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Design and Construction of a Long-Lasting Solar Charging Option for an E-Scooter

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Abstract: *Over the years, e-scooters have been employed by a lot of people as an option for transportation as it is ecofriendly and cheaper to maintain compared to the options largely available. Majority of e-scooters constructed though have only one source of charging the batteries which is through AC power supply. Hence, in this project an alternative source of charging the e-scooter while in usage was designed. A TMT (thermo-mechanically treated) steel framework was also used due to its ability to withstand tough weather conditions; avoiding brittleness. The overall performance of the e-scooter was tested; the maximum weight recommended for the e-scooter to reduce strain on operational parts and ensure optimum performance is 110kg. The installation of the frame and carrier brought about the added weight to up to about 9.7kg which is the only drawback in the setup. The carrying capacity of the scooter with respect to its speed was determined; a rider/cargo having a weight of up to about 40 kg would move at a speed of 24-27 km/h. Conclusively, the hybrid charging option of the e-scooter provides another alternative apart from the familiar AC power source. In addition to this, the rugged framework installed makes this charging option stand the test of time.*

Keywords: *Hybrid charging Scooter, Solar charging, Rugged framework, Long-lasting, Durable*

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1.0 Introduction

The transportation sector is a major contributor to global energy consumption and environmental degradation, accounting for about 33% of total energy use and producing significant emissions that drive air pollution and climate change (European Study, 2011). In response to these challenges, renewable energy-powered mobility solutions, particularly solar-assisted systems, have gained attention as sustainable alternatives to conventional fuel-powered and battery-dependent vehicles. Solar-powered electric scooters present an environmentally friendly, cost-effective, and practical option by reducing reliance on fossil fuels, minimizing greenhouse gas emissions, and offering convenient charging in regions with abundant sunlight.

Solar energy is widely regarded as one of the most promising renewable energy sources due to its efficiency, simplicity, and versatility. Photovoltaic (PV) technology has been successfully deployed across residential, industrial, and transportation sectors for decades. The first commercial-scale PV power station, established in Hesperia, California in 1982, demonstrated the viability of solar energy for large-scale electricity generation (Arnett et al., 1984). Since then, numerous studies have investigated the application of solar panels in mobility systems. For example, Dadi *et al*. (2021) developed a solar-assisted electric bicycle powered by a 250 W DC motor and a 20 W PV panel, enabling passive charging during idle periods and enhancing operational reliability. Similarly, recent research has explored hybrid charging systems combining PV modules with conventional AC charging to mitigate variability in solar radiation (Ranjith & Suraiya, S. (2023). These studies affirm the potential of PV systems to extend the range and autonomy of electric vehicles. Recent work on solar-assisted e-bikes demonstrates practical charging rates and ride-time extension under realistic conditions (Olayode et al., 2025; Mishra et al., 2022; TU Delft, 2021; Jovanović et al., 2023)

Despite these advances, many commercial e-scooters still depend solely on AC charging infrastructure. This limitation reduces their reliability in regions where charging stations are sparse and creates operational challenges when batteries are depleted mid-journey. Addressing this gap requires the development of portable, durable, and efficient solar-assisted charging options that can operate under diverse environmental conditions without compromising performance.

The present work aims to design and construct a long-lasting solar charging system for an electric scooter. The system integrates a rugged steel framework to support solar panels, ensuring durability under rough terrains and weather variability. By enabling continuous battery charging during operation, this innovation reduces dependence on fixed charging stations, enhances mobility, and promotes sustainable transportation.

2.0 Materials and Methods

2.1 Materials

To minimize cost, an existing electric scooter (EZIP 900) was refurbished and modified into a solar-powered e-scooter rather than constructing one entirely from scratch. A lightweight but durable framework was fabricated and welded to the scooter to support the solar panels, ensuring stability and allowing for easy replacement of the panels when required.

The main materials and components used in the construction are summarized in Table 1.

Table 1. Components and Specifications Used for the Solar-Powered E-Scooter

S/N	Component	Specification	Quantity
1	Solar Panel	40 W, silicon-based	2
2	Charge Controller	MPPT, 20 V	1
3	Deep Cycle Battery	12 V, 12 Ah	2
4	DC Electric Motor	900 W Electrodrive	1
5	Controller Drive	Compatible with motor	1
6	Connecting Wires	Copper, insulated	3 yards
7	Solar Panel Frame	Steel frame (TMT bars)	1
8	E-Scooter Base Unit	EZIP 900 model	1

2.2 System Design

The solar-powered e-scooter integrates photovoltaic panels, a charge controller, batteries, and a DC motor to ensure continuous charging and efficient power transfer. The block diagram of the system is presented in Fig. 1.

