



DESIGN AND IMPLEMENTATION OF SMART SOLAR ENERGY OPTIMIZATION SYSTEM

Tathe Shubham Sunil

*UG Student, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
shubhamtathe2005@gmail.com*

Garande Rajkumar Mahadev

*UG Student, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
rajkumargarande12@gmail.com*

Thombare Amit Tanaji

*UG Student, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
amitthombare1301@gmail.com*

Sarak Ganesh Sanjay

*UG Student, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
sarakganesh4924@gmail.com*

Savalgi Abhishek Santosh

*UG Student, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
abhisheksavalgi601@gmail.com*

Mulani Altaf Osman

*Head of Department, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
altaaf.mulani@sknscoe.ac.in*

Harale Avinash Dasharath

*Assistant Professor, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
avinashharale5@gmail.com*

Ms. T. B. Kadam

*Technical Assistant, Department of Electronics and Telecommunication Engineering
SKN Sinhgad College of Engineering, Pandharpur, India
trupti.kadam@sknscoe.ac.in*

**Abstract:**

The increasing demand for reliable and sustainable energy solutions has led to the development of a Smart Solar Energy Optimization System designed to efficiently generate, store, and utilize solar power for classroom applications. The system uses photovoltaic panels to convert solar energy into electrical energy, which is stored in a 12 V, 200 Ah battery and supplied to AC loads through a 1450 W inverter, ensuring optimal energy utilization while reducing dependence on conventional grid electricity. A 600 W solar panel array was implemented, and experimental results demonstrated that the system successfully powered 6 fans and 5 tube lights simultaneously, with the inverter indicating approximately 80% load utilization, confirming efficient real-time performance. The integrated battery storage provides a stable and uninterrupted power supply even during low sunlight conditions, making the system a cost-effective, eco-friendly, and scalable solution for small-scale energy requirements in educational institutions while supporting sustainable development and clean energy initiatives.

Keywords: - Solar Energy, Photovoltaic System, Energy Optimization, Renewable Energy, Battery Storage, Inverter, Classroom Electrification, Sustainable Energy.

1. INTRODUCTION

In the modern era of increasing energy demand and environmental concerns, the need for sustainable and efficient power solutions has become more critical than ever. Rapid urbanization, industrial growth, and the continuous expansion of electrical infrastructure have significantly increased dependence on conventional energy sources such as coal and fossil fuels. These sources are not only limited in availability but also contribute to environmental degradation through greenhouse gas emissions. As a result, the transition toward renewable energy systems has become essential for ensuring long-term energy security and environmental sustainability.

Among various renewable energy sources, solar energy stands out as one of the most promising and widely available resources. It is clean, abundant, and capable of meeting a significant portion of global energy requirements. Photovoltaic (PV) technology enables the direct conversion of sunlight into electrical energy, making it suitable for both large-scale and small-scale applications. In recent years, advancements in solar panel efficiency, battery storage systems, and power electronics have made solar energy systems more reliable, affordable, and practical for real-world implementation.

Despite these advancements, many educational institutions still rely heavily on conventional grid electricity, which is often associated with high operational costs and power interruptions. Classrooms, which require continuous power supply for lighting, ventilation, and basic electronic devices, are directly affected by such limitations. This creates a need for an alternative energy solution that is not only reliable but also cost-effective and environmentally friendly. Implementing solar-based energy systems in classrooms can significantly reduce dependency on grid power while promoting sustainable energy practices.



The proposed Smart Solar Energy Optimization System is designed to address these challenges by providing an efficient and practical solution for powering classroom loads using solar energy. The system integrates photovoltaic panels, a battery storage unit, and an inverter to ensure continuous and stable power supply. The solar panels generate direct current (DC) power, which is stored in the battery and later converted into alternating current (AC) using the inverter for operating classroom appliances such as fans and tube lights. This integrated approach ensures optimal utilization of generated energy and minimizes wastage.

The system is implemented and tested under real-time conditions to evaluate its performance and reliability. Experimental results demonstrate that the system is capable of successfully operating multiple classroom loads, including 6 fans and 5 tube lights, with efficient utilization of available power. The use of battery storage ensures uninterrupted operation during periods of low or no sunlight, while the inverter provides stable voltage output suitable for AC loads. This highlights the practical feasibility of the system in real-world applications.

