ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26may1909

Smart Hybrid Inverter

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Publication Date: 2026/06/18

Abstract: In this paper, a prototype for a smart hybrid inverter is designed. A Smart Hybrid Inverter is an advanced power solution that works to best utilise energy from different sources, which include solar panels, batteries, and the utility grid. In this study, we present the design, operation, and performance evaluation of a smart hybrid inverter using current control methods and intelligent monitoring systems. The proposed system integrates renewable energy sources with battery storage to provide an uninterrupted, reliable, and energy-efficient power supply for residential and small industrial applications.

The inverter we installed uses Maximum Power Point Tracking (MPPT), which maximises solar energy collection and improves overall system performance. We use a microcontroller for smart monitoring, automatic source transfer, fault detection, and remote control via the cloud. Also, we've included features for overvoltage, overload, and short-circuit protection, which in turn improve safety and reliability. We aim to reduce our dependence on traditional power sources, minimise energy loss, and improve power quality. We saw that the smart hybrid inverter we studied provided stable output voltage, efficient energy management, and better use of renewable energy, which is a step up from conventional inverter systems. Also, our proposed model is cost-effective, environmentally friendly, and well-suited for future smart energy applications.

Keywords: *Smart Hybrid Inverter, Renewable Energy, Solar Panel, MPPT, ESP32, Battery Management, IoT, Power Electronics.*

How to Cite: Bardan Chhetri; Bivendra Rai; Meghna Yonzon; Nobin Rai; Mukesh Kumar Sharma (2026) Smart Hybrid Inverter. *International Journal of Innovative Science and Research Technology*, 11(5), 4465-4470.
https://doi.org/10.38124/ijisrt/26may1909

I. INTRODUCTION

People are consuming more electricity these days, and the usual sources are running out quickly. That has pushed things toward renewable options, you know. Solar energy stands out in all that. It's everywhere, does not pollute much, and can last a long time. I think that makes it pretty reliable compared to others. But solar power is not always steady. It comes and goes with the weather or time of day, so keeping a constant supply gets tricky. That part feels like the main downside. To address those issues, they developed Smart Hybrid Inverter systems. These pull together solar panels, batteries, and even the regular power grid. It becomes a single setup that manages energy more efficiently overall. This paper examines the design and features of a smart hybrid inverter that integrates renewable energy with smart controls and efficient power conversion. The goal is an affordable, eco-friendly option for today's needs. It seems to cover how it works, the parts involved, what makes it good, the tough parts, and where it might go next in renewables and electronics. Some of that integration with batteries stands out, but I am not totally sure how all the IoT details fit perfectly yet. Overall, it reduces waste and improves quality, though challenges like cost may persist.

II. LITERATURE REVIEW

A smart hybrid inverter is an advanced power electronic device that integrates solar energy, battery storage, and grid power to provide reliable and efficient electricity. It manages energy flow among renewable sources, batteries, and electrical loads. Recent advancements emphasise increasing efficiency, reducing switching losses, enhancing grid stability, and enabling advanced monitoring and control.

Initial research on smart inverters addressed grid integration and renewable energy management. Studies in power electronics demonstrate that smart inverters improve voltage regulation, frequency control, and power quality in distributed energy systems. Arbab-Zavar et al highlighted the significance of control techniques for microgrid applications, including reactive power compensation, load sharing, and energy optimisation.

Hybrid inverter topologies have received considerable attention in recent years. Researchers have investigated both

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isolated and non-isolated converter structures to improve conversion efficiency and reduce system costs. Reviews of hybrid converter topologies indicate that integrating solar photovoltaic systems with battery storage enhances system reliability and energy utilisation. These studies also emphasise that hybrid inverters ensure an uninterrupted power supply during grid failures. Contemporarily, smart hybrid inverters increasingly incorporate intelligent control algorithms and IoT-based monitoring systems. Recent studies demonstrate that artificial intelligence and machine learning techniques enhance inverter performance by predicting load demand, optimising battery charging, and improving fault detection capabilities. Researchers have shown that AI-based control strategies support system stability under varying environmental and load conditions.

Another significant area of research involves power quality improvement and grid support functionality. Smart hybrid inverters perform voltage regulation, frequency stabilisation, and harmonic reduction. Studies on grid-interactive smart inverters have demonstrated that these systems maintain stable operation even with high photovoltaic penetration. Advanced control methods, including Volt-VAR and frequency-Watt control, enhance grid performance and mitigate voltage fluctuations.

