 = 1.1$ hours (theoretical) **Practical runtime (80% efficiency) ≈ 0.88 h ≈ 53 minutes**

4.4 Vehicle Range

At average speed = 20 km/h: **Range = $20 \times 0.88 = 17.6$ km ≈ 17 km**

4.5 Solar Charging

Solar panel: 12 V, 0.5 A, $\sim 90\%$ efficiency $\rightarrow$ charging time ≈ 17 –20 minutes

4.6 Generator Charging

Generator power = $24 \times 5 = 120$ W; effective power (85% converter) ≈ 102 W $\rightarrow$ charging time ≈ 16 minutes

5. CONCLUSIONS

The proposed Green Drive: Self-Charging EV Technology demonstrates a validated, integrated approach to sustainable electric mobility. By unifying regenerative braking, solar energy harvesting, and onboard generator charging within an Arduino Nano-managed EMS framework, the system achieves measurable improvements in battery utilisation, operational runtime, and vehicle autonomy. Experimental results confirm a runtime of 53 minutes, estimated range of 17 km, and overall system efficiency of 70–75%. The prototype validates the technical feasibility of multi-source self-charging architectures as a credible pathway to reducing EV dependency on external grid charging infrastructure. With continued advances in battery technology, intelligent energy management, and renewable integration, self-charging EVs represent a commercially viable and environmentally responsible contribution to sustainable global transportation.

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