



## Review: Smart Inverter: Real Time Monitoring and Control

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**Abstract :** The increasing demand for efficient and intelligent power management systems has driven the development of smart inverters capable of real-time monitoring and control. This paper presents the design and implementation of the Smart Inverter, a robust system that integrates advanced monitoring and control features to enhance energy utilization and system reliability. The proposed system leverages microcontroller-based architecture and IoT connectivity to provide users with real-time data insights and remote operability. Key functionalities include load optimization, fault detection, and predictive maintenance alerts. This paper discusses the underlying architecture, algorithms, and methodologies employed to achieve a seamless and efficient inverter solution. The Smart Inverter aims to redefine conventional inverter systems by introducing an intelligent and user-friendly approach, addressing the limitations of existing systems while paving the way for future innovations in power management.

**Keywords :** Intelligent inverter, IoT, load optimization, real-time monitoring, smart energy management

### I. INTRODUCTION

The modern world's increasing dependence on electronic devices and renewable energy systems has underscored the importance of efficient power management solutions. Traditional inverter systems, while essential for energy conversion and backup power, often lack the intelligence and adaptability required to meet the demands of today's interconnected environments. Limitations such as manual control, lack of real-time insights, and inefficient load management reduce their utility and scalability.

This paper introduces the Smart Inverter, an intelligent inverter system designed to overcome these challenges. "Smart," reflects the system's ability to monitor and control energy usage dynamically. By leveraging a microcontroller-based architecture and Internet of Things (IoT) technologies, the Smart Inverter enables real-time monitoring, fault detection, load optimization, and remote operability.

The proposed system integrates innovative hardware and software design to ensure user-friendly interaction, energy efficiency, and operational reliability. Furthermore, the Smart Inverter incorporates predictive maintenance alerts, enhancing system longevity and reducing downtime.

### II. LITERATURE SURVEY

M. Ansari et al. [1] explores the integration of IoT devices with cloud computing, highlighting several key benefits and challenges. The advantages include increased efficiency through automation and remote monitoring, improved decision-making with real-time data analytics, enhanced customer experience through data-driven insights, reduced costs due to automation, and enhanced security provided by cloud platforms. However, the integration also poses several disadvantages, such as security issues and privacy concerns related to IoT devices, reliability concerns due to malfunctions or data loss, lack of standardization among IoT devices, internet dependence, high initial costs, and the complexity of integrating diverse technologies. The paper underscores the importance of addressing these challenges to fully leverage the potential of IoT-cloud fusion.

K.-H. Huang et al. [2] focuses on the online control of smart inverters for photovoltaic power generation systems in a smart grid. The system utilizes smart inverter technology, proportional-integral (PI) controllers, and voltage-power control technology to manage active and reactive power. The advantages include improved tracking speed, high conversion efficiency, and enhanced power quality. However, the system also has some limitations, such as automatic shutdown during islanding, complexity of implementation, and sensitivity to

environmental changes. The paper demonstrates the potential of smart inverters in improving the power quality of the grid system.

Umar, B. U. et al. [3] presents the development of an IoT-based smart inverter for energy metering and control. The system utilizes IoT technology, mobile application development, and wireless communication technologies to enable remote monitoring and control of the inverter system. The advantages include remote monitoring and control, energy efficiency, and security features. However, the system also has some limitations, such as dependency on internet connectivity, complexity of setup, and potential for technical failures. The paper highlights the potential of IoT-based smart inverters in promoting energy efficiency and reducing power wastage.

B. Veena et al. [4] proposes an IoT-based smart inverter design using Arduino UNO and ESP8266 Wi-Fi module. The system utilizes solar panels to charge the inverter's battery, enabling sustainable energy generation. The study highlights the energy efficiency, cost-effectiveness, and improved reliability of the system, but also notes the limitations of internet dependency, setup complexity, and battery limitations. The paper showcases a user-friendly interface developed with Android Studio, making the system accessible to a wider audience.

Catruc, I. et al. [5] discusses the integration of IoT devices with mobile and cloud solutions, emphasizing the benefits and challenges of this convergence. The advantages include an enhanced user experience through real-time and tailored data services, dynamic scaling enabled by Infrastructure-as-a-Service (IaaS), cost efficiency in data management and infrastructure maintenance, automation via chatbots, and extensive data collection for improved decision-making. However, the paper also notes several disadvantages, such as security risks including data breaches and unauthorized access, integration complexity due to service-oriented architecture, user awareness issues regarding security, and the requirement for stable internet connections. The study highlights the need for robust security measures and user education to mitigate these risks.

