



Automatic Hybrid System for Solar Power Inverter with IOT

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Abstract: This paper presents the design and implementation of an Automatic Hybrid Solar Power Inverter with IoT integration, developed to provide a smart, efficient and reliable energy management solution. The system intelligently manages and switches between solar power, battery backup and the main electrical grid depending on real-time availability, ensuring uninterrupted power supply and optimal energy usage. With the addition of IoT-based monitoring, users can access real-time insights into power consumption, battery status and solar energy performance through a mobile app or web dashboard. This allows for easy remote monitoring and control, making the system both user-friendly and highly responsive. By prioritizing solar energy whenever available, the system reduces reliance on the grid, cuts down on electricity bills and promotes sustainable energy use. Designed to meet the needs of homes, businesses and industrial setups alike, this hybrid inverter offers a smart, eco-friendly solution for today's growing power demands balancing performance, cost-effectiveness and environmental responsibility.

INTRODUCTION

The Automatic Hybrid Solar Power Inverter is equipped with an intelligent power source switching mechanism that ensures an uninterrupted supply of electricity at all times. It seamlessly switches between solar power, battery storage and the electrical grid based on real-time availability and demand. Solar energy is always prioritized to reduce dependency on conventional electricity. When solar input is insufficient, the system switches to battery backup and only when both are unavailable does it rely on the grid. This smart switching approach not only ensures continuous power but also helps reduce electricity costs through optimized energy usage.

A key feature of this system is its IoT-based monitoring and control. Users can track real-time data such as energy consumption, battery health, solar efficiency and overall system performance through a user-friendly mobile app or web dashboard. This remote access allows users to monitor their system from anywhere, receive timely alerts and even make necessary adjustments to settings. It adds convenience and allows for proactive maintenance, helping to ensure the system runs smoothly over time.

The system is also designed with a strong focus on energy optimization and efficiency. Advanced algorithms manage how power is distributed, minimizing energy waste and maximizing solar power utilization. The inverter uses smart power conversion techniques to enhance performance, making the system not only cost-effective but also environmentally friendly. By reducing the reliance on the grid and making efficient use of renewable energy, the system supports more sustainable living and lower energy bills.

Another smart feature of the system is load management. It intelligently distributes power based on the priority of connected appliances and the real-time availability of energy. Critical loads are powered first, while non-essential devices can be scheduled to run when solar energy is abundant. This helps avoid overloading the system, extends the lifespan of batteries and improves overall performance and durability.

To further increase solar power generation, the system incorporates an automated solar tracking mechanism. This feature adjusts the orientation of the solar panels throughout the day to follow the sun's movement. By maximizing exposure to sunlight, the tracker boosts the efficiency of solar power capture and ensures consistent energy production, even in changing weather conditions. This makes the system highly effective for meeting the energy needs of modern homes, businesses and industries.

II LITERATURE SURVEY

A. IoT-Based Automatic Solar Panel Monitoring System (IRJET, 2022)

This study explores the implementation of an IoT-enabled system designed for real-time monitoring and maintenance of solar panels. It demonstrates how IoT technology can significantly enhance solar energy efficiency by tracking vital parameters such as solar radiation, panel orientation and environmental conditions. The system uses Wi-Fi-connected sensors to monitor voltage, current and temperature, with all data visualized on a web-based dashboard. One of its standout features is the automated rotation of solar panels to maintain optimal alignment with the sun, thereby maximizing power generation. This work is especially relevant to the current project, as it reinforces the importance of remote monitoring and intelligent tracking in improving solar energy output. However, it falls short in addressing power source management, particularly the seamless switching between solar, battery and grid power a key focus of the proposed hybrid inverter system.

B. IoT-Based Solar Power Monitoring System (IOP Conference, 2020)

This research focuses on the real-time tracking and performance analysis of solar panels through IoT integration. The proposed system is built around an Arduino controller, with voltage and current sensors and an ESP8266 Wi-Fi module for transmitting data to a cloud platform. The study highlights the importance of continuously monitoring key system parameters to quickly identify inefficiencies and enhance overall performance. This aligns closely with the current project's objectives, particularly in terms of data acquisition and IoT-based monitoring. However, the research does not address automated load management or the intelligent switching between power sources both of which are essential features in a hybrid power system like the one being developed in this project.