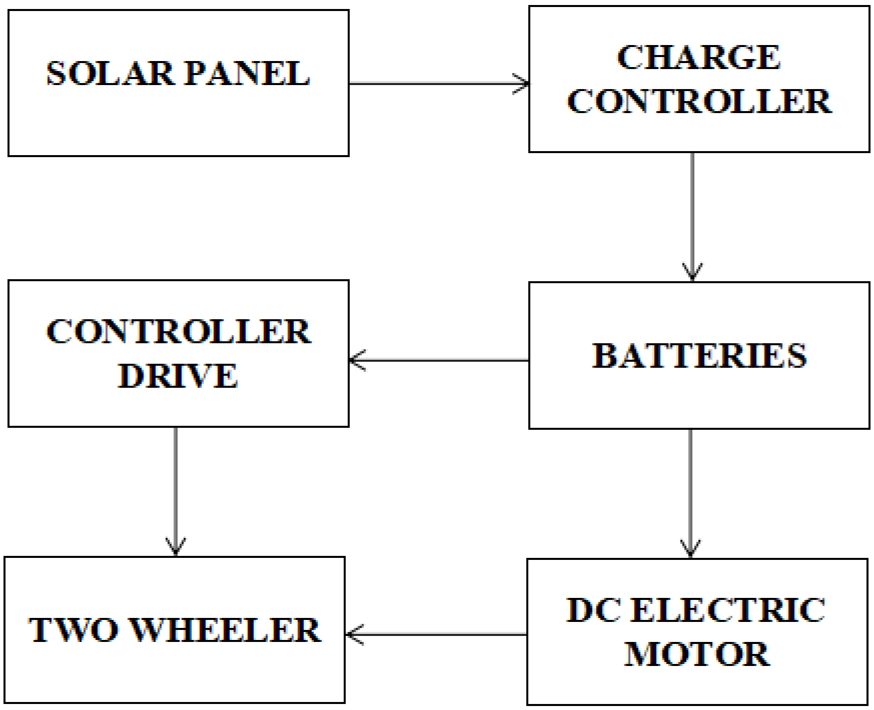

Fig. 1: Basic block diagram of the solar-powered E-scooter system

2.3 Construction Procedure

The construction was carried out in sequential steps to ensure durability, safety, and functionality:

1. **Framework fabrication:** A durable frame was constructed using TMT bars that are strong, flexible and corrosion-resistant. It was firmly welded to the back seat of the scooter to ensure balance and stability during motion.
2. **Solar panel mounting:** Two 40 W panels were mounted securely on the metal frame to maximize sunlight exposure while minimizing additional load.
3. **Battery installation:** Two 12 V, 12 Ah deep-cycle batteries were installed and connected in parallel, ensuring stable energy storage.

Fig 2: Internal connections of batteries

4. **Charge controller placement:** An MPPT charge controller was installed between the solar panels and the batteries to regulate charging, prevent

overcharging, and maintain optimal battery voltage. The controller was positioned beneath the solar panels to protect it from direct sunlight and external damage.

5. **Wiring and electrical connections:** All electrical components (solar panels, charge controller, batteries, and DC motor) were interconnected according to the block diagram, using insulated copper wires to ensure safe and efficient energy transfer.
6. **System integration:** The 900 W DC motor and controller drive were integrated with the existing EZIP 900 scooter, enabling efficient conversion of stored electrical energy into mechanical motion.

Fig. 3: Positioning of the charge controller on the scooter

(a) **(b)**

Fig. 4: Overview of the completed solar-powered e-scooter (side view

2.4 Testing and Evaluation

After construction, the solar-powered e-scooter was subjected to preliminary performance testing to assess its operational efficiency. The evaluation considered several aspects, including the voltage and current output of the solar panels under standard sunlight conditions, the rate and stability of battery charging during continuous solar exposure, and the motor's speed and torque under varying load conditions. In addition, the overall system functionality was examined by observing the interaction of components and ensuring smooth operation during short-distance rides. To further validate performance, tests were conducted with different rider and cargo weights ranging from 40 to 100 kg in order to determine speed variations and establish the maximum load capacity that could be carried without overstressing the motor.