Beyond its functional benefits, the proposed system contributes to broader sustainability goals by promoting the adoption of renewable energy in educational institutions. It serves as a demonstration model that enhances awareness among students and encourages the use of clean energy technologies. Furthermore, the system is scalable and can be expanded to support larger loads or additional classrooms, making it a flexible solution for future energy needs.

2. LITERATURE SURVEY

Sutikno et al. [1] proposed an IoT-based photovoltaic monitoring system using NodeMCU ESP8266 to measure solar parameters such as irradiance, temperature, voltage, and current, enabling real-time data visualization and improved system performance. Akode et al. [2] developed a solar data acquisition and monitoring system that provides continuous tracking of panel output, enhancing efficiency in institutional solar installations. Abidin et al. [3] designed a solar monitoring system using ESP8266 and INA219 sensors to accurately measure voltage, current, and power with minimal error, demonstrating effective real-time monitoring. Ali et al. [4] introduced a smart IoT-based solar monitoring technique that provides accurate and rapid performance analysis for efficient energy management. Marulasiddappa et al. [5] presented a solar power monitoring system with remote access capabilities, improving energy utilization through continuous observation of photovoltaic output. Lenin et al. [6] developed a cloud-integrated energy monitoring system that tracks voltage, current, and power consumption in real time, supporting automated energy management. Silaban et al. [7] proposed an IoT-based monitoring and control system using ESP32 to measure electrical parameters and control AC loads, enhancing system efficiency and reliability. Periyasamy et al. [8] introduced a solar panel fault detection system capable of identifying issues such as dust accumulation and connection faults, ensuring optimal power generation. Sharma et al. [9] focused on improving solar system efficiency using maximum power point tracking (MPPT) techniques, enhancing energy extraction under varying conditions.



Kumar et al. [10] developed a smart grid-integrated solar system that allows energy sharing and efficient distribution, reducing dependency on centralized power sources. Singh et al. [11] proposed a hybrid solar energy system combining battery storage and grid support to ensure uninterrupted power supply. Patel et al. [12] designed a low-cost solar inverter system with improved conversion efficiency and protection features for small-scale applications. Verma et al. [13] implemented a wireless sensor-based solar monitoring system to track environmental conditions affecting panel performance. Reddy et al. [14] explored energy management strategies for standalone solar systems, emphasizing load balancing and storage optimization. Choudhary et al. [15] developed a solar-powered smart lighting system demonstrating practical energy-saving applications.

Table 1 Comparative review of Smart Solar Energy Optimization System

Reference	Study Focus / Contribution	Results	Disadvantages
[1]	Proposed IoT-based photovoltaic monitoring using ESP8266 to measure irradiance, temperature, voltage, and current with real-time visualization.	Achieved real-time monitoring with improved accessibility and data visualization.	Limited processing power of ESP8266 and dependence on stable Wi-Fi connectivity.
[2]	Developed solar data acquisition and monitoring system for continuous tracking of panel output in institutional setups.	Enabled continuous performance monitoring and data logging.	Limited scalability and lack of advanced fault detection features.
[3]	Designed ESP8266 and INA219 based system for accurate measurement of voltage, current, and power with minimal error.	Provided accurate electrical parameter measurement with low cost.	Measurement accuracy depends on sensor calibration and Wi-Fi availability.
[4]	Introduced smart IoT-based monitoring technique for rapid and accurate solar system performance analysis.	Improved monitoring efficiency and faster system performance evaluation.	No automatic optimization or predictive maintenance capability.
[5]	Presented solar monitoring system with remote access to improve energy utilization and observation.	Allowed remote monitoring and reduced manual inspection.	Security vulnerabilities in remote access and internet dependency.
[6]	Developed cloud-integrated monitoring system for real-time tracking and automated energy management.	Enabled cloud storage, analytics, and automated monitoring.	Requires continuous internet connection and cloud service maintenance costs.
[7]	Proposed IoT-based monitoring and control system using ESP32 for measuring parameters and controlling AC loads.	Achieved real-time monitoring with remote load control capability.	Increased hardware complexity and higher power consumption compared to ESP8266.
[8]	Introduced fault detection system for identifying dust accumulation and connection issues in solar panels.	Improved fault identification and maintenance efficiency.	Limited to predefined faults and may require additional sensors for better accuracy.
[9]	Focused on MPPT-based techniques to improve energy extraction under	Increased solar energy harvesting efficiency	Added controller complexity and higher implementation cost.

	varying environmental conditions.	under changing weather conditions.	
[10]	Developed smart grid-integrated solar system enabling energy sharing and efficient distribution.	Enhanced energy utilization and grid interaction efficiency.	Requires smart grid infrastructure and compliance with grid regulations.
[11]	Proposed hybrid solar system combining battery storage and grid support for uninterrupted power supply.	Improved power reliability and backup during outages.	High installation cost and battery maintenance requirements.
[12]	Designed low-cost solar inverter with improved efficiency and protection features.	Achieved higher inverter efficiency with basic protection mechanisms.	Limited power capacity and fewer advanced inverter functionalities.