Research has also addressed multilevel and reduced-switch inverter designs to increase efficiency and minimise switching losses. Hybrid multilevel inverter structures yield improved output waveform quality and reduced harmonic distortion. These designs decrease stress on switching devices and enhance overall inverter reliability.

Cybersecurity and communication technologies have become critical aspects of smart inverter systems. As modern hybrid inverters utilise IoT and wireless communication for monitoring and remote control, researchers have identified cybersecurity as a significant challenge. Secure communicationprotocols and protection mechanisms are essential for preventing unauthorized access and ensuring the safe operation of smart grids. In summary, the literature demonstrates that smart hybrid inverter technology is essential in contemporary renewable energy systems. Current research primarily addresses intelligent energy management, grid integration, AI-based control, power quality improvement, and efficient converter topologies. These advancements enhance the reliability, efficiency, and applicability of smart hybrid inverters for residential, commercial, and industrial use.

III. METHODOLOGY

The methodology for the smart hybrid inverter project emphasises the design, development, and testing of a system capable of managing power from solar energy, battery storage, and the electrical grid. The proposed system is intended to ensure a continuous power supply, enhance energy efficiency, and minimise reliance on conventional electricity sources. The initial stage of the methodology involves designing the overall architecture of the smart hybrid inverter system. The system comprises solar panels, a battery storage unit, a charge controller, an inverter circuit, a relay module, a microcontroller, and a step-up transformer. These components are configured to enable automatic switching between power sources based on energy availability and load demand.

In the second stage, appropriate hardware components are selected according to the required voltage and power ratings. The solar panel serves as the primary renewable energy source for generating direct current (DC) power. A rechargeable battery is incorporated to store the generated energy for backup purposes. The charge controller manages the battery's charging and discharging and safeguards it against overcharging and deep discharge. The inverter section is designed to convert DC power from the battery into alternating current (AC) power suitable for household and electrical applications. Metal-oxide-semiconductor field-effect transistor (MOSFET) switching devices and a step-up transformer are utilised to achieve the required AC output voltage. The inverter circuit is optimised for efficient power conversion and reduced switching losses. A microcontroller-based control system is implemented to provide intelligent energy management. The microcontroller continuously monitors solar power enhances efficiency, stability, lifespan, and overall performance while minimising energy losses and maintenance availability, battery voltage, and grid supply conditions. Based on these parameters, the controller automatically operates the relay system to switch between solar mode, battery backup mode, and grid supply mode. This automatic switching mechanism ensures an uninterrupted power supply and efficient utilisation of renewable energy. The hardware components are integrated into a single system using appropriate wiring and circuit connections. Following integration, the smart hybrid inverter is tested under various operating conditions, including changes in solar input, battery charging levels, and load conditions. Key performance parameters such as output voltage, inverter efficiency, switching response, battery backup duration, and load handling capability are measured and analysed.

Finally, the results obtained are evaluated to assess the performance and reliability of the proposed smart hybrid inverter system. The developed system aims to provide stable output power, efficient energy management, and improved reliability for residential and small-scale renewable energy applications.

➢ *Material Selection*

Material selection for a smart hybrid inverter involves choosing appropriate electrical, electronic, and mechanical components to ensure efficient system operation. Key considerations include power rating, efficiency, durability, safety, cost, reliability, and performance. It requires careful selection of components, including solar panels, batteries, transformers, MOSFETs, relays, microcontrollers, capacitors, and wiring, to enable efficient energy conversion, storage, and intelligent power management.

