Design and Performance Analysis of Solar-Powered Electric Vehicle

Mr. Nagesh Satish Naiknaware, Dr. A.P. Pandhare

Department of Mechanical Engineering
Sinhgad College of Engineering, Pune- 41

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Abstract
This project explores the design and performance of a solar-powered EV, integrating renewable energy for sustainable transportation. The study focuses on solar panel integration, energy storage, and propulsion systems. Performance analysis includes evaluating energy efficiency, range, and overall sustainability compared to conventional EVs and fossil fuel vehicles. Simulations and real-world tests assess performance under varying environmental conditions and driving patterns. Data gathered will inform optimization strategies for energy management and system resilience. The project aims to demonstrate the viability of solar EVs as a sustainable alternative, contributing to reduced emissions and reliance on non-renewables, ultimately providing insights for scaling solar technology in the automotive sector.

Key Words: Solar-powered electric vehicle (Solar EV) Sustainability, Performance analysis, Solar panel integration
Real-world testing

1. INTRODUCTION

The increasing depletion of fossil fuels and the adverse effects of environmental pollution have accelerated the need for sustainable transportation solutions. Electric vehicles (EVs) have emerged as a viable alternative yet concerns over the source of electricity generation persist. Integrating solar energy into EV systems offers a promising path toward cleaner mobility. This project explores the design and performance analysis of a solar-powered electric vehicle (SPEV), which utilizes photovoltaic panels to harness solar energy for propulsion. By combining electric mobility with renewable energy, SPEVs aim to reduce greenhouse gas emissions and dependence on conventional fuels. The study encompasses the selection of key components, energy management, and performance evaluation under real-world conditions to validate the system's efficiency and sustainability.

2. LITERATURE REVIEW

M. Patel (2018) - Provided a comprehensive overview of existing solar-powered EV designs and concluded that combining photovoltaic (PV) systems with efficient battery storage can significantly extend driving range and reduce dependency on grid charging. Identified challenges such as limited solar surface area and efficiency losses.

K. Alagheband et al. (2019) - Studied the impact of solar panel orientation and tilt on energy output. Recommended dynamic tilt systems that adjust according to sunlight angle to improve daily energy capture by 15–20% over fixed installations.

R. Sharma et al. (2020)- Investigated solar EV performance in real-world urban conditions. Found that stop-and-go traffic allows better regenerative braking utilization. Solar input was found to significantly contribute to daily energy needs when vehicles are parked in sunlight during daytime hours.

S. Kumar and N. Jain (2021)- Built and tested a prototype solar-powered EV using polycrystalline PV panels and a lithium-ion battery pack. Employed MPPT (Maximum Power Point Tracking) to optimize energy harvesting. Reported a 25% improvement in energy utilization over systems without MPPT.

P. Singh et al. (2022) - Conducted a lifecycle cost analysis comparing conventional EVs with solar-powered EVs. Found that although solar EVs require 25–30% higher initial capital, they offer 35–45% savings in operational cost over a 10-year period due to reduced charging expenses.

A. Gupta (2023) - Used MATLAB/Simulink to model a solar EV driving through diverse Indian terrains. Found that road gradient, ambient temperature, and traffic significantly influence energy efficiency. Highlighted the importance of terrain-aware driving strategies.

3. WORKING PRINCIPLE

The working principle of a solar-operated vehicle revolves around converting sunlight into electrical energy to power the vehicle's motor. Photovoltaic (PV) panels mounted on the vehicle's surface capture solar energy and convert it into direct current (DC) electricity. This electricity is either used directly to drive the electric motor or stored in a battery pack for later use. A charge controller regulates the power flow between the solar panels, battery, and motor to ensure efficient energy management and prevent overcharging. The stored energy in the battery powers the electric motor, which drives the wheels through a transmission system, enabling the vehicle to move. This system allows the vehicle to operate with minimal dependence on grid electricity, offering a clean and renewable mode of transportation.

