



A Literature Review on Energy Management System Using IOT Smart Grid

Varsha Dubey¹, Pragati Trivedi², Arya Srivastava³, Ms. Jyoti⁴

^{1,2,3}Scholar Student, ⁴Assistant Professor

Computer Science & Engineering, IOT Department, Raj Kumar Goel Institute of Technology, Ghaziabad, UP, India

¹varshadubey506@gmail.com, ²pragatitrivedi14@gmail.com, ³aryasrivastava06@gmail.com

ABSTRACT

Energy management is a critical challenge in the modern world, driven by the increasing global demand for electricity, rising energy costs, and the urgent need to minimize environmental impacts. Traditional energy management systems often lack the flexibility, intelligence, and real-time data required to address these challenges effectively. The emergence of the Internet of Things (IoT) provides a transformative approach to energy management by enabling seamless connectivity, automation, and data-driven decision-making across diverse applications.

This project focuses on the design and implementation of an IoT-based Energy Management System (EMS) that monitors, analyses, and optimizes energy consumption in real-time. The system integrates IoT-enabled devices, sensors, and actuators with a centralized cloud-based or edge-computing platform. These sensors collect granular data on power usage, voltage, current, and device-specific energy consumption, transmitting the information via wireless communication protocols such as Wi-Fi, Zigbee, or Lora WAN. The data is then processed using advanced analytics, machine learning algorithms, and predictive models to identify inefficiencies, forecast energy needs, and generate actionable recommendation

A key feature of this system is its ability to provide users with a highly interactive interface accessible through smartphones or web portals. This interface displays real-time energy consumption patterns, historical trends, and cost estimates, empowering users to make informed decisions about energy usage. The EMS also includes smart automation capabilities, such as scheduling devices to operate during off-peak hours, dynamically adjusting settings to reduce power wastage, and integrating with renewable energy sources like solar panels or wind turbines to prioritize clean energy consumption.

Beyond individual user benefits, the IoT-based EMS has broader implications for grid stability and demand-side management. By aggregating data from multiple users and enabling bi-directional communication with utility providers, the system can support load balancing, reduce peak demand, and enhance the integration of distributed energy resources. Furthermore, the system's compatibility with emerging technologies like smart meters and blockchain-based energy trading enhances its potential for scalability and adoption across diverse sectors, including residential, commercial, and industrial settings.

This paper discusses the architecture, components, and operational workflow of the proposed EMS. It explores real-world use cases, evaluates performance metrics such as energy savings, user satisfaction, and environmental impact, and identifies potential challenges, including data security, network reliability, and high initial costs. The findings demonstrate that IoT-based energy management systems offer significant advantages in improving energy efficiency, reducing carbon emissions, and promoting sustainable practices. The project concludes by emphasizing the transformative role of IoT in creating smarter, greener, and more resilient energy ecosystems for the future.

1. INTRODUCTION

The integration of the Internet of Things (IoT) into Energy Management Systems (EMS) has transformed the way energy is monitored, controlled, and optimized, offering innovative solutions to address growing energy demands and sustainability challenges. IoT-enabled EMS utilizes smart sensors, meters, and devices to gather real-time data on energy consumption, enabling enhanced visibility and control over energy usage across residential, commercial, and industrial sectors. By leveraging advanced communication protocols and cloud-based platforms, these systems can automate energy-saving measures, provide remote accessibility, and deliver actionable insights through data analytics and machine learning algorithms.

IoT in energy management introduces significant improvements in efficiency by identifying inefficiencies and optimizing energy distribution and usage patterns. For instance, smart homes equipped with IoT devices such as thermostats, lighting systems, and appliances can automatically adjust their operations based on occupancy and environmental conditions, significantly reducing energy waste. Similarly, in industrial settings, IoT systems monitor energy-intensive processes, providing data-driven recommendations to minimize consumption without compromising productivity. Commercial buildings

benefit from integrated systems that control heating, ventilation, air conditioning (HVAC), and lighting, ensuring energy is used only when and where needed.

