



IOT BASED SMART ENERGY METER USING CLOUD COMPUTING: COMPREHENSIVE REVIEW

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Abstract: The increasing electricity demand driven by energy-intensive devices and industrial growth is putting immense pressure on conventional power grids and escalating energy costs. This review investigates the transformative potential of Internet of Things (IoT)-enabled smart energy meters integrated with cloud computing for modern energy management. These systems facilitate real-time monitoring, cost estimation, remote load control, and outage detection—enabling intelligent energy optimization and seamless integration of Distributed Energy Resources (DERs) such as solar and wind. Various implementations report up to 49% reductions in energy consumption, enhanced grid stability, and greater user engagement through mobile applications and wireless sensor networks. However, challenges including data security, interoperability, and scalability persist. The convergence of IoT, cloud computing, and advanced analytics offers a sustainable, scalable, and efficient framework for the evolution of future energy systems.

Keywords: Smart grid, Smart meter, Energy balance, Internet of things, cloud computing

1. INTRODUCTION

The rapid global rise in electricity consumption driven by the increasing use of energy-intensive household appliances and industrial expansion has revealed significant limitations in traditional power grids concerning energy balance, power quality, and cost efficiency [1], [2]. These challenges have accelerated the transition toward Smart Grid (SG) infrastructures, which leverage Internet of Things (IoT) technologies to enable real-time monitoring, predictive analytics, and improved power distribution control [3].

Recent advancements in Intelligent Energy Management Systems (IEMS), Wireless Sensor Networks (WSNs), and IoT-enabled Smart Meters (SMs) have substantially strengthened the capabilities of modern smart grids [4]. These systems facilitate bidirectional communication, continuous power quality monitoring, and seamless integration of Distributed Energy Resources (DERs) such as solar and wind power. Empirical studies indicate that IoT-based energy management systems can achieve energy savings ranging from 15% to 49% across various applications [5].

This review critically examines existing IoT-based smart grid solutions, evaluates their effectiveness in optimizing energy usage, and identifies emerging trends in smart energy management [6]. Traditional grids, characterized by one-way communication and limited automation, lack the analytics and responsiveness required for efficient energy distribution. Consequently, they are prone to frequent outages, high transmission losses, and elevated operational costs [7].

In contrast, IoT-based smart grids overcome these challenges through automated demand-side management, real-time data acquisition, and DER integration, enhancing energy efficiency, reducing costs, and improving overall grid reliability [8]. By incorporating intelligent automation, bidirectional communication, and predictive insights, IoT-enabled smart grids represent a transformative paradigm for sustainable energy management [9].

Furthermore, this review highlights the crucial roles of IEMS, smart meters, and wireless sensor networks in building resilient and optimized power networks. Despite their potential, several challenges remain particularly in the areas of data security, interoperability, and system scalability. Emerging technologies such as AI-driven analytics, edge computing, and blockchain-based security offer promising pathways to address these issues and further reinforce the reliability and sustainability of next-generation smart grid infrastructures [10].

Table No. 1: Comparison between Traditional Energy Meters and IoT-Based Smart Energy Meters with Cloud Computing

Traditional Energy Meter	IoT-Based Smart Energy Meter with Cloud Computing
Manual reading by meter readers	Automated real-time data collection and continuous monitoring using IoT devices and wireless communication
Limited to local meter display	Remote access through cloud platforms, web dashboards, and mobile applications
Monthly manual billing	Automatic, real-time billing generation and consumption alerts
No real-time monitoring	Real-time monitoring with detailed usage analytics
Not supported	Enables demand-side management and intelligent load control
One-way communication (meter to utility)	Bidirectional communication between users and utility providers
Difficult or not supported	Seamless integration with Distributed Energy Resources (DERs) such as solar and wind
Passive: users receive bills after consumption	Active: users gain usage insights and control options
Manual and periodic maintenance	Remote diagnostics and over-the-air firmware updates
Limited, fixed infrastructure	Highly scalable and adaptable to multiple applications
No direct contribution to optimization	Enables energy optimization and efficiency improvement
Higher operational costs due to manual processing	Reduced operational costs through automation and cloud analytics

2. LITERATURE SURVEY

The rapid growth in electricity consumption has intensified the need for intelligent and efficient energy management systems. To address this, researchers have explored the integration of the Internet of Things (IoT) and cloud computing technologies into smart energy metering systems to enhance monitoring, control, and optimization of energy usage.

