

Green Energy Gazebo: A Solar PV Based Public Charging Solution

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ABSTRACT: The Smart Solar Gazebo is a standalone renewable energy powered public charging hut designed to provide safe charging facilities for mobile phones, laptops, and lighting in public spaces without dependence on the utility grid to Green Energy Gazebo: A Solar PV Based Public Charging Solution. The system integrates rooftop solar photovoltaic (PV) modules, a hybrid inverter, battery storage, protection devices, earthing, and optional IoT monitoring within a gazebo structure that also provides shaded seating. This paper presents the system architecture, component selection, protection scheme, structural design considerations, and expected performance of the proposed installation. The model is suitable for Green Energy Gazebo: A Solar PV Based Public Charging Solution, College campuses, parks, bus stops, and rural areas with unreliable grid access. The solution promotes green energy awareness while delivering a practical public utility.

KEYWORDS: Green Energy Gazebo, Solar PV, Gazebo, Public charging station, Hybrid inverter, Battery storage, Earthing, Surge protection, IoT monitoring..

I. INTRODUCTION

Public places often lack safe and reliable charging facilities for personal electronic devices. Grid-connected charging points increase wiring complexity, operational cost, and safety concerns. A solar-powered gazebo offers an innovative solution by combining a shaded seating structure with an integrated renewable energy system for public charging and lighting. This concept is particularly beneficial for educational campuses, transport locations, tourist spots, and rural markets..

In this research paper proposes replicable framework for future sustainable infrastructure projects, combining technical innovation with practical utility. As communities worldwide seek to reduce their environmental impact and enhance public amenities, the Smart Solar Gazebo provides a comprehensive solution that balances performance, sustainability, and user needs. Its successful implementation paves the way for broader adoption of renewable energy technologies in public spaces, contributing to the global transition toward cleaner, smarter cities. This initiative not only addresses immediate energy needs but also serves as an educational platform and catalyst for further innovation in sustainable urban development. The lessons learned and technologies demonstrated will inform future projects, accelerating the integration of renewable energy solutions into everyday public infrastructure

Public spaces often lack safe charging infrastructure. Grid extensions add cost and safety risk. A solar PV gazebo combines shelter, seating, and clean energy for charging and lighting. Global PV deployment trends and best practices support such distributed, small-scale applications [1], [13].

II. LITERATURE SURVEY

Rapid growth in distributed solar PV has encouraged small, standalone applications for public utility spaces. Industry outlook reports emphasize the suitability of modular PV for decentralized services in campuses, parks, and transport locations [1], [13].

Guidelines for safe PV design, wiring, and installation practices are well documented by National Renewable Energy Laboratory (NREL) and industry handbooks, covering conductor sizing, grounding, and protection layouts for small PV systems [2], [12], [15]. Safety of power converters and PV hazard control are standardized through IEC and UL frameworks, ensuring inverter reliability and user safety in public-facing installations [3], [8], [14].

Surge and lightning protection are critical for exposed rooftop PV structures. IEC standards for SPDs and lightning protection outline coordination between DC SPDs, earthing, and structural bonding to reduce transient risks [7], [17], [19]. Proper earthing design per Indian practice is essential for touch/step potential control in public areas [21].

Performance and reliability studies from International Energy Agency (IEA) PVPS highlight common failure modes in PV systems and recommend preventive design for outdoor environments [11]. Manufacturer manuals from Schneider Electric and Eaton Corporation provide practical protection layouts for inverters and PV circuit protection [9], [10].

Research on hybrid inverter performance demonstrates improved energy utilization and battery management in small PV-battery systems [16]. Battery lifetime and thermal management considerations for VRLA batteries are discussed in prior energy studies [20]. MPPT techniques for maximizing PV harvest under varying irradiance are extensively reviewed in literature [25]. PV efficiency benchmarking work provides context for module selection [18].

Structural integrity of PV mounting under wind and extreme loads has been analytically studied, informing safe gazebo-top installations [23]. Indian Standards for wind loads, earthquake resistance, steel construction, corrosion protection, and earthing provide the civil and safety backbone for such outdoor structures [21], [24], [26], [28], [29].

These works collectively inform the safe, reliable, and standards-aligned design of the proposed Smart Solar Gazebo for public charging applications.

III. METHODOLOGY

The methodology for The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut focuses on the systematic design, sizing, integration, and safe installation of a standalone solar photovoltaic (PV) system to provide reliable public charging and lighting in outdoor locations. The approach follows established PV design practices, safety standards, and installation guidelines recommended by National Renewable Energy Laboratory, Solar Power Europe, and international standards for PV protection and converters.

3.1. System Planning and Load Assessment : The first step involved identifying the expected public load requirements:

- USB and Type-C charging ports for mobile devices,
- 230 V AC outlet for laptops and small appliances,
- LED lighting for night operation.

The total daily energy demand was estimated considering average device charging time and lighting duration. This load assessment formed the basis for PV panel, battery, and inverter sizing.

3.2. Solar PV Module Selection and Sizing

Based on efficiency, space constraints, and reliability, 110 W monocrystalline PV modules were selected. Monocrystalline technology offers higher efficiency ($\approx 19\text{--}21\%$) and superior low-light performance, suitable for compact installations. The number of panels was calculated to meet the daily energy requirement with a margin for cloudy conditions. PV sizing considered:

- Open circuit voltage (V_{oc}) and maximum power voltage (V_{mp}),
- Series-parallel configuration for required system voltage,
- Mounting orientation and tilt for maximum solar irradiance capture.
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3.3. Battery Bank Design

A VRLA/SMF battery bank was chosen for maintenance-free operation and safety in public spaces. Battery capacity was calculated to:

- Store sufficient energy for night lighting,
- Provide backup during low sunlight,
- Support simultaneous charging loads.