Rathy G A et al. [6] presents an innovative approach to energy management through the integration of Internet of Things (IoT) technology with photovoltaic (PV) solar systems. The authors propose a smart controlled inverter that enables users to monitor and manage energy loads wirelessly, enhancing the efficiency and reliability of solar energy utilization. By utilizing components such as the ESP 8266 Node MCU Wi-Fi module and ACS 712 current sensor, the system allows for real-time control and diagnostics, addressing common challenges in traditional PV monitoring systems. This research not only emphasizes the importance of renewable energy sources but also highlights the potential of IoT in creating sustainable and user-friendly energy solutions, paving the way for advancements in smart grid technologies and eco-friendly energy management practices.

B. A. Zavar et al. [7] explores advanced smart inverter technologies for microgrid applications, focusing on power conversion, control systems, and communication protocols. The paper highlights the decentralized control and adaptability of these inverters, emphasizing their ability to improve power quality, isolate faults, and integrate seamlessly into existing systems. While smart inverters enhance reliability and performance through real-time diagnostics, they also introduce complexity and higher costs compared to traditional inverters. Furthermore, communication dependency and vulnerability to cyber threats present challenges in large-scale implementations. Overall, the paper illustrates the importance of smart inverters in modern microgrid applications.

X. Zhao et al. [8] examines the power system support functions provided by smart inverters, including reactive power control, fault ride-through, harmonic compensation, and frequency ride-through. The study highlights the benefits of enhanced grid stability, improved power quality, flexibility, cost reduction, and environmental benefits. However, it also notes the complexity, implementation cost, dependence on standards, overvoltage risk, and computational burden as limitations. The paper emphasizes the importance of smart inverters in supporting the integration of renewable energy sources and maintaining grid stability.

Megha A Joshi et al. [9] presents a novel bi-level configuration for a photovoltaic (PV) based microgrid tailored for low-power residential applications. It integrates a supervisory control scheme that defines set points for local controllers, enhancing the efficiency of solar energy harvesting and battery monitoring. The local level employs adaptive double mode controllers, enabling seamless transitions between grid-tied and standalone modes, thereby optimizing energy management. Additionally, the implementation of a dynamic price scheduling framework, utilizing time series-based regression techniques for load and solar energy forecasting, addresses the challenges of renewable energy source (RES) output fluctuations. This innovative approach not only aims to improve the reliability and efficiency of energy systems but also contributes to the broader goal of reducing reliance on fossil fuels and promoting sustainable energy practices in residential settings.

M. Mnati et al. [10] presents a cost-effective smart voltage and current monitoring system for three-phase inverters using an Arduino Nano V3.0 and an Android smartphone application. The system enables remote monitoring of voltage and current measurements via a smartphone app, enhancing safety and user-friendliness. The study highlights the advantages of low-cost components, wireless monitoring, and a user-friendly interface. However, it also notes the limitations of limited current measurement, Bluetooth dependence, and potential

interference. The paper demonstrates the potential of IoT-based monitoring systems in enhancing the efficiency and safety of three-phase inverters.

Ufoaroh, S. U. et al. [11] focuses on the design and construction of an RF remote-controlled inverter system, utilizing technologies like Pulse Width Modulation (PWM) and Radio Frequency (RF) remote control. The system offers several benefits, including noiseless operation, low maintenance and zero fuel cost, environmental benefits due to emission-free operation, and automation and convenience through RF remote control. However, the system also has some limitations, such as dependence on battery voltage which affects operation duration, complexity in maintenance despite the design for easier upkeep, and potential malfunctions if the battery voltage exceeds 25V. The paper demonstrates the potential of RF-controlled inverters for convenient and eco-friendly power generation but also highlights the need for careful maintenance and voltage management.