Mehmet Güçyetmez and Husham Sakeen Farhan [1] developed an IoT- and cloud-enabled smart metering framework that predicts energy consumption using time-series analysis. Their system demonstrated a significant

improvement in prediction accuracy and up to 49% energy savings. Similarly, Joseph et al. [2] designed an IoT-based smart meter employing an ESP8266 microcontroller for real-time load control and energy billing, proving to be reliable and energy-efficient for small-scale applications.

Hussein and Abdul-Rahaim [3] presented a cloud-based metering system using the MQTT protocol for real-time monitoring of household power consumption. Their approach achieved low latency and effective visualization through a cloud dashboard. Yadav et al. [4] proposed a smart dynamic energy management model using IoT and cloud integration for the built environment, enabling optimized load control and energy conservation. D. Adinarayana Naik et al. [5] enhanced grid communication and real-time data access through a cloud-based smart meter design, though the system required improved data security measures.

Condon et al. [6] developed a cloud-IoT-based home energy management system integrating renewable energy sources and intelligent scheduling to reduce operational costs. Similarly, Krishna et al. [7] implemented a low-cost IoT smart energy meter using ESP8266 with Google Sheets integration for data logging, offering a simple and efficient solution for individual users. Hallur et al. [8] explored a cloud-connected metering system emphasizing online monitoring and energy data storage, laying the groundwork for later predictive systems.

Usman Saleem et al. [9] introduced an IoT- and cloud-integrated smart energy management framework featuring machine learning for demand-side management, achieving improved grid stability and reduced peak demand. Finally, Sulthana et al. [10] demonstrated an IoT-based real-time monitoring system capable of measuring and displaying energy consumption through a web interface, contributing to user awareness and efficient energy usage. Overall, existing studies highlight the potential of IoT and cloud computing to transform energy management systems through features like real-time monitoring, predictive analytics, and remote control. However, persistent challenges such as interoperability, data security, scalability, and dependency on stable internet connectivity must be addressed for large-scale deployment in smart grids.

2.1 Comparison of Existing project ideas Table 2

Sr. No.	Authors / Year	Title / Source	Technology / Tools Used	Key Contributions / Features	Results / Outcomes	Limitations / Future Scope
[1]	Mehmet Güçyetmez, H. S. Farhan (2023)	Enhancing smart grids with a new IoT and cloud-based smart meter... (AEJ)	IoT, Cloud computing, Time series prediction	Predicts energy consumption using cloud-based analytics; integrates IoT meters with forecasting	Achieved improved consumption prediction accuracy and 49% energy saving	Needs better data security and real-time synchronization
[2]	B. Joseph et al. (2025)	IoT Based Smart Energy Meter (IJSREM)	ESP8266, IoT sensors	Real-time monitoring, remote billing and load control	Demonstrated reliable data transmission and low power operation	Limited scalability for large-scale grids
[3]	Z. M. Hussein, L. A. Abdul-Rahaim (2022)	Cloud Computing Smart Metering... (IEEE AEST)	Cloud computing, MQTT protocol	Measures household consumption and uploads to cloud dashboard	Efficient data visualization with low latency	Limited field testing; small sample size