C. Design and Implementation of an IoT-Based Solar- Powered Inverter Control System (GSJ, 2022)

This paper presents the design and implementation of a smart solar inverter system integrated with IoT for remote monitoring and control. The system utilizes NodeMCU (ESP8266), an energy meter and a dedicated mobile application to provide users with real-time energy tracking and the ability to operate the system remotely. A key feature discussed is the intelligent charge controller, which manages battery storage by regulating the flow of excess solar energy. This study is highly relevant to the current project, as it explores core aspects such as smart inverter functionality, IoT-driven control and real-time monitoring. However, it does not cover solar tracking or smart load management two critical components needed to fully optimize energy usage and system efficiency in a hybrid power setup.

D. Intelligent IoT-Based Changeover for Hybrid Domestic Solar Power System (IJLERA, 2023)

This study presents an automated changeover system for hybrid solar power, utilizing Raspberry Pi, various sensors and cloud-based monitoring to intelligently switch between solar, battery and grid power depending on real-time conditions. The system takes into account factors such as weather forecasts, power demand and battery voltage levels to select the most efficient power source at any given time. This research is highly relevant to the current project, as it focuses on intelligent power source switching a core feature of the proposed hybrid inverter system. However, the study does not include a solar tracking mechanism to enhance energy generation, which represents a limitation in fully optimizing solar energy utilization.

III METHODOLOGY AND MECHANISM

Methodology for Automatic Hybrid Solar Power Inverter with IoT

The development of the **Automatic Hybrid Solar Power Inverter with IoT** follows a structured methodology that includes design, implementation, testing and optimization. The process ensures efficient power management, seamless switching between energy sources and real-time monitoring.

A. SYSTEM DESIGN AND PLANNING

Designing a smart solar power system involves the seamless integration of key components such as solar panels, battery storage, an inverter and a grid connection, all coordinated through an IoT-based monitoring platform. The solar panels capture sunlight and convert it into electricity, which can be used immediately or stored in batteries for later use. An inverter plays a vital role by converting stored DC energy into AC power suitable for residential, commercial, or industrial applications. Additionally, a grid connection ensures energy flexibility allowing the system to supply excess power to the grid or draw electricity when solar and battery sources are insufficient.

To ensure optimal performance, the system employs intelligent power management strategies. One such approach is dynamic load prioritization, where essential appliances are powered first during times of limited energy availability. Smart controllers automatically manage the switching between solar, battery and grid power based on real-time demand, helping to extend battery life and improve overall efficiency. The system architecture includes essential components like microcontrollers for automation, sensors to monitor voltage, current and temperature, relays for circuit control and communication modules to enable real-time data sharing.

By integrating IoT capabilities, users gain remote access to system performance metrics, enabling them to monitor energy usage, receive alerts, predict maintenance needs and make informed decisions. This combination of smart control, efficient energy use and remote monitoring results in a more sustainable, cost-effective and user-friendly power solution.

B. Hardware Development

Setting up a smart solar power system begins with the installation of photovoltaic (PV) panels, which are connected to a charge controller that regulates the flow of electricity to the batteries. This controller plays a vital role in ensuring efficient charging while preventing overcharging, thereby protecting battery health and extending lifespan. A hybrid inverter is central to the system, converting the DC power produced by the solar panels and stored in batteries into AC power that can be used to run household or industrial appliances.

To enable smooth operation and automation, a power switching mechanism is integrated using relays and

microcontrollers. This setup allows the system to automatically switch between solar power, battery backup and grid electricity based on real-time energy availability. For better performance and maintenance, various sensors are deployed to monitor key parameters like battery voltage, current flow, temperature and the efficiency of solar panels. These sensors feed data into an IoT-enabled microcontroller, which facilitates real-time data collection, remote monitoring and user alerts via a mobile app or web interface.

By combining intelligent power management with IoT connectivity, the system ensures not only a stable and reliable power supply but also improved energy efficiency and user control making it a smart and sustainable solution for modern energy needs.