N. Krishnan and D. H. [12] presents the development of an IoT-based smart inverter for energy metering and control using a cascaded H-bridge topology and pulse width modulation (PWM). The system utilizes a microcontroller to manage the solar tracking mechanism and inverter operation. The advantages include increased efficiency, reduced harmonic distortion, and enhanced reliability. However, the system also has some limitations, such as complexity of design, cost, and common ground problem. The paper highlights the potential of IoT-based smart inverters in promoting energy efficiency and improving power quality.

### III. METHODOLOGY

The Smart Inverter employs a microcontroller-based architecture combined with IoT technology to achieve real-time monitoring and control. The system's design integrates advanced hardware and software components to optimize energy usage, detect faults, and enhance user interaction.

The hardware architecture comprises a microcontroller that serves as the central processing unit, interfacing with sensors for real-time data acquisition. These sensors monitor key parameters, including voltage, current, and temperature, ensuring the system's operational reliability. The communication module, utilizing Wi-Fi or GSM technology, enables seamless IoT connectivity for data transmission to a cloud-based platform. A power control unit is responsible for load balancing and energy distribution, ensuring efficient power utilization.

On the software side, the microcontroller is programmed with firmware to process sensor data and execute control commands. The cloud platform performs data storage, analysis, and visualization, while a mobile application provides users with an intuitive interface to access real-time data, fault alerts, and control options. The system also incorporates predictive algorithms to identify anomalies and provide maintenance alerts, minimizing downtime and operational costs.

The operation begins with the microcontroller acquiring data from sensors. The collected data is transmitted to the cloud platform, where it is analyzed for fault detection and load optimization. The system employs the equation:  $P = V \times I$  where  $P$  is the power,  $V$  is the voltage, and  $I$  is the current, to calculate energy consumption dynamically. Anomalies in these parameters trigger alerts, notifying users through the mobile application. Users can then issue commands remotely, which are executed by the microcontroller to adjust system performance.

### IV. ANALYSIS TABLE

The Analysis Table summarizes the research papers on Smart Inverters and IoT controlled inverters. Below is a detailed description of various algorithms and methodologies employed in the referenced studies, highlighting their applications and relevance to the Smart Inverter.

Table 4.1: Analysis Table

| Title   | Technology Used   | Advantages  | Disadvantages   |
|---|---|---|---|
| Internet of things (IoT) fusion with cloud computing: current research and future direction. [1] (2023) | Cloud Computing Platforms<br>Middleware Technologies<br>Big Data Analytics<br>Networking Technologies | Increased Efficiency<br>Improved Decision-Making<br>Enhanced Customer Experience<br>Enhanced Security<br>Increased Scalability<br>Efficient Data Handling | Security Issues<br>Privacy Concerns<br>Reliability<br>Lack of Standardization<br>Internet Dependence<br>Cost Complexity |
| Online Control of Smart Inverter for  | Smart Inverter Technology   | Improved Tracking Speed   | Automatic Shutdown During Islanding   |