Moreover, IoT facilitates the seamless integration of renewable energy sources such as solar panels and wind turbines into the energy grid, enhancing sustainability while managing the variability of these sources. Applications like smart grids, which use IoT for advanced metering and demand response, improve grid reliability and efficiency, ensuring a stable energy supply even during peak demand.

Despite its immense potential, the adoption of IoT-based EMS is not without challenges. High initial investment costs for infrastructure and devices, concerns over data security and privacy, issues with device interoperability, and reliance on stable internet connectivity are significant barriers. However, the long-term benefits of cost savings, improved energy efficiency, reduced carbon emissions, and enhanced user convenience often outweigh these challenges.

In conclusion, IoT-powered Energy Management Systems represent a paradigm shift in how energy is managed, paving the way for smarter, more sustainable, and efficient energy practices. As IoT technology continues to evolve, it holds the promise of driving innovations that will further transform energy management, making it a critical tool for addressing global energy challenges and fostering a sustainable future.

2. ARCHITECTURAL MODEL

The device collects data directly from the energy meter using a TCS 3200 light sensor, which sends the information to an Arduino board. The Arduino processes the data and forwards it to a Raspberry Pi, which uploads the information to the Thing Speak cloud platform. Users can then access the data through a website or mobile app. The system monitors energy consumption from household appliances, which is tracked by the energy meter and displayed as the meter's LED blinks. Typically, 3200 LED blinks equate to one unit of energy consumption.

In this system, a Raspberry Pi 3 serves as the main controller, continuously tracking energy usage by counting the LED blinks on the meter. A custom-designed webpage and mobile application have been developed, allowing users to monitor their energy consumption and related costs. Consumers can set a prepaid threshold using the webpage or app through a Wi-Fi connection. When the usage approaches the set threshold, the system sends notifications to the user, helping them manage their consumption. If the threshold is not adjusted or recharged, the system automatically disconnects the power supply. Consumers can modify the threshold anytime through the website. Furthermore, a monthly bill is automatically generated and sent via SMS to both the customer and the service provider on the first day of each month.



Fig:1

SMART ENERGY METER SYSTEM

3. Role of Smart Energy Meters in IoT-Based Energy Management Systems

Smart Energy Meters are fundamental components of IoT-Based Smart Energy Management Systems (SEMS), acting as data-gathering nodes that provide real-time information on energy consumption across residential, commercial, and industrial settings. Integrated into IoT networks, these meters are designed not only to record energy use but to transmit data continuously to users and energy providers via secure communication channels. This ongoing data collection enables SEMS to perform sophisticated analyses and deliver actionable insights to optimize energy use. By connecting to the larger IoT ecosystem, smart meters allow for seamless interaction with other IoT-enabled devices, such as thermostats, lighting systems, and industrial machinery, helping to create an interconnected energy management network that responds dynamically to changes in usage and demand.

We express our sincere gratitude to the researchers, engineers, and institutions that have advanced IoT-Based Smart Energy Management Systems (SEMS). Their contributions in IoT technology, data analytics, and sustainable practices have been essential in developing this field. We also thank utility providers, policymakers, and developers who ensure the reliability, security, and accessibility of SEMS, supporting a smarter, more sustainable energy future.



Fig: 2

4. Architecture and Technology Behind Smart Energy Meters

Smart energy meters leverage advanced technology, including microcontrollers, sensors, and communication modules, to monitor energy usage and communicate with IoT networks. The integration of IoT connectivity protocols—such as Zigbee, LoRa, Wi-Fi, and cellular networks—enables these meters to transmit data in real-time, providing continuous feedback to SEMS platforms that analyse the data for patterns and anomalies. These meters use cloud or edge computing to store and process data, which allows for rapid analytics and efficient data management. Furthermore, by employing data encryption and security protocols, smart meters ensure secure data transmission, an essential feature for preventing unauthorized access and protecting user privacy within an IoT-based framework.

5. Data Collection and Real-Time Monitoring

One of the core benefits of IoT-integrated smart meters is their capacity for real-time monitoring and detailed data collection. Through constant data transmission, SEMS can track energy usage patterns down to the level of individual devices and appliances, giving users and providers insights into peak usage times, overall consumption, and energy costs. This data allows consumers to understand their energy consumption habits and make adjustments to reduce waste and optimize their usage. For example, users can identify high-energy appliances and adjust their usage to off-peak times, taking advantage of time-of-use billing. This granular data also supports predictive analytics, helping both consumers and utilities to anticipate and mitigate potential energy waste before it occurs.