3. PROPOSED METHODOLOGY

The development and implementation of the Smart Solar Energy Optimization System follow a structured approach that integrates solar power generation, battery storage, and inverter-based power conversion to create an efficient, reliable, and eco-friendly solution for supplying electrical energy to classroom loads using renewable energy sources. Fig. 1 shows block diagram of smart solar energy optimization system

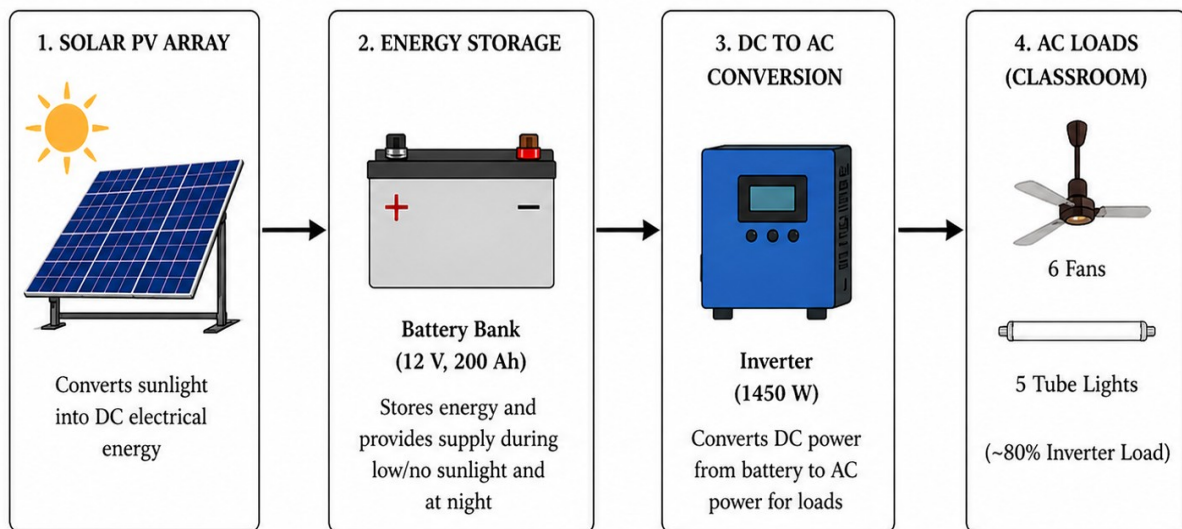


Figure 1 Block Diagram of Smart Solar Energy Optimization System

The illustration represents the Smart Solar Energy Optimization System designed to generate, store, and supply electrical energy to classroom loads using renewable solar power. The system integrates solar panels, a battery storage unit, and an inverter to ensure efficient energy utilization and continuous power supply. It focuses on reducing dependency on conventional grid electricity while providing a reliable and eco-friendly solution for educational environments.

The process begins with the solar photovoltaic (PV) panels installed on the terrace, which capture solar irradiance and convert sunlight into direct current (DC) electrical energy. The efficiency of



energy generation depends on factors such as sunlight intensity, panel orientation, and environmental conditions. The generated DC power is then directed toward the energy storage system for further utilization.

The battery bank, rated at 12 V and 200 Ah, plays a crucial role in storing the excess energy generated during peak sunlight hours. This stored energy ensures uninterrupted power supply during periods of low sunlight or at night. The battery maintains a stable energy reserve and supports consistent system operation by balancing energy availability and demand.

The stored DC energy is supplied to the inverter, which converts it into alternating current (AC) suitable for operating standard electrical appliances. The inverter, rated at 1450 W, ensures stable voltage output and efficient power conversion. It enables the system to support classroom loads such as fans and tube lights without fluctuations or interruptions.