[4]	M. Yadav et al. (2021)	IoT based Smart Dynamic Energy Management... (IEEE ISCON)	IoT sensors, NodeMCU, Cloud	Dynamic load management and automation for buildings	Improved load optimization and reduced wastage	Needs integration with renewable energy sources
[5]	D. A. Naik et al. (2023)	Cloud Based Smart Energy Meter for Smart Grid (IJFMR)	IoT, Cloud server, Wi-Fi	Cloud dashboard for real-time consumption and control	Demonstrated improved grid communication efficiency	Data privacy concerns and limited hardware validation
[6]	Felipe Condon et al. (2023)	Cloud-IoT-Based Home Energy Management System (MDPI Sensors)	IoT, Cloud, AI algorithms	Smart home control with renewable energy integration	Achieved intelligent load scheduling and reduced cost	Requires large data storage and cloud dependency
[7]	M. S. R. Krishna et al. (2024)	IoT Based Smart Energy Meter using ESP8266 with Google Sheet Integration (IJCRT)	ESP8266, Google Sheets, IoT	Cloudless real-time monitoring via Google Sheets	Simple low-cost implementation with high reliability	Limited scalability and lacks data security
[8]	S. Hallur et al. (2018)	Cloud Based Smart Energy Meter (IJSRT)	Wi-Fi, IoT, Cloud	Online monitoring and energy data storage	Improved data accessibility	Early work; lacks predictive capability
[9]	M. U. Saleem et al. (2023)	Integrating Smart Energy Management System with IoT and Cloud Computing... (MDPI Energies)	IoT, Cloud, Machine Learning	Demand-side management using IoT and cloud analytics	Enhanced grid stability and peak load reduction	Complex integration; requires high bandwidth
[10]	N. Sulthana et al. (2020)	Smart Energy Meter and Monitoring System using IoT (IJERT)	Arduino, Wi-Fi, IoT	Measures and displays real-time power usage on web dashboard	Accurate monitoring with user-friendly interface	No cloud storage or AI-based analytics

Research Gap Analysis

Despite the considerable progress in developing IoT-based smart energy meters integrated with cloud computing, several research gaps continue to hinder the realization of fully intelligent and sustainable smart grid infrastructures. Most existing studies emphasize real-time monitoring and data visualization but provide limited attention to predictive analytics and adaptive energy control. Current forecasting techniques often struggle to handle dynamic and uncertain energy demand patterns, especially when renewable sources such as solar and wind are integrated into the grid. Moreover, data security and privacy remain pressing concerns. Although cloud

computing enhances accessibility and scalability, the risk of cyberattacks and unauthorized access persists due to inadequate encryption and authentication mechanisms.

Another major challenge lies in interoperability and standardization. The diversity of IoT protocols such as Wi-Fi, ZigBee, LoRa, and MQTT creates compatibility issues among different systems and platforms, restricting large-scale integration. Similarly, many reported implementations are confined to small-scale or pilot projects, revealing limitations in scalability and network reliability when deployed in real-world grid environments. Furthermore, the heavy reliance on centralized cloud infrastructures introduces latency, potential single points of failure, and higher operational costs. These gaps highlight the need for future research focused on developing hybrid cloud–edge architectures and blockchain-enabled security frameworks to ensure real-time responsiveness, data integrity, and system interoperability. Addressing these challenges is crucial for advancing toward a truly resilient, scalable, and intelligent energy management ecosystem.

III. CONCLUSION

The integration of Internet of Things (IoT) technology with cloud computing has emerged as a transformative approach to modernizing energy management systems. This review highlights how IoT-based smart energy meters enable real-time monitoring, automated billing, predictive analysis, and seamless integration of Distributed Energy Resources (DERs), ultimately improving grid stability and operational efficiency. Compared to traditional energy meters, these systems offer intelligent automation, bidirectional communication, and enhanced user engagement through mobile and cloud interfaces. However, despite their significant advantages, several challenges remain unresolved. Issues such as data security, interoperability among heterogeneous devices, scalability for large-scale deployment, and dependency on stable network infrastructure continue to limit widespread adoption. Furthermore, most existing implementations remain confined to small-scale or experimental settings rather than fully integrated smart grid environments. To overcome these barriers, future research should focus on developing secure and interoperable frameworks through blockchain and ensuring scalability through standardized communication protocols. With these advancements, IoT-enabled smart grids can achieve sustainable, efficient, and reliable energy distribution paving the way for the next generation of intelligent energy infrastructures.

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