4. COMPONENTS AND THEIR FUNCTIONS

A solar electric vehicle (EV) consists of several integrated components, each playing a vital role in ensuring efficient operation. The solar panels capture sunlight and convert it into direct current (DC) electricity using photovoltaic cells. This energy is regulated by a Maximum Power Point Tracking (MPPT) controller, which optimizes the power output from the solar panels and directs it efficiently to the battery pack for storage. The battery stores the electrical energy and supplies power to the vehicle's electric motor, which converts electrical energy into mechanical energy to drive the wheels. The motor controller manages the power flow from the battery to the motor, controlling speed and torque based on driver input. A vehicle control unit (VCU) coordinates the overall system operation, including energy distribution, safety protocols, and user interfaces. Additional components such as the drivetrain, cooling systems, and instrumentation panel support the transfer of power to the wheels, maintain safe operating temperatures, and provide real-time data to the driver, ensuring reliable and efficient vehicle performance**.**

4.1 Solar Panel

Fig -1 Solar Panel

A solar panel converts sunlight directly into electricity using the photovoltaic effect and is typically made from mono- or poly-crystalline silicon cells. It generates direct current (DC) power, which can be stored in batteries or used immediately to power electric vehicle components. The panel's output depends on factors such as sunlight intensity, temperature, and angle of exposure, and it often utilizes MPPT (Maximum Power Point Tracking) controllers to maximize power extraction. Constructed with protective glass and durable encapsulation, solar panels are designed to withstand environmental conditions while remaining lightweight and aerodynamically integrated into electric vehicles. They require minimal maintenance, offer a long operational lifespan, and provide a clean, sustainable, and emission-free energy source for EVs.

4.2 Maximum Power Point Tracking (MPPT)

The MPPT (Maximum Power Point Tracking) solar charge controller is a crucial component in solar-powered electric vehicles, designed to optimize the energy harvested from solar panels. It works by continuously tracking and adjusting the panel's voltage and current to operate at the maximum power point, ensuring the most efficient energy conversion under varying sunlight conditions. Compared to traditional charge controllers, MPPT technology can improve charging efficiency by up to 30%, converting excess voltage into usable current to charge the battery more effectively. Additionally, it safeguards the battery system by preventing overcharging, deep discharging, and voltage fluctuations, thereby enhancing the overall reliability and performance of the solar charging system in the vehicle.

4.3 Control Circuit

The power management system in a solar-powered electric vehicle manages the flow of energy between the photovoltaic (PV) panel, battery, and motor, ensuring safe and efficient power delivery. It regulates voltage and current while often incorporating MPPT functionality to optimize solar energy utilization. This system controls the charging and discharging cycles of the battery to prevent overcharging or deep discharging, thereby extending battery life. It includes essential protection features such as over-voltage, over-current, and thermal shutdown mechanisms. Interfacing with various sensors, it monitors parameters like temperature, voltage, current, and motor speed. Additionally, it converts DC power from the battery into a suitable form for driving the electric motor and supports motor control functions like speed regulation and braking. Designed for high efficiency, the power management system minimizes energy loss and heat generation, acting as the central control unit that coordinates all major subsystems within the EV.

4.4 Battery Unit and DC Motor

The energy storage and propulsion system in a solar-powered electric vehicle plays a vital role in overall performance and efficiency. Solar energy is stored in batteries, typically lithium-ion types, due to their high energy density, long cycle life, and ability to support numerous charge-discharge cycles with minimal degradation. These batteries are managed by a Battery Management System (BMS) that ensures safe operation, efficiency, and protection against overcharging, overheating, and deep discharging. The battery system is carefully sized and configured to meet the EV’s power demands and desired driving range. For propulsion, the stored electrical energy is converted into mechanical motion using a motor—commonly a Brushless DC (BLDC) motor—chosen for its high efficiency, reliability, and low maintenance. The motor, integrated with a controller, provides smooth and controllable speed and torque under various load conditions, and often includes regenerative braking functionality to recover energy during deceleration, further enhancing the system’s overall efficiency.