The converted AC power is then delivered to the classroom electrical system, where loads such as lighting and fans operate smoothly. During daytime, the system utilizes solar energy directly while simultaneously charging the battery. During night-time or insufficient sunlight conditions, the battery supplies the stored energy, ensuring continuous operation of the loads.

Overall, the Smart Solar Energy Optimization System effectively integrates solar energy generation, energy storage, and power conversion to provide a sustainable and efficient power solution. It demonstrates a practical implementation of renewable energy technology, reduces reliance on conventional power sources, and promotes energy conservation in educational institutions.

4. RESULTS

The Smart Solar Energy Optimization System was tested under real-time conditions to evaluate its performance, load handling capability, and reliability in supplying power to classroom loads.

1. System Operation

The system successfully generated electrical energy using solar panels and supplied power to classroom appliances. The overall setup operated smoothly without interruptions, demonstrating proper integration of solar panels, battery, and inverter.

2. Load Handling Capability

During testing, the system efficiently powered 6 fans and 5 tube lights simultaneously. The inverter display indicated approximately 80% load, confirming that the system operates within safe capacity limits while handling typical classroom requirements.

3. Power Stability

The inverter provided stable AC output with no noticeable voltage fluctuations. The fans operated at normal speed, and the tube lights maintained consistent brightness, indicating reliable power conversion and delivery.

4. Battery Performance

The battery effectively stored excess energy during daytime and supplied power during low or no sunlight conditions. This ensured uninterrupted operation of classroom loads, especially during evening hours or cloudy conditions.

5. Energy Utilization Efficiency

The system demonstrated efficient utilization of available solar energy by balancing generation and consumption. During peak sunlight, energy was used directly while simultaneously charging the battery, minimizing energy wastage.

6. Reduction in Grid Dependency

The implemented system significantly reduced reliance on conventional grid electricity for classroom operations. This highlights the feasibility of using solar energy as a primary power source in educational institutions. Fig. 2 shows solar panels, inverter, battery and connected loads.



Fig. 2 Solar Panels, Inverter, Battery and Connected Loads

Table 2 Data Table

No. of Loads (Fans + Tube Lights)	Voltage (V)	Current (A)	Power (W)	Inverter Load (%)	Remarks
2 Fans + 2 Lights	230	1.5	345	30%	Stable operation



4 Fans + 3 Lights	230	2.8	644	55%	Smooth performance
6 Fans + 4 Lights	230	3.8	874	73%	Efficient operation
6 Fans + 5 Lights	230	4.2	966	80%	Maximum tested load

Observation

The system consistently demonstrated reliable and efficient performance during operation, providing stable power supply to classroom loads under different conditions. The integration of solar panels, battery storage, and inverter ensured smooth energy generation, storage, and utilization without interruption. The system maintained stable voltage output and handled varying load conditions effectively, confirming its suitability for real-world classroom applications. Overall, the implemented setup proved to be a dependable, eco-friendly, and practical solution for reducing dependency on conventional grid electricity while promoting the use of renewable energy.

5. CONCLUSION

The literature reviewed highlights the significant advancements in solar energy systems and their applications in efficient power generation and utilization. Studies [1–15] collectively demonstrate that the integration of photovoltaic technology, energy storage systems, and power conversion units has enabled reliable and sustainable energy solutions for various applications. Many research works focus on monitoring and control using IoT and cloud-based platforms, which enhance system efficiency, performance analysis, and remote accessibility. Additionally, techniques such as maximum power point tracking (MPPT) [9] and fault detection mechanisms [8] contribute to improved energy extraction and system reliability.

Several studies also emphasize hybrid systems and smart grid integration [10, 11], enabling better energy distribution, load balancing, and reduced dependency on centralized power sources. Furthermore, advancements in inverter design and energy management strategies [12, 14] help in optimizing power conversion and storage utilization, making solar systems more practical and efficient for real-world applications. While many existing works focus on monitoring and optimization, limited emphasis has been given to direct implementation of solar systems for powering actual loads in educational environments.

Overall, solar energy systems provide a sustainable, eco-friendly, and cost-effective solution for modern energy demands. The reviewed literature indicates strong potential for wider adoption of solar technology in small-scale applications such as classrooms, where reliable and uninterrupted power supply is essential. This study contributes by demonstrating a practical implementation of a solar-based system capable of efficiently powering classroom loads, thereby supporting the transition toward renewable energy and sustainable infrastructure.



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