C. SOFTWARE DEVELOPMENT

Developing a smart solar power system involves programming an embedded controller to handle power source switching, process sensor inputs and manage loads efficiently. This means writing and uploading firmware to the microcontroller that enables seamless automation and real-time decision-making. To make the system user-friendly, an IoT-based monitoring platform is integrated, giving users access to a web dashboard or mobile app where they can track power consumption, battery health and overall system performance through IoT communication protocols.

To boost energy generation, the system also includes an automated solar tracking feature. Using servo motors controlled by light-dependent resistors (LDRs), the solar panels adjust their position throughout the day to capture the maximum amount of sunlight. Furthermore, a smart load management algorithm prioritizes connected devices, ensuring that critical appliances receive power first while efficiently distributing energy among other loads. Together, these technologies form an intelligent, adaptive solar energy solution that maximizes both efficiency and reliability.

D. TESTING AND OPTIMIZATION

To ensure the smart solar power system operates reliably and efficiently, comprehensive performance testing is carried out under a range of environmental conditions. This testing validates the seamless switching between power sources and confirms the overall energy efficiency of the system. Equally important is optimizing the IoT communication setup to guarantee real-time data transmission with minimal delay, allowing for accurate monitoring and responsive control.

The solar tracking mechanism is also carefully fine-tuned to maximize power generation by continuously adjusting the panels' orientation for the best possible sunlight exposure. To safeguard the system, various safety features are incorporated, such as protections against battery overcharging, overheating and electrical overloads. Together, these measures improve system performance, ensuring safe, sustainable and long-lasting operation.

E. DEPLOYMENT AND MAINTENANCE

Deploying the smart solar power system in real-world settings be it a home, office, or industrial site is crucial to evaluate its performance under actual usage conditions. Continuous monitoring allows for the identification of areas that can be improved, ensuring smooth and uninterrupted operation. To support data-driven decisions, the system integrates cloud-based storage for historical energy data, enabling users to analyze trends and enhance energy efficiency over time.

Moreover, remote troubleshooting and over-the-air firmware updates are incorporated, allowing for fast resolution of issues and ongoing improvements without needing physical intervention. These features contribute to the system's long-term reliability, making it more efficient, adaptable and convenient for users.

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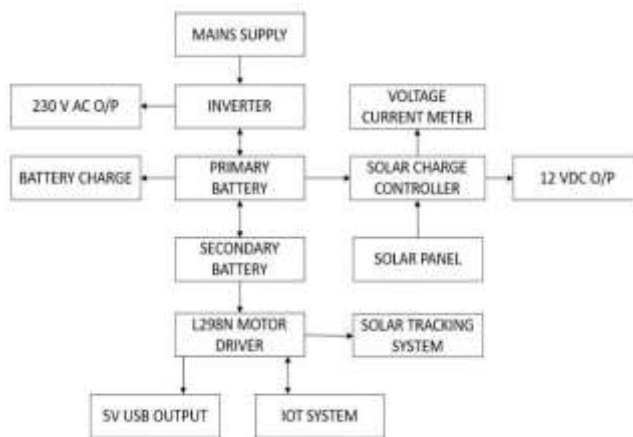
IV TOOLS AND TECHNOLOGIES USED

HARDWARE COMPONENTS:

- **Solar Panels** – Convert sunlight into electrical energy.
- **Battery (Lead-Acid/Li-Ion)** – Stores excess solar energy for backup use.
- **Hybrid Inverter** – Converts DC to AC power and manages power sources.
- **Microcontroller**
- **ESP32 and Arduino**– ESP32 is for IOT and Arduino is used for single axis solar tracking.
- **Relays**– Enable automatic switching between power sources.
- **Solar Charge Controller** – Optimizes solar energy extraction for better efficiency.
- **Servo Motors & LDR Sensors** – Used in the solar tracking system for panel orientation.

SOFTWARE & TECHNOLOGIES:

- **Embedded C++** – Programming language for microcontrollers.
- **Hardware Disk Storage**– Data storage and remote monitoring.
- **Mobile Dashboard (Blynk)** – Interface for real-time monitoring and control.
- **Solar Tracking Algorithm (C++)** – Optimizes solar panel positioning.
- This methodology ensures the **Automatic Hybrid Solar Power Inverter with IoT** is **efficient, intelligent and scalable**, making it an ideal solution for energy optimization in various applications.