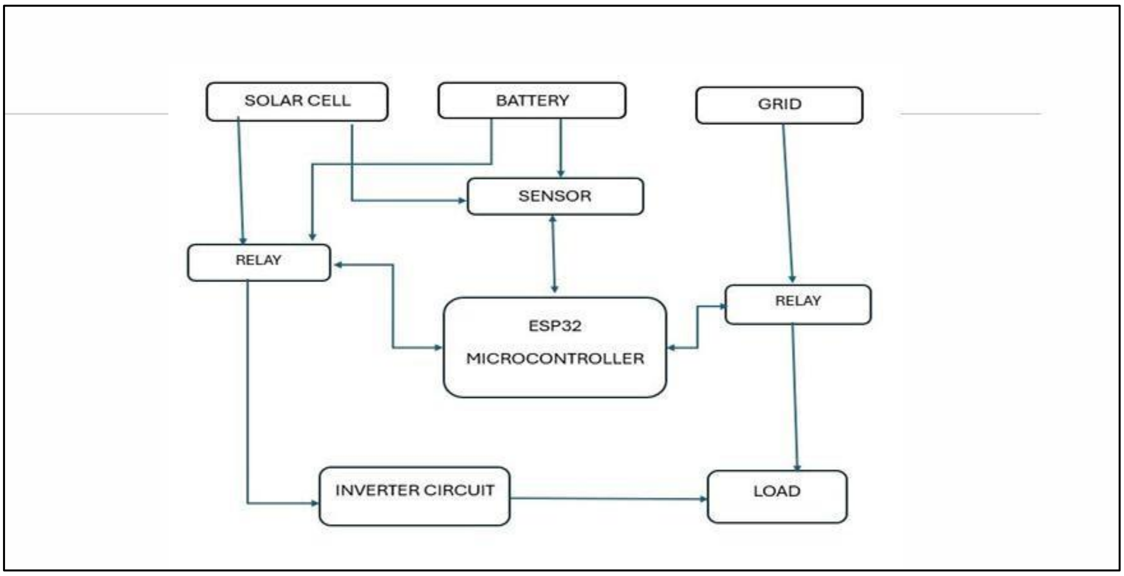

Fig 1 Block Diagram

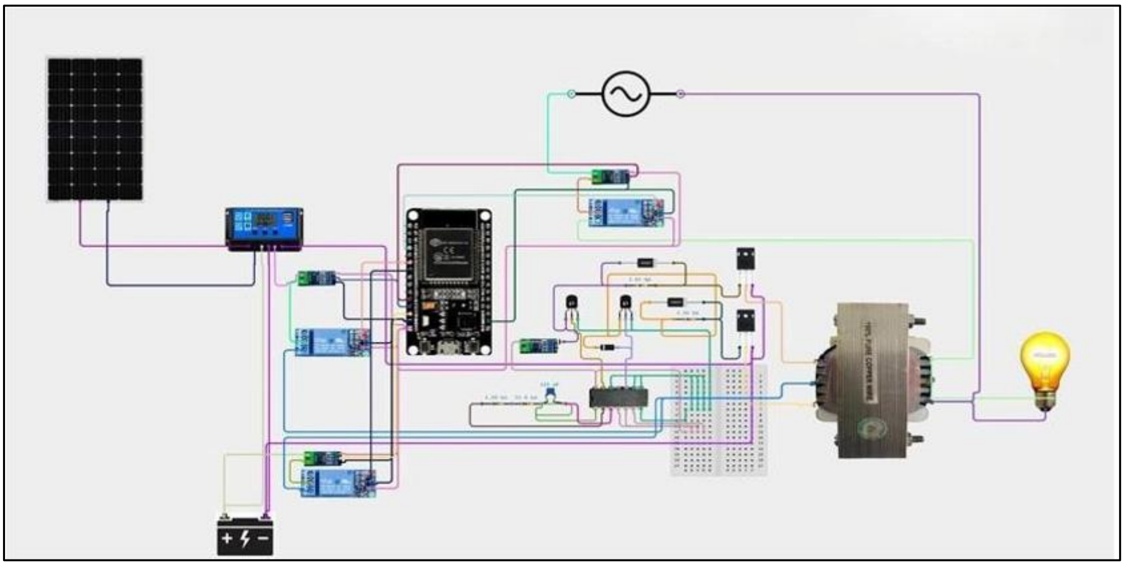

Fig 2 Circuit Diagram

The main purpose of a smart hybrid inverter is to provide continuous, efficient, and reliable power by combining different energy sources.

- *Solar Panel*

The solar panel generates electrical energy from sunlight and supplies power to the system. It serves as the main renewable energy source, charging the battery and running electrical appliances. It produces direct current (DC) electricity, which is managed by the smart hybrid inverter and converted into alternating current (AC) for household or industrial use. It also reduces dependence on grid electricity and lowers costs.

- *Battery*

A battery is an electrochemical device that is used to store energy from solar panels or the grid for later use. It provides backup power during outages and maintains appliance operation when solar energy is not available.

- *Step-up Transformer*

A step-up transformer is used to increase a low voltage input to a higher voltage output, depending on what the system needs. It works through electromagnetic induction and helps with efficient power transmission and voltage conversion. It usually raises the low AC voltage from the inverter circuit to the level needed to run electrical appliances and other loads.

