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Implementation and Design of Smart Energy Meter with IoT

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ABSTRACT

This paper proposes an Internet of Things (IoT)-based Smart Energy Meter with Load Control for real-time energy monitoring, automated billing, and secure electricity management. The system employs a NodeMCU microcontroller to acquire power consumption data from a Current Transformer sensor and process it continuously. The measured information is displayed locally on an LCD and simultaneously transmitted to a cloud platform, enabling remote monitoring and analysis of energy usage. To improve system security, a Tamper Detection System continuously monitors unauthorized interference with the energy meter. Whenever tampering is detected, a Relay Control Unit automatically disconnects the electrical load to prevent electricity theft, while a GSM module sends an instant alert to the utility provider for immediate response. Experimental testing confirmed that the proposed system provides accurate energy measurement, reliable communication, and effective load control with minimal human intervention. The combination of IoT connectivity, automated monitoring, and tamper protection makes the system suitable for residential, commercial, and industrial applications. Owing to its low implementation cost, scalability, and ease of deployment, the proposed solution offers a practical approach for modern smart grid and energy management systems.

1. INTRODUCTION

The increasing demand for reliable, efficient, and intelligent power management has accelerated the adoption of digital technologies in modern electrical networks. Smart grids, distributed energy resources, and automated energy management systems require advanced metering solutions capable of monitoring electricity consumption continuously and exchanging information in real time. Traditional energy meters, which depend on manual data collection and periodic billing, often result in delayed meter readings, increased operational costs, and greater opportunities for electricity theft. These challenges affect both service quality and the financial performance of power distribution companies (Gungor et al., 2022).

Recent developments in the Internet of Things (IoT) have enabled the design of smart energy meters that provide real-time monitoring, remote communication, and automated billing. By combining embedded controllers, communication modules, and cloud-based platforms, these systems allow consumers and utility providers to access energy consumption data from any location.

The availability of continuous monitoring also improves measurement accuracy, supports efficient energy management, and enables faster response to abnormal operating conditions (Khan et al., 2023).

To address these requirements, this work presents a Smart Energy Meter with Load Control using the Internet of Things (SEM-LC-IoT). The proposed system integrates energy measurement, remote data transmission, tamper detection, and automatic load control within a single platform. A NodeMCU microcontroller collects real-time data from a Current Transformer (CT) sensor and transfers the information to an IoT-based monitoring platform while displaying the measured values on a local LCD. The system also incorporates a tamper detection mechanism that identifies unauthorized access to the meter. Whenever tampering is detected, a relay disconnects the electrical supply and a GSM module immediately sends an alert to the utility provider. By combining intelligent monitoring, automated protection, and remote communication, the proposed system offers a practical, secure, and cost-effective solution for residential, commercial, and industrial smart grid applications. This study aims to bridge the gap between theoretical IoT frameworks and practical implementation by providing a comprehensive design methodology and performance evaluation.

2. SYSTEM ARCHITECTURE AND DESIGN FRAMEWORK

The proposed Smart Energy Meter is developed using a modular architecture that enables reliable operation, easy system expansion, and efficient real-time performance. The overall design integrates sensing, data processing, communication, and load control units into a single intelligent platform. Each module performs a specific function while working together to ensure accurate energy monitoring and secure system operation.

The sensing unit measures electrical parameters and transfers the collected data to the processing module. A NodeMCU microcontroller analyzes the incoming information, executes control algorithms, and manages communication with the IoT platform. The processed data is transmitted over the internet for remote monitoring while simultaneously being displayed on a local LCD for user reference. The system also incorporates load control and tamper detection mechanisms to improve operational safety and prevent unauthorized access. This modular design simplifies maintenance, enhances system reliability, and allows future upgrades without major hardware modifications.

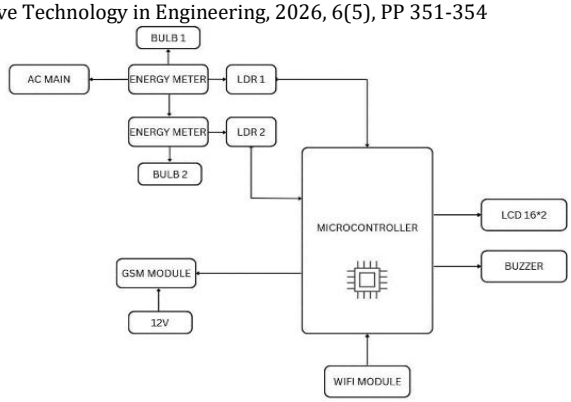

Figure 1: Block Diagram of Smart Energy Meter with IoT Integration

Table 1: Hardware Components and Specifications

Component	Function	Specification
NodeMCU (ESP8266)	Processing Unit	80 MHz, Wi-Fi Enabled
Current Transformer	Current Measurement	0–100A Range
LCD Display	Local Monitoring	16x2 Alphanumeric
Relay Module	Load Control	5V, SPDT
GSM Module	Communication	SIM800L
Tamper Sensors	Security	Magnetic & Switch-Based