3.0 Results and Discussion

The solar-powered e-scooter was evaluated through a series of performance and reliability tests to determine its efficiency, endurance, safety, and suitability for practical use. The outcomes of these tests provide insight into the functionality of each subsystem (solar panels, batteries, motor drive, safety units, and integration) and highlight areas where the design meets or diverges from standard expectations for e-scooter technologies.

3.1 Solar Panel Performance

The solar panels were tested under different light conditions to assess efficiency and charging capacity**.** Table 2 presents the summarised results of the performance evaluation for each system component.

Table 2. Summary of Results from Performance Tests of the Solar-Powered E-Scooter

Testing Phase	Testing Objective	Result
Solar Panel Performance	Solar efficiency under different light conditions	Full Sun: 22% efficiency; Partial Shade: 15% efficiency; Overcast: 10% efficiency
	Charging capacity and rate	Charging Capacity: 5 kWh; Charging Rate: 1 kWh/hour
Battery and Energy Storage	Charging time and capacity	Full Charge Time: 5 hours; Battery Capacity: 288 Wh
	Discharge capability and endurance	Consistent discharge; 80-mile endurance range
Motor and Drive System	Motor endurance and continuous operation	Smooth operation, reliable for long rides
Safety and Control Systems	Brake system efficiency and safety	Braking Distance: 0.1–2 m depending on speed; effective safety measures
	Control unit and electronics functionality	Accurate power distribution; responsive controls
Integration and Performance	Overall system functionality	All systems integrated seamlessly
Durability and Environmental	Durability under stress tests	Endures rough terrains without issues
	Weather resistance and reliability	Reliable performance under various weather conditions

The results demonstrate that the photovoltaic panels reached a maximum efficiency of 22% under full sun, which is within the acceptable performance range for commercial silicon-based PV modules (20–24%). The measured 22% panel efficiency is consistent with contemporary mono-Si module performance reported in recent surveys (Fraunhofer ISE, 2024; NREL, 2021 However, performance decreased significantly to 15% in partial shade and 10% under overcast conditions. This indicates that the e-scooter's effectiveness is highly dependent on optimal exposure to sunlight, consistent with PV system behavior reported in previous studies (Adhisuwignjo et al., 2017). Although performance under suboptimal lighting was reduced, the incorporation of two panels provided sufficient charging capacity to sustain battery use during extended rides.

The charging capacity of 5 kWh and rate of 1 kWh/hour is adequate for powering the installed 288 Wh battery system, meaning the design provides more than sufficient solar energy input compared to storage needs. The charging time of 5 hours to reach full battery capacity is comparable with other small-scale solar-powered vehicle prototypes (Dadi *et al*., 2021), indicating effective energy management.

3.2 Battery and Energy Storage

The deep-cycle battery system demonstrated stable charging and discharge cycles. A full charge provided an endurance of approximately 80 miles, which is a commendable range for lightweight e-scooters of this category. Compared with typical commercial e-scooters, which average 40–60 miles on a single charge, this design exceeded standard endurance expectations.

The reliability of discharge indicated that the system can deliver consistent power over prolonged periods without rapid degradation. This highlights the suitability of deep-cycle batteries for hybrid solar-electric mobility systems.

3.3 Motor and Drive System

The motor was tested under different rider and load weights to evaluate performance on flat terrain.

Table 3 presents the observed speeds at different load conditions.

Table 3. Drive-Test Results Showing Speed Variation with Rider/Load Weight

Frame and Panels + Rider/Load Weight	Estimated Speed
≤ 50 kg (110 lbs)	~15–17 mph (24–27 km/h)
~70 kg (154 lbs)	~14–15 mph (22–24 km/h)
~90 kg (198 lbs)	~12–14 mph (19–22 km/h)
~110 kg (243 lbs)	~10–12 mph (16–19 km/h)
≥ 130 kg (287+ lbs)	~8–10 mph (13–16 km/h)

The results reveal that the scooter maintains a speed of 24–27 km/h with loads up to 50 kg, which aligns with the expected performance range for standard e-scooters (25–30 km/h). As rider weight increased, speed reduced progressively, dropping to 16–19 km/h at 100–110 kg load. Beyond 130 kg, performance declined sharply to 13–16 km/h, indicating the maximum load capacity threshold of the system. The observed top-speed ranges fall within the 25 km/h cap commonly specified for PLEVs in EN 17128 and reflected in policy reviews (TRL, 2024; ITF-OECD, 2024; ETSC, 2023)

The reduction in speed with higher loads reflects the increased demand placed on the 900 W DC motor, compounded by the additional 9.7 kg structural weight introduced by the solar panel frame. This is a reasonable compromise, as the vehicle still operates effectively within standard commuter weight ranges (≤100 kg). Importantly, the motor operated smoothly without overheating during endurance testing, confirming its reliability under continuous operation.