Table 1 Specification of Step-up Transformer

Specifications	**Values**
Operating Voltage	12V
Output	220-240V
Frequency	50HZ

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ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26may1909

- *ESP32 Microcontroller*

The ESP32 helps monitor, control, and automate tasks like battery management, voltage monitoring, load control, and communication between system parts. With the ESP32, the system can process data in real time and manage energy more efficiently. This makes the inverter system work better, with improved reliability and smarter operation.

Table 2 Specification of ESP32 Microcontroller

Specifications	Values
Operating Voltage	3.3V
Processor Type	Dual-core 32-bit microprocessor
Clock Speed	Up to 240 MHz

- *Solar Charge Controller*

A solar charge controller is used to manage the voltage and current from the solar panel to the battery. It keeps the battery safe from overcharging, deep discharging, and voltage changes, which helps the battery last longer and the system work better.

- *MOSFET*

A MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor switching device used for high-speed switching and power control. It controls the flow of electrical current in the inverter circuit and helps in converting direct current (DC) into alternating current (AC). It is widely used for its high efficiency, fast switching, and low power loss.

- *Single-Channel Relay*

The single-channel relay is used to automatically switch between power sources such as solar power, battery power, and grid electricity. It controls loads, protects circuits, and improves system automation and reliability.

- *Current Sensor*

The current sensor is used to monitor power consumption, battery charging and discharging current, and load conditions. It plays an important role in system protection, energy management, and improving the efficiency and safety of the inverter system.

- *Transistor*

Transistors are used for signal processing, switching, voltage regulation, and power control. They efficiently convert direct current (DC) into alternating current (AC), improving the inverter system's performance and reliability.

- *PF Capacitor*

The PF (Power Factor) capacitor improves energy efficiency, stabilises voltage, and reduces power loss in the system. It also supports the smooth operation of electrical loads and enhances the overall performance of the inverter system.

- *General Purpose Diode (1N4007)*

The 1N4007 diode is commonly used in rectifiers, battery charging, and protection circuits. It converts alternating current (AC) into direct current (DC) and ensures safe, stable operation of the inverter system.

- *General Purpose Resistor*

General-purpose resistors are used for control circuits, voltage dividers, signal processing, and protection circuits. They keep circuits stable, make systems more reliable, and help electronic parts work as they should.

✓ *Flowchart*

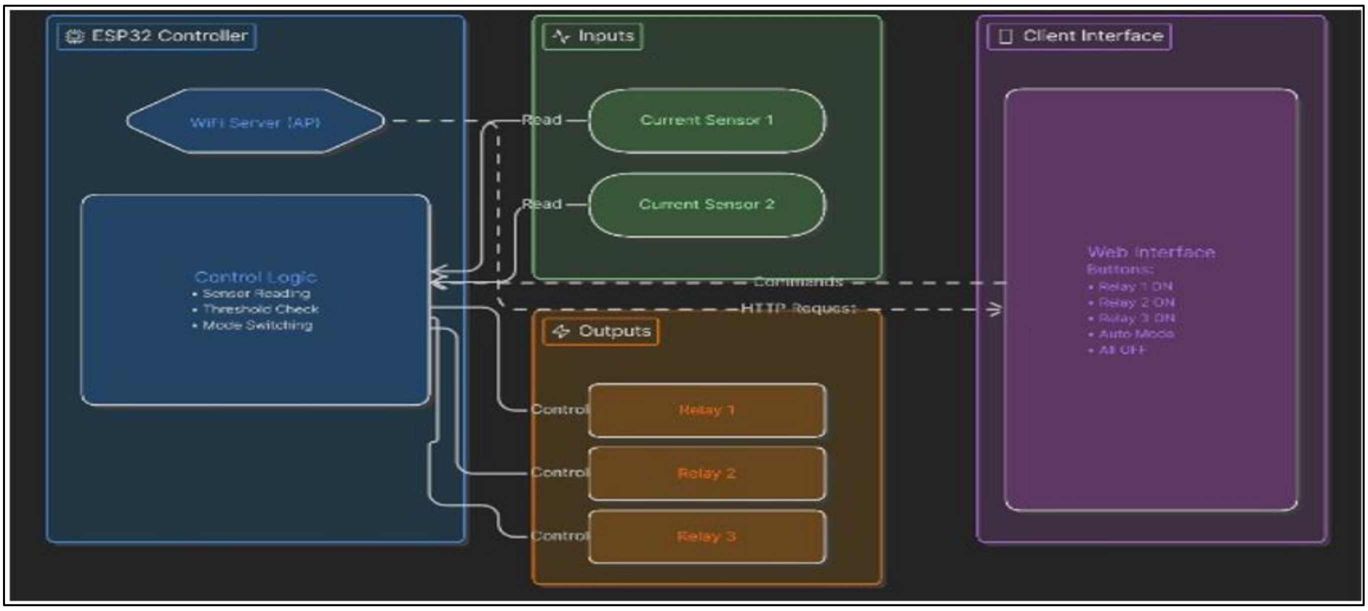

Fig 3 Flowchart of Smart Hybrid Inverter

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International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165
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IV. HARDWARE TESTING