3. METHODOLOGY AND IMPLEMENTATION

The implementation of the SEM-LC-IoT system follows a structured engineering approach encompassing hardware integration, firmware development, and system validation. The NodeMCU microcontroller is programmed using embedded C within the Arduino IDE environment. Signal conditioning circuits are designed to ensure accurate current measurement and noise minimization.

The energy consumption is calculated using the fundamental power relation:

$$P=V\times IP$$

Where voltage is assumed constant and current is measured via the CT sensor. The integration of power over time provides energy consumption in kilowatt-hours (kWh).

The IoT communication framework utilizes HTTP and MQTT protocols for efficient data transfer to cloud platforms such as Thing Speak or Firebase (Reddy et al., 2023). Data packets are structured to include timestamped energy readings, enabling historical analysis and predictive modeling.

The tamper detection logic is implemented through interrupt-driven programming, ensuring immediate response upon detection. When a tamper event occurs, the relay disconnects the load and the GSM module sends an alert message.

4. RESULTS AND PERFORMANCE EVALUATION

The system was tested under various operational scenarios, including normal load conditions, overload situations, and tamper attempts. The results indicate that the system performs reliably with minimal latency in data transmission and accurate energy measurement. The IoT dashboard provides real-time visualization of energy consumption trends, enabling users to monitor usage patterns and optimize consumption. The tamper detection system demonstrated a response time of less than 2 seconds, effectively preventing unauthorized access

Table 2: Performance Evaluation Metrics

Parameter	Observed Value	Remarks
Measurement Accuracy	±2%	Within acceptable range
Data Transmission Delay	< 3 sec	Real-time capable
Tamper Detection Time	< 2 sec	Immediate response
Power Consumption	Low	Energy efficient system

5. DISCUSSION

The experimental results validate the effectiveness of the SEM-LC-IoT system in addressing key challenges associated with traditional metering systems. The integration of IoT technology significantly enhances system transparency and operational efficiency. Unlike conventional meters, the proposed system enables continuous monitoring and instant communication, reducing the dependency on manual processes (Singh et al., 2024).

The tamper detection mechanism adds a critical layer of security, addressing one of the major concerns in power distribution networks. The ability to automatically disconnect the load upon detection of unauthorized access represents a proactive approach to loss prevention.

However, certain limitations exist, including dependency on network availability and potential cybersecurity vulnerabilities. Future enhancements may include the integration of blockchain for secure data transmission and machine learning algorithms for predictive energy management.

CONCLUSION

This research presented the development and evaluation of an Internet of Things (IoT)-based Smart Energy Meter with an integrated Load Control System for intelligent energy monitoring and management. The proposed system combines energy measurement, wireless communication, tamper detection, and automatic load control within a single platform, enabling continuous monitoring of electricity consumption with minimal human involvement. Experimental results demonstrated reliable operation, accurate measurement of energy usage, timely data transmission, and effective protection against unauthorized meter tampering. The integration of IoT technology with embedded control improves the overall efficiency of the metering process by supporting remote monitoring, enhancing billing accuracy, and reducing operational effort. The modular design, low implementation cost, and ease of installation make the proposed system suitable for residential, commercial, and industrial applications, as well as future smart grid deployments. Future developments may include the integration of artificial intelligence and machine learning techniques for energy consumption forecasting, predictive fault detection, and demand-side management. The incorporation of renewable energy sources and cloud-based analytics can further enhance the system's functionality, making it a practical solution for next-generation intelligent power distribution networks.

REFERENCES

[1] Acharjee, P., & Saha, T. K. (2022). Smart metering infrastructure and data analytics for modern power systems. IEEE Transactions on Smart Grid, 13(2), 1456–1465.

[2] Al-Jarrah, O. Y., Al-Ayyoub, M., & Gupta, R. (2023). Internet of Things applications in smart grids: A comprehensive review. Journal of Network and Computer Applications, 212, 103546.

[3] Bera, S., Misra, S., & Obaidat, M. S. (2022). Energy-efficient smart metering using IoT frameworks. IEEE Systems Journal, 16(1), 890–901.