Depth of discharge (DoD), autonomy period, and charging efficiency were considered in capacity calculations.

3.4. Hybrid Inverter and MPPT Charge Controller Integration

A solar hybrid inverter with inbuilt MPPT charge controller was used as the central energy management unit. As required by IEC 62109 and UL 1741, the inverter:

- Converts DC from PV/battery to 230 V AC,
- Optimizes PV output using MPPT,
- Manages charging and discharging of the battery,
- Supplies uninterrupted power to loads.

3.5. Electrical Protection and Safety Measures

Since the gazebo operates in open public areas, extensive protection mechanisms were implemented following IEC 63027 and UL 3741:

- DC and AC Miniature Circuit Breakers (MCBs),
- DC Surge Protective Device (SPD),
- Proper earthing and lightning arrester,
- PVC conduit wiring and weatherproof MC4 connectors,
- Load Distribution Board (LDB) for safe circuit segregation.

3.6. Structural Fabrication and Mounting

The gazebo structure was fabricated using Hot-Dip Galvanized Iron (HDGI) pipes to ensure corrosion resistance and long service life. The PV panels were mounted on the roof with appropriate tilt. All electrical components were housed in a protected enclosure to avoid environmental exposure.

3.7. Lighting Automation Using Photocell

LED luminaires were integrated with a photocell sensor for automatic dusk-to-dawn operation. The photocell controls a relay connected to the lighting circuit, ensuring energy conservation and autonomous operation without human intervention.

3.8. Public Charging Interface Integration

Multiple charging standards were integrated for universal usability:

- 5 V USB ports (2.1 A),
- Type-C fast charging with PD/QC,
- 230 V AC outlet from inverter output.

Each charging line was individually protected through MCBs to ensure user safety.

3.9. Installation, Testing, and Commissioning

The complete system underwent staged installation:

1. Gazebo frame erection,
2. PV panel mounting,
3. Wiring through conduits,
4. Inverter, battery, and protection device installation,
5. Testing of lighting automation and charging ports.

Performance testing was conducted under sunlight and battery mode to verify uninterrupted operation. This methodology ensures that the Smart Solar Gazebo is energy-efficient, safe, reliable, and suitable for public use, demonstrating practical implementation of solar PV technology in community infrastructure.

IV. EXPERIMENTAL RESULTS

Figure 4.1 presents the real-time implementation of Green Energy Gazebo: A Solar PV Based Public Charging Solution & The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut with integrated PV, storage, protection, lighting, and public charging interfaces. The observed results validate technical performance, structural integrity, safety compliance, and user functionality in an outdoor public setting.

4.1. System Performance Results

- The 110 W monocrystalline PV modules delivered stable DC output under varying irradiance, supporting continuous daytime operation.
- The MPPT-enabled hybrid inverter improved solar energy harvesting by approximately **15–25%**, maintaining optimal charging across the day as recommended in PV design practices by **National Renewable Energy Laboratory**.
- The SMF/VRLA battery bank ensured uninterrupted supply during evenings and low-sunlight periods, enabling reliable device charging and lighting.



Figure 4.1 (a) The real-time implementation of Green Energy Gazebo: A Solar PV Based Public Charging Solution & The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut

4.2. Structural Results

- The HDGI gazebo framework satisfied load verification tests:
 - Maximum measured deflection: **6.5 mm** (within allowable limits),
 - No foundation uplift at simulated wind speeds up to **150 km/h**,
 - Overall structural **safety factor > 2.0**, confirming durability for outdoor deployment.

4.3. Electrical Safety and Protection Results

- Earthing resistance was maintained **below 5 Ω** , ensuring safe fault-current dissipation in line with **IS 3043**.
- Lightning arrester and DC/AC surge protection effectively mitigated overvoltage risks consistent with **IEC 61643** and PV hazard control guidance in **UL 3741**.
- Proper circuit segregation through MCBs and an LDB enhanced operational safety for public users.
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4.4. Maintenance and Reliability Results

- Preventive maintenance checks indicated stable operation with no major faults.
- Panel surface condition and wiring insulation showed negligible degradation after installation.
- Battery health parameters remained within recommended charge–discharge limits, supporting dependable cycling.

4.5. User Functional Results

- LED luminaires operated automatically via photocell control, minimizing energy wastage.
- USB, Type-C, and 230 V AC outlets supported simultaneous charging of multiple devices, demonstrating practical usability in community spaces.



Figure 4.1 (b) The real-time implementation of Green Energy Gazebo: A Solar PV Based Public Charging Solution & The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut



Figure 4.1 (c) The real-time implementation of Green Energy Gazebo: A Solar PV Based Public Charging Solution & The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut at College Premises

V. CONCLUSION

The real-time implementation of Green Energy Gazebo: A Solar PV Based Public Charging Solution & The Smart Solar Gazebo: A Renewable Energy-Based Public Charging Hut at College Premises The Smart Solar Gazebo successfully demonstrates how a compact solar PV system, integrated with storage, intelligent power management, and robust protection, can serve as a **self-sustaining public charging infrastructure**. The project validates:

- **Technical feasibility** through efficient PV generation, MPPT optimization, and reliable battery backup,
- **Structural robustness** using HDGI fabrication suitable for harsh outdoor conditions,
- **Electrical safety compliance** via proper earthing, surge protection, and standards-aligned design,
- **Public usability** with automated lighting and universal charging interfaces.

This implementation research highlights the practical role of renewable energy in everyday public utilities, reducing dependence on grid electricity and promoting clean energy awareness. The Smart Solar Gazebo model can be replicated in parks, campuses, bus stops, and community centers as a scalable step toward sustainable public infrastructure.

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