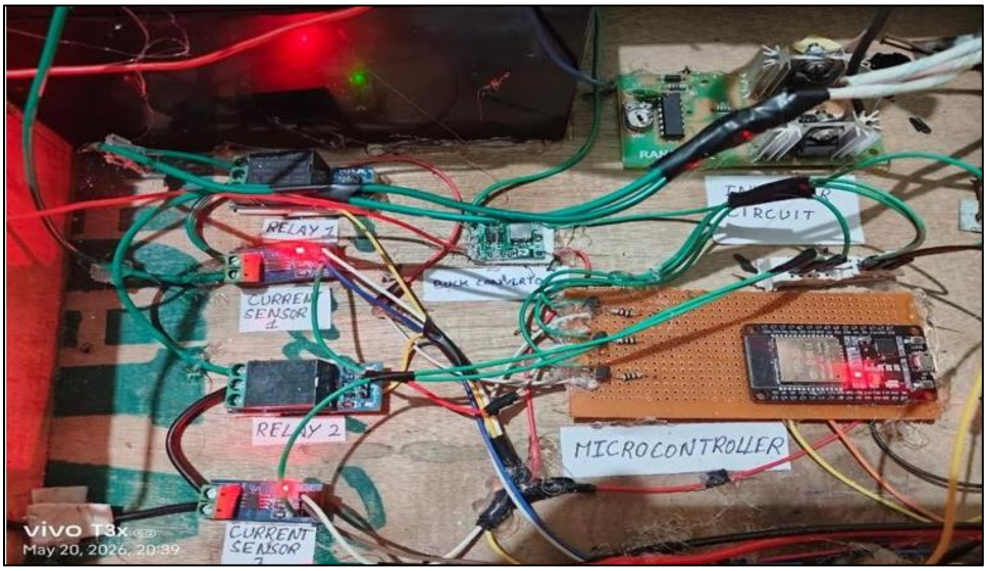

Fig 4 Testing of Hardware

Fig 5 Solar Module

Table 3 Solar Module Specification

Specifications	Values
Power Rating	50-100W
Output Voltage	12/24/36V
Open Circuit Voltage (Voc)	12V to 45V
Short Circuit Current	3A to 15A (approx.)
Effienciey	15% to 22%

V. RESULT & DISCUSSION

The smart hybrid inverter system was designed and tested using components including solar panels, battery storage, an ESP32 microcontroller, a MOSFET switching circuit, a relay module, a transformer, a charge controller, and a current sensor. This system integrates solar energy, battery backup, and grid supply to deliver continuous and reliable electrical power. Testing demonstrated that the solar panel provided direct current (DC) power, which the controller regulated and stored in the battery. The inverter circuit converted alternating current (AC) to operate the ESP32 microcontroller-monitored system, measuring voltage, current, and battery, and managed automatic switching. The relay module provides a transition between solar, battery, and grid supply without interruption of power to the connected

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ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26may1909

loads. The MOSFET-based switching circuit improved the efficiency of the inverter by reducing switching losses and ensuring stable power conversion. Current sensors accurately measured load current and helped in system protection and monitoring.

VI. CONCLUSION

In this research, we have designed and fabricated a smart hybrid inverter which provided efficient, reliable, and uninterrupted power supply using solar energy, battery storage, and grid electricity. The system effectively managed multiple power sources and automatically switched between them according to power availability and load requirements. Integrating components such as solar panels, a battery, an ESP32 microcontroller, a charge controller, a MOSFET, a relay module, a transformer, and a current sensor enhanced the inverter system's performance, efficiency, and automation. The inverter reliably converted DC power to AC power and maintained the stable operation of electrical appliances.

FUTURE SCOPE

- In future, it can be improved with IoT for remote monitoring and control.
- The system efficiency can be increased using modern electronic components.
- It can support additional renewable energy sources like wind energy.
- Future systems may include automatic fault detection and smart protection features.
- Compact and portable inverter designs for future applications.
- Improvement in battery technology for longer backup and fast charging.
- Reduction in electricity costs and environmental pollution.

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