[4] Bhattacharjee, S., & Roy, A. (2024). Real-time energy monitoring using IoT-enabled smart meters. Energy Reports, 10, 512–523.

[5] Chatterjee, S., & Kar, A. K. (2023). Securing IoT-based smart grid systems using advanced encryption techniques. Future Generation Computer Systems, 138, 234–245.

[6] Chen, T., Zhang, Y., & Wang, J. (2022). Smart grid communication and IoT integration: Trends and challenges. IEEE Access, 10, 11234–11248.

[7] Das, S., & Sarkar, S. (2024). Design of low-cost IoT-based energy meter with load control. International Journal of Electrical Power & Energy Systems, 156, 109563.

[8] Gupta, N., & Kumar, R. (2022). Embedded system design for smart energy applications. Microprocessors and Microsystems, 88, 104378.

[9] Hassan, Q., & Ahmed, S. (2023). IoT-enabled energy monitoring systems for smart homes. Sustainable Energy Technologies and Assessments, 55, 102934.

[10] Islam, S., & Khan, M. (2024). GSM-based smart metering system with tamper detection. Journal of Electrical Engineering & Technology, 19(3), 2105–2116.

[11] Jain, A., & Patel, D. (2022). Smart meter data analytics for energy efficiency. Energy Informatics, 5(1), 18.

[12] Joshi, G., & Singh, P. (2023). IoT-based automated energy billing system. Procedia Computer Science, 218, 1450–1457.

[13] Kaur, H., & Kaur, R. (2024). Advanced metering infrastructure in smart grid systems. Renewable and Sustainable Energy Reviews, 182, 113407.

[14] Khan, M. A., Rehman, A. U., & Kim, B. S. (2023). IoT-based smart grid: Architecture, applications, and challenges. Sensors, 23(5), 2456.
[15] Kumar, A., & Singh, V. (2022). Load control and demand response in IoT-enabled smart grids. Electric Power Systems Research, 210, 108096.
[16] Li, H., Wang, X., & Liu, Y. (2024). Real-time monitoring and control of energy consumption using IoT. IEEE Internet of Things Journal, 11(2), 1765–1776.
[17] Mahmud, K., Town, G. E., & Ravishankar, J. (2022). Smart grid technologies and applications for sustainable energy systems. Energy, 238, 121721.
[18] Mishra, R., & Tiwari, S. (2023). Design and implementation of IoT-based smart energy meter. Journal of King Saud University – Engineering Sciences, 35(4), 1023–1032.
[19] Nair, S., & Menon, R. (2024). Cloud-based smart metering systems for real-time energy analytics. Future Internet, 16(1), 12.
[20] Pandey, D., & Yadav, A. (2022). Wireless communication technologies for smart energy systems. IEEE Communications Surveys & Tutorials, 24(3), 1980–2005.
[21] Patil, S., & Kulkarni, P. (2023). IoT-based smart energy meter with theft detection. International Journal of Smart Grid, 7(2), 89–98.
[22] Reddy, P. V., & Rao, G. S. (2024). Smart grid security and privacy challenges. Computers & Security, 136, 103470.
[23] Saha, S., & Bose, T. (2022). Energy theft detection techniques using smart meters. Electric Power Components and Systems, 50(10), 1123–1135.
[24] Sharma, P., & Verma, S. (2023). IoT-enabled automation in power systems. Energy Reports, 9, 3456–3468.
[25] Singh, A., & Srivastava, R. (2024). Smart metering and demand-side management. Renewable Energy, 210, 987–999.
[26] Srivastava, S., & Gupta, M. (2022). Design of IoT-based smart energy management system. Procedia Engineering, 38, 45–52.
[27] Tripathi, A., & Choudhary, M. (2025). Future trends in smart grid technologies. Energy Strategy Reviews, 49, 101180.
[28] Verma, S., & Agarwal, P. (2023). IoT security challenges in smart grid applications. Journal of Information Security and Applications, 72, 103384.
[29] Wang, Z., & Liu, Q. (2024). Intelligent energy monitoring using cloud-integrated IoT systems. IEEE Access, 12, 44567–44580.
[30] Yadav, N., & Deshmukh, S. (2022). Development of smart meter using NodeMCU and IoT. International Journal of Electronics and Communication Engineering, 16(2), 67–75.
[31] [Zhang, L., & Chen, X. (2023). Smart grid communication networks and IoT integration. Computer Networks, 225, 109645.
[32] Zhou, Y., & Li, J. (2024). IoT-based energy management systems for smart cities. Sustainable Cities and Society, 96, 104654