5. PROTOTYPE MODEL ASSEMBLY

Fig.- 2 Prototype Model for SPEV

The construction of the solar-powered electric vehicle involved a meticulous and structured approach to ensure both performance and safety. Lightweight 2.3 mm thick plywood sheets were used to build the chassis, chosen for their strength-to-weight ratio. The chassis layout was designed based on the dimensions of all major components to ensure a balanced and symmetrical structure for stability. A laser cutter was used to precisely cut the wooden sheets, followed by edge-smoothing with sandpaper for both safety and aesthetics. Precise holes were drilled for mounting motors, axles, batteries, and controllers, with weak sections reinforced using additional wood or metal strips. The base was prepared with all necessary mounting holes, and side frames were securely attached using screws or strong adhesives. The DC motor was mounted near the rear axle and connected to the wheels using gears, pulleys, or belts, while the battery holder was positioned close to the motor for efficient energy delivery. The ON/OFF switch or controller was installed in an accessible area, and the solar panel was mounted on top of the vehicle frame. Electrical wiring was completed using low-voltage insulated wires, with all joints soldered properly and protected with heat shrink tubing. Metal rods were selected for the axles, inserted through drilled holes, and secured using bushings or clips to prevent lateral movement, with compatible wheels push-fitted onto the axles. The axle assembly was tested for smooth rotation and reinforced if necessary. Finally, all wires were organized and secured with clips or ties to avoid tangling during operation, and the entire system was tested by toggling the switch to confirm proper motor function.

6. TESTING AND CALIBRATIONS

The testing and calibration phase involved a series of checks to ensure the reliable operation of the solar-powered electric vehicle. All electrical connections were tested for continuity using a multimeter, and the motor’s rotation direction was verified, adjusting the polarity if necessary. The output voltage of the solar panel was measured under both sunlight and artificial light to assess energy generation. Battery voltage was recorded before and after charging to confirm proper charging behavior. Wheel alignment was calibrated to maintain straight and stable movement, while the forward/reverse switch was tested for consistent motor control. Vehicle speed was measured under both no-load and load conditions to evaluate performance. The motor-to-wheel coupling was inspected for any slippage or misalignment, and the solar charging efficiency was evaluated over a fixed interval. Finally, a full system test was conducted to ensure smooth operation, with any issues identified and addressed during troubleshooting**.**

7. PERFORMANCE ANALYSIS

The performance of a solar-powered electric vehicle (SPEV) is determined by a combination of key parameters that reflect its efficiency and practicality. Solar panel output efficiency measures how effectively sunlight is converted into electrical energy, directly influencing the battery charging rate and overall energy availability. The charging rate and efficiency of the battery define how quickly and effectively energy from the solar panels is stored for use. Vehicle range per full charge indicates the maximum distance the EV can travel solely on solar-charged power, while energy consumption per kilometer (Wh/km) reflects the vehicle's operational efficiency. Motor efficiency and power output determine how well electrical energy is converted into mechanical motion, impacting acceleration performance and speed. The vehicle's maximum and average speed, along with its ability to accelerate over a specific range (e.g., 0–1.5 km/h), highlight its driving capabilities. Load handling capacity assesses performance under varying weight conditions, while system thermal performance monitors temperature rise in critical components such as the battery, motor, and electronics to ensure safe operation. Finally, the overall system efficiency integrates the effectiveness of the photovoltaic panels, battery system, MPPT controller, motor, and drivetrain, offering a comprehensive view of the vehicle's real-world performance.

Table -1: Performance analysis

Parameter	Value
Solar Panel Output (mA)	100
Battery Charging Time (hrs)	6–8
Battery Charge Achieved (%)	80%
Battery Run Time (min)	20–25
Distance Covered (m)	80–100
Max Speed (km/h)	1.2
Average Speed (km/h)	0.9
Acceleration Time (s)	4
Max Load Capacity (g)	100
Motor Temp Rise (°C)	5–6
Energy Consumption (Wh/km)	60
Charging Efficiency (%)	70
Overall System Efficiency (%)	45–50