|  |   |   |  |
|--|---|---|--|
| Photovoltaic Power Generation Systems in a Smart Grid [2] (2022)                   | Proportional-Integral (PI) Controller<br>Voltage-Power Control Technology   | High Conversion Efficiency<br>Enhanced Power Quality  | Complexity of Implementation<br>Sensitivity to Environmental Changes                                     |
| Development of IoT Based Smart Inverter for Energy Metering and Control [3] (2021) | IoT (Internet of Things)<br>Mobile Application Development<br>Wireless Communication Technologies   | Remote Monitoring and Control<br>Energy Efficiency<br>Security Features   | Dependency on Internet Connectivity<br>Complexity of Setup<br>Potential for Technical Failures           |
| An IoT Based Smart Inverter Design [4] (2020)                                      | Arduino UNO<br>ESP8266 Wi-Fi Module<br>Solar Panels   | Energy Efficiency<br>Remote Monitoring<br>Cost-Effective<br>Improved Reliability<br>User-Friendly Interface           | Internet Dependency<br>Setup Complexity<br>Battery Limitations<br>Environmental Factors                  |
| IoT Integration with Mobile and Cloud Solutions [5] (2020)                         | IoT Devices<br>Cloud Computing<br>Chatbots  | Enhanced User Experience<br>Dynamic Scaling<br>Cost Efficiency<br>Automation Data Collection                          | Security Risks<br>Integration Complexity<br>User Awareness<br>Internet Dependence                        |
| IOT Based Smart Controlled Inverter. [6] (2020)                                    | Solar Panels<br>Inverter<br>NodeMCU ESP8266<br>Relay Module<br>Current Sensor<br>Blynk App<br>Battery   | Renewable Energy<br>Remote Monitoring<br>Energy Efficiency<br>Eco-friendly<br>Real-time Information<br>Scalability    | Initial Cost<br>Internet Dependency<br>Maintenance<br>Complexity<br>Limited Power Supply                 |
| Smart Inverters for Microgrid Applications: A Review Technology [7] (2019)         | Power Conversion Technology<br>Control Systems<br>Communication Protocols<br>Monitoring and Diagnostics<br>Power Quality Management                                       | Decentralized Control<br>Self-Awareness<br>Adaptability<br>Fault Tolerance<br>Improved Power Quality<br>Plug and Play | Complexity<br>Cost<br>Communication Dependency<br>Vulnerability to Cyber Attacks<br>Interference Issues  |
| Power System Support Functions Provided by Smart Inverters—A Review [8] (2018)     | Smart Inverters<br>Reactive Power Control Strategies<br>Harmonic Compensation Methods<br>Voltage Ride-Through (VRT) Techniques<br>Frequency Ride-Through (FRT) Techniques | Enhanced Grid Stability<br>Improved Power Quality<br>Flexibility<br>Cost Reduction<br>Environmental Benefits          | Complexity<br>Implementation Cost<br>Dependence on Standards<br>Overvoltage Risk<br>Computational Burden |
| IOT Based Smart Inverter Using Raspberry PI [9] (2017)                             | Solar Panels<br>Buck-Boost Converter<br>Smart Inverter<br>Raspberry Pi  | Remote Control<br>Energy Efficiency<br>Security<br>Real-time Monitoring   | High Initial Cost<br>Complexity<br>Internet Reliance   |

|  | IoT Integration   | Adaptability  | Technical Issues  |
|--|---|---|---|
| A Smart Voltage and Current Monitoring System for Three Phase Inverters Using an AndroidSmartphone Application [10] (2017) | Arduino Nano V3.0<br>Voltage Sensor<br>Current Sensor<br>Bluetooth HC-05<br>Android Application | Cost-Effective<br>Safety<br>Low-Cost Components<br>software.<br>Wireless Monitoring<br>User-Friendly Interface          | Limited Current<br>Measurement<br>Bluetooth Dependence<br>Potential Interference<br>Smartphone<br>Requirement<br>Quantization Noise |
| Design and Construction of an RF Remote Control 5kva Inverter System [11] (2016)   | Pulse Width Modulation (PWM)<br>Radio Frequency (RF)<br>Remote Control                          | Noiseless Operation<br>Low Maintenance and<br>Zero Fuel Cost<br>Environmental Benefits<br>Automation and<br>Convenience | Dependence on Battery<br>Voltage<br>Complexity in<br>Maintenance<br>Potential for<br>Malfunctions                                   |
| Development of IoT Based Smart Inverter for Energy Metering and Control [12] (2015)  | Cascaded H-Bridge<br>Topology<br>Pulse Width Modulation (PWM)<br>Microcontroller (Atmega328p)   | Increased Efficiency<br>Reduced Harmonic<br>Distortion<br>Enhanced Reliability  | Complexity of Design<br>Cost<br>Common Ground<br>Problem  |

## V. CONCLUSION

The Smart Inverter represents a significant advancement in the domain of smart power management systems. By integrating real-time monitoring, remote operability, and predictive maintenance, the system addresses critical limitations of traditional inverters. Its microcontroller-based architecture, combined with IoT connectivity, ensures seamless data acquisition, analysis, and control. The key contributions of this work include enhanced energy efficiency, dynamic load optimization, and improved system reliability. Furthermore, the user-friendly mobile application simplifies interaction, making it accessible for both residential and industrial applications.

While the Smart Inverter demonstrates considerable promise, there are limitations that provide opportunities for future research. These include scaling the system for larger power setups and incorporating advanced machine learning algorithms for more precise fault prediction. Future developments could also explore renewable energy integration and adaptive energy management to further enhance its utility. In conclusion, the Smart Inverter offers a practical and innovative solution to modern power management challenges, paving the way for more intelligent and efficient energy systems.

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