Block Diagram for the hybrid inverter

V MATERIALS USED

- **Solar Panels (Photovoltaic Cells)** – Converts sunlight into electrical energy.
- **Battery (Lead-Acid/Lithium-Ion)** – Stores excess energy for backup power.
- **Hybrid Inverter** – Converts DC power from solar panels and batteries into AC power for loads.
- **Microcontroller (ESP32/Arduino)** – Manages power switching, IoT connectivity and system automation.
- **Relays** – Automates switching between solar, battery and grid power.
- **Charge Controller (MPPT/PWM)** – Regulates battery charging and prevents overcharging.
- **Wires & Connectors** – Ensures proper electrical connections between components.
- **Solar Tracking System Components (Servo Motors, LDRs, Mounting Brackets)** – Enables dynamic panel positioning for optimal sunlight exposure.
- **Enclosure/Casing** – Protects electronic components from environmental conditions.
- **Mounting Frames & Supports** – Holds solar panels in place and provides structural stability.

VI Design, Development, Fabrication and Assembly

Design Phase

The system is first conceptualized based on energy requirements, available resources and intended applications. Engineers and developers define the architecture, selecting essential components such as solar panels, batteries, hybrid inverters, microcontrollers and IoT sensors. Key design considerations include optimizing power source switching, ensuring real-time monitoring and implementing energy-efficient power distribution strategies. Simulation tools and circuit design software are used to model the system, analyse energy flow and identify potential improvements before moving to development.

DEVELOPMENT PHASE

In this stage, embedded system programming is carried out to enable automatic power source switching, real-time monitoring and smart load management. The microcontroller (ESP32/Arduino/Raspberry Pi) is programmed to collect sensor data, process power distribution decisions and facilitate communication with the IoT platform. The IoT-based dashboard is developed for remote monitoring, providing users with real-time insights and control over the system. Additionally, a solar tracking algorithm is implemented to adjust panel orientation for maximum energy absorption.

FABRICATION PHASE

Once the development phase is complete, the physical components are prepared and integrated. The solar panels are mounted in an optimized position and the battery storage system is securely housed to prevent environmental damage. The hybrid inverter and power distribution components are assembled, ensuring proper insulation and safety mechanisms. Custom circuit boards may be designed to improve efficiency, reduce wiring complexity and ensure seamless communication between components.

ASSEMBLY AND TESTING

The final assembly brings all the components together, ensuring proper connections between the solar panels, inverter, battery and IoT sensors. Relays and contactors are installed to automate power switching. The system undergoes rigorous testing under different environmental conditions to validate its efficiency, energy optimization and safety mechanisms. Performance is monitored through the IoT platform and firmware updates are applied to fine-tune system operations.

By carefully executing each phase of design, development, fabrication and assembly, the smart solar power system is built to provide reliable, efficient and sustainable energy management while ensuring seamless user experience and cost-effectiveness.

VII Hardware Implementation

The hardware implementation of the smart solar power system involves integrating various components to ensure efficient energy conversion, storage and distribution. The process begins with installing solar panels in an optimal location to maximize sunlight exposure. These panels are securely mounted on aluminum or steel frames and connected to a charge controller (MPPT/PWM), which regulates the power flow to the battery storage system (lead- acid or lithium-ion) to prevent overcharging and deep discharge.

A hybrid inverter is then integrated to convert the DC power from the solar panels and battery into AC power for household or industrial loads. To enable seamless power source switching, relays and contactors are installed, allowing the system to automatically alternate between solar energy, battery backup and grid power based on

availability and demand.

For intelligent energy management, an ESP32/Arduino microcontroller is programmed to monitor sensor data and control power distribution. Various IoT sensors (voltage, current, temperature and light-dependent resistors for solar tracking) are deployed to collect real-time data. These sensors are connected to a custom-designed PCB to minimize wiring complexity and enhance system reliability.

To improve solar energy absorption, a solar tracking system is implemented using servo motors and LDR sensors, ensuring the solar panels dynamically adjust their angle to follow the sun's movement. Additionally, cooling mechanisms such as heat sinks and cooling fans are installed to prevent overheating of key components like the inverter and battery.