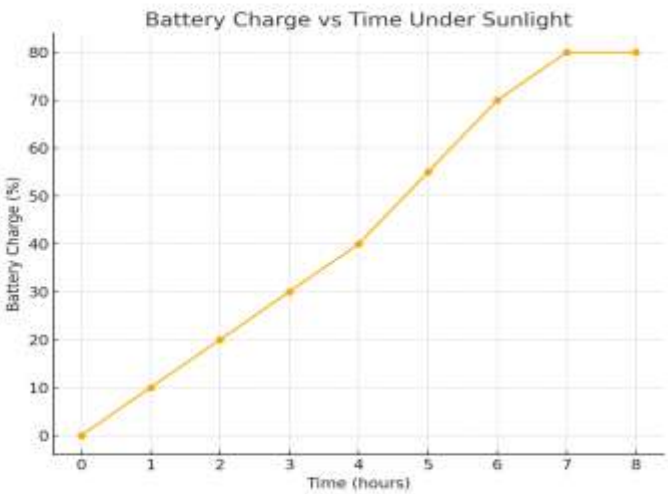

Fig -3 Battery charging performance under sunlight

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8. CHALLENGES FACED

The solar-powered vehicle faced several challenges during its operation and testing. The limited power output from the 0.6 W solar panel restricted real-time operation, and the long charging time made testing cycles slow and time-consuming. Maintaining consistent motor speed was difficult due to low voltage, and vehicle performance dropped significantly with even a slight increase in load. The compact size of the vehicle made wiring and component mounting challenging, while weather dependency, especially during cloudy days, negatively impacted solar charging. Alignment issues in the axles led to mechanical resistance and energy loss, and the battery discharge rate was faster than expected during continuous runs. Precise calibration of components was essential to ensure smooth operation, and the limited availability of miniature lightweight components further complicated the prototyping process.

9. SOLUTION AND IMPROVEMENTS

To enhance the performance of the solar-powered electric vehicle, several upgrades and optimizations can be made. Using a higher wattage solar panel (2–5 W) will allow for faster charging and provide real-time energy support, ensuring that the vehicle can run longer without relying heavily on stored power. Adding a rechargeable battery bank will store excess solar energy, extending usage time. Integrating a basic MPPT (Maximum Power Point Tracking) controller or a voltage regulator will optimize the solar input, ensuring the battery receives the most efficient charge. Lightweight materials should be used in the chassis and other components to reduce overall load, thereby improving speed and range. Upgrading to a more efficient low-voltage DC motor with higher torque will enhance performance, while improving wheel alignment and axle support will reduce friction losses, contributing to smoother motion. A redesigned chassis layout will facilitate easier wiring and more secure component mounting. Incorporating a gear or pulley system can enhance torque transmission, improving acceleration and load handling. The system should be tested under controlled lighting conditions to simulate sunlight consistently, and adding a charging indicator or basic telemetry will help monitor the battery status and performance in real time.

10. CONCLUSIONS

The solar-powered toy electric vehicle successfully demonstrated the feasibility of using solar energy for small-scale electric vehicles. Although the 0.6 W solar panel was limited, it efficiently charged the battery over extended periods, making the vehicle suitable for small-scale use. The project highlighted the challenges associated with low-power solar systems but also provided valuable insights into the potential of renewable energy in transportation. Future improvements could include using a higher wattage solar panel, a more efficient motor, and lightweight components to enhance vehicle performance. This project serves as an educational tool to promote solar energy and eco-friendly transportation options. Additionally, it suggests that the concept could be scaled for practical, small-scale solar-powered vehicles in urban or off-grid areas. The design and testing process also provided valuable hands-on experience in renewable energy applications and vehicle design, offering a deeper understanding of system efficiency, charging speed, and battery capacity for improved performance.

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12. REFERENCES

- Chau, K. T., & Wong, Y. S. (2002). *Overview of power management in hybrid electric vehicles*. Energy Conversion and Management, 43(15), 1953–1968.
- Kalair, A. R., Abas, N., & Saleem, Z. (2021). *Review of solar power programs in leading countries*. Renewable and Sustainable Energy Reviews, 144, 110896.
- Subramaniam, R., & Kumar, S. (2020). *Modeling and simulation of solar-powered electric vehicle with MPPT*. International Journal of Power Electronics and Drive Systems (IJPEDS), 11(1), 431–438.
- Tiwari, G. N., & Dubey, S. (2010). *Fundamentals of Photovoltaic Modules and Their Applications*. Royal Society of Chemistry.
- Gautam, A., & Kumar, D. (2022). *Performance analysis of MPPT techniques for solar PV systems*. Journal of Cleaner Production, 358, 131894.