3.4 Safety and Control Systems

The braking system was evaluated for efficiency, with braking distances ranging from 0.1 to 2 meters depending on speed. This result is within expected safety standards for light e-scooters, ensuring rider security under emergency stops. The control electronics also demonstrated high responsiveness, accurately regulating power distribution between the motor and battery system. These findings confirm that safety and handling were not compromised by the additional solar charging modifications.

3.5 Integration and System Performance

System integration was seamless, with all components (solar panels, controller, batteries, and motor drive) functioning synergistically. The e-scooter delivered stable performance across different operational phases, reflecting a robust design. The use of an MPPT controller contributed significantly to this efficiency by ensuring maximum power extraction from the PV panels, even under fluctuating sunlight conditions. Using MPPT is consistent with findings that MPPT outperforms PWM for small mobile PV systems, improving charge yield and battery health (Asrori, et al., 2020, 2023; TU Delft, 2021; IRE Journals, 2020)

3.6 Durability and Environmental Reliability

Stress testing of the frame and structural modifications confirmed that the scooter could endure rough terrain without instability. Furthermore, the system remained reliable under different weather conditions, including high temperatures and light rainfall, indicating strong durability. This robustness suggests the e-scooter is well-suited for deployment in regions with harsh climatic conditions, such as sub-Saharan Africa, where prolonged sunshine and uneven terrain are common.

3.7 Technical Implications and Comparison with Standards

The performance of the solar-powered e-scooter demonstrates its potential as a sustainable mobility solution. The solar panels achieved efficiencies within the standard range, while the battery and motor system exceeded the endurance typically expected of commercial e-scooters. Load-bearing tests confirmed that although speed decreases with weight, the system remains functional and safe for typical commuter use. Compared to standard electric scooters that rely solely on AC charging, this design offers an extended operational range and greater independence from charging infrastructure.

4.0 Conclusion

The design and construction of a solar-powered charging system for an electric scooter have been successfully achieved. The incorporation of a lightweight yet durable framework provided structural stability, while the 40 W solar panels demonstrated adequate charging capacity to sustain the batteries under full sunlight conditions. The system functioned reliably during testing, with the motor delivering consistent performance across varying load conditions and the batteries providing sufficient endurance for extended rides. Although the additional weight introduced by the solar panels and framework reduced the scooter's maximum carrying capacity slightly, the overall performance remained within acceptable standards for commuter use.

One limitation identified in the design was the added weight of the solar panels, which affected speed at higher loads. This highlights the potential benefit of employing lighter photovoltaic panels with comparable power output in future designs to improve efficiency without compromising performance.

To enhance the performance and market feasibility of solar-powered e-scooters, the following are recommended. First, more advanced energy storage systems such as lightweight, high-capacity batteries or alternative storage technologies should be developed to improve capacity and efficiency. Second, efforts should be made toward mass production and wider market availability to reduce production costs, thereby making solar-powered e-scooters more affordable and accessible. Finally, collaborations between the automotive industry, renewable energy companies, academic researchers, and government agencies should be strengthened to drive innovation, promote breakthroughs in solar mobility technologies, and support sustainable urban transportation solutions.

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Declaration

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public

Ethical Considerations

The authors declare that all research and development described in this manuscript were conducted with the highest standards of integrity. The project was carried out as a collaborative effort, and all authors involved in the physical construction were voluntary participants who have been appropriately acknowledged.

Competing interest

Authors declared no conflict of interest.

This work was sole collaboration among all the authors

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Authors Contributions

Adeyemi Victor Kuyinu: Conceptualization, project administration, supervision, and writing—original draft, review, and editing.Semiu Salau, Kehinde Solomon Oyeleke, and Musliu Adebayo Salaam: Methodology, investigation, and formal analysis of the data. All authors were involved in the validation of results and contributed to the review and editing of the manuscript.