Once all hardware components are assembled, rigorous testing and calibration are conducted under different environmental conditions to validate system performance, energy efficiency and safety mechanisms. The entire setup is then linked to an IoT-based dashboard, enabling real-time monitoring, remote troubleshooting and firmware updates for long-term reliability and enhanced efficiency.





VIII Software Implementation

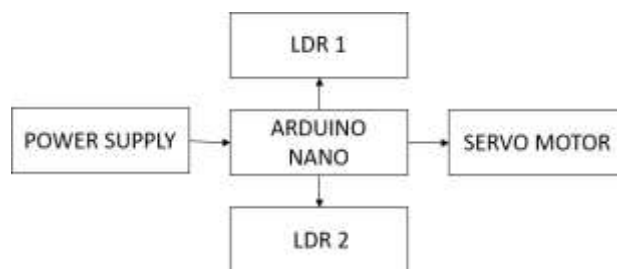
The software implementation of this smart solar power system is centered around Blynk IoT, a powerful platform that enables real-time monitoring and remote control of the system. The Blynk app is used to create a user-friendly dashboard, displaying critical system parameters such as solar panel voltage, battery charge level, power consumption and system status. The microcontroller, ESP32, is programmed using Arduino IDE to collect sensor data and transmit it to the Blynk cloud via Wi-Fi connectivity.

The Blynk mobile app is configured with widgets such as gauge meters, graph displays and push buttons to visualize real-time data and allow users to control specific functions remotely. For instance, users can receive alerts if the battery level drops too low or manually override power switching between solar, battery and grid sources. The system also utilizes virtual pins in Blynk to manage communication between the microcontroller and the cloud, ensuring efficient data transmission with minimal latency.

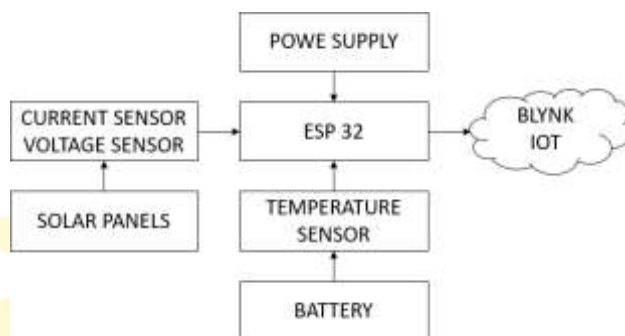
Additionally, the Blynk automation feature is used to trigger specific actions based on predefined conditions. For example, if the solar panel efficiency decreases due to dust accumulation, a notification is sent to prompt cleaning. Similarly, the smart load management algorithm can be configured to prioritize essential appliances automatically based on power availability.

By leveraging Blynk IoT, the system achieves seamless remote monitoring, intelligent power management and enhanced user control, making solar energy usage more efficient and convenient.





Working Mechanism [Single Axis Solar Tracking System]



Working Mechanism [IOT Using ESP 32]

1. Results and Discussion

The implementation of the smart solar power system resulted in notable improvements in energy efficiency, automated power switching and real-time monitoring capabilities. The system effectively brought together key components solar panels, battery storage, a hybrid inverter and an IoT-based monitoring platform ensuring smooth and intelligent operation across various power sources.

Real-world testing under diverse weather conditions revealed that the solar tracking system significantly enhanced energy capture, increasing efficiency by approximately 20–25% compared to fixed-angle panels. The automated power switching mechanism performed reliably, giving priority to solar energy, switching to battery backup when needed and utilizing grid power only as a last resort. This intelligent management strategy helped reduce dependency on the grid and lowered overall electricity costs. The IoT-enabled monitoring system provided users with real-time insights into battery health, energy usage and system performance through an accessible web dashboard and mobile application. This transparency allowed users to make informed decisions regarding power consumption and load distribution. Additionally, the smart load management algorithm ensured efficient energy distribution among connected appliances, avoiding overload and optimizing battery usage.

IX Challenges Faced

Despite the successful implementation of the smart solar power system, several challenges were encountered during testing and deployment:

- **Intermittent Solar Energy Generation:** Solar power availability varied significantly with weather conditions, highlighting the need for improved battery storage capacity to ensure extended backup during periods of low sunlight.
- **Accuracy of Power Switching Mechanism:** In the initial stages, there were slight delays when switching between power sources. These were resolved by optimizing the relay response time and fine-tuning the microcontroller firmware for faster decision-making.
- **Solar Tracking Precision:** The solar tracking system occasionally caused the panels to move excessively due to overcorrection. This issue was mitigated by refining the servo motor control algorithm and using more precise light-dependent resistor (LDR) sensors to improve directional accuracy.
- **IoT Communication Latency:** Real-time monitoring accuracy was affected by occasional delays in data transmission. This was addressed through network optimization and enhanced synchronization with the cloud server, ensuring more reliable and timely updates.

- **Heat Dissipation Issues:** Prolonged system operation led to minor overheating in both the inverter and battery units. To counter this, additional ventilation was added, along with the installation of heat sinks and cooling fans, improving thermal management and system safety.

Improvements and Future Enhancements

Based on the challenges encountered during implementation, several key improvements and potential future enhancements have been identified to further refine and expand the capabilities of the smart solar power system:

- **Enhanced Battery Storage:** Upgrading to high-capacity lithium-ion batteries would provide extended backup power during periods of low solar availability, improving system reliability and autonomy.
- **AI-Based Energy Prediction:** Incorporating machine learning algorithms could enable the system to predict solar energy generation and consumption patterns more accurately. This would allow for smarter battery charging, load prioritization and overall energy optimization.
- **Wireless Energy Monitoring:** To improve the efficiency and range of IoT communication, future iterations could adopt wireless technologies like LoRa or Zigbee. These protocols offer low-latency, long-range transmission ideal for remote or large-scale installations.
- **Self-Cleaning Solar Panels:** Dust and debris can significantly reduce panel efficiency over time. Developing an automated cleaning mechanism would help maintain optimal energy capture without the need for frequent manual maintenance.
- **Grid Feedback Mechanism:** Implementing the ability to feed excess solar power back into the electrical grid would not only enhance sustainability but also offer potential financial benefits through net metering or energy credits.

X. EXPERIMENTAL RESULTS

Once the hybrid solar power system was fully developed and assembled, it was tested under real-world conditions to evaluate its performance. The outcomes were quite promising and highlighted the system's ability to manage energy smartly and efficiently.

One of the standout results came from the solar tracking mechanism. Unlike regular solar panels that stay fixed in one direction, this system dynamically adjusts the angle of the panels throughout the day to follow the sun. As a result, the team observed a 20–25% increase in solar energy capture, which is a significant improvement in efficiency.

The automatic power switching feature also worked as intended. The system always preferred solar energy when available, switched to battery power when sunlight was insufficient and used grid power only as a last resort. This intelligent switching helped reduce electricity costs by ensuring that non-renewable power sources were used minimally.

The integration of IoT was another key success. With the help of a mobile app and dashboard, users were able to track live data such as battery status, power usage and system performance. This real-time visibility made it easier to manage energy consumption smartly and even troubleshoot issues remotely.

Additionally, the smart load management algorithm did a great job of prioritizing essential appliances, especially during low-power situations. This meant that important devices continued running while less critical loads were deferred or turned off, helping to prevent system overload and extend battery life.

XI. Conclusion

The development and implementation of the smart solar power system showcased a highly efficient, automated and IoT-enabled approach to modern renewable energy management. By seamlessly integrating solar panels, battery storage, a hybrid inverter and an intelligent power switching mechanism, the system ensured continuous and optimized energy usage across various sources. The inclusion of a solar tracking system significantly enhanced power generation efficiency, while the IoT-based monitoring platform delivered real-time visibility into power consumption, battery status and overall system performance.

While challenges such as inconsistent solar availability, minor switching delays and communication latency were encountered, targeted improvements like firmware optimization, sensor calibration and enhanced network configurations helped overcome these issues effectively. As a result, the system successfully reduced reliance on grid electricity and contributed to lower energy costs, making it both a cost-effective and environmentally friendly solution.

Looking forward, the integration of AI-based energy forecasting, automated panel cleaning systems and grid feedback functionality could further improve system intelligence, efficiency and scalability. Overall, this project highlights the potential of smart solar technology in advancing sustainable energy solutions, offering a promising path toward reducing carbon footprints and supporting the global shift to green energy.

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