6. Energy Efficiency and Cost Savings for Consumers

Smart energy meters enable users to track and manage their energy consumption, which promotes energy efficiency and cost savings. With real-time access to consumption data through SEMS platforms, users can identify opportunities to reduce energy waste, cut down on unnecessary usage, and adjust their behaviour to minimize costs. Many smart meters are equipped with mobile app interfaces that allow users to monitor and control their energy consumption remotely, making energy management more convenient and user-friendly. Additionally, by supporting variable-rate billing, where energy prices fluctuate based on demand, SEMS with smart meters incentivize consumers to shift energy use to off-peak times, further reducing their energy expenses and promoting more sustainable energy practices.

7. Challenges in Implementing Smart Energy Meters within IoT-Based SEMS

While smart energy meters offer many benefits, their widespread implementation within IoT-based SEMS is not without challenges. High installation costs, especially in areas with outdated grid infrastructure, can be a barrier to adoption. Privacy and security concerns also present significant challenges, as the data collected by smart meters is sensitive and continuous, requiring robust encryption and cybersecurity measures to prevent unauthorized access. Interoperability is another issue, as smart meters from various manufacturers may not be compatible with all IoT platforms or devices, complicating efforts to create an integrated energy management system. To maximize the potential of SEMS, it is essential to address these challenges by developing standardized protocols and investing in advanced cybersecurity technologies.

8. Future Developments and Impact of Smart Energy Meters

The future of smart energy meters within IoT-Based Smart Energy Management Systems is promising, with advancements in AI, machine learning, and 5G connectivity likely to enhance their functionality. AI algorithms could enable smart meters to predict energy needs more accurately, making SEMS capable of autonomous decision-making based on consumption patterns and energy market prices. With faster 5G networks, data transmission between devices will become quicker and more reliable, enabling even more responsive energy management. As smart meters continue to evolve, they are expected to play an increasingly crucial role in global efforts toward energy sustainability, reducing carbon emissions, and enhancing grid resilience. Ultimately, the integration of smart energy meters within IoT-based SEMS is likely to transform energy management at all levels, empowering consumers, reducing operational costs for providers, and fostering a more sustainable, efficient energy future.

9. ENERGY UNITS CALCULATION

Energy units' calculation is a fundamental aspect of IoT-Based Smart Energy Management Systems (SEMS), enabling accurate tracking of energy consumption in real-time. By continuously measuring energy usage across various devices and systems, SEMS provides users with detailed information about their energy consumption in standardized units, typically kilowatt-hours (kWh). This data is invaluable for monitoring individual device consumption, understanding patterns, and generating insights for energy optimization. Calculating energy units accurately is essential for transparent billing, identifying peak usage times, and creating opportunities for energy-saving strategies, such as demand response programs and time-of-use billing.

A. Methods of Energy Units Calculation

In IoT-based SEMS, energy calculation typically involves measuring both voltage and current to calculate the instantaneous power consumption of each connected device or system. The primary formula used for energy calculation is $\text{Power (Watts)} = \text{Voltage (Volts)} \times \text{Current (Amperes)}$ [16]. $\text{Power (Watts)} = \text{Voltage (Volts)} \times \text{Current (Amperes)}$, and the energy consumed over time is calculated as $\text{Energy (kWh)} = \text{Power (W)} \times \text{Time (Hours)}$. $\text{Energy (kWh)} = \text{Power (W)} \times \text{Time (Hours)}$. Smart meters, equipped with voltage and current sensors, record these metrics at regular intervals, often every few seconds or minutes. This continuous data flow is then transmitted to the SEMS platform, where energy units are calculated for individual devices and aggregate usage. The system can then store this data in the cloud or an edge server, making it available for real-time analytics and reporting.

B. Real-Time Monitoring and Dynamic Calculation

One of the key advantages of IoT-enabled energy units' calculation is the ability to monitor energy use dynamically and calculate units in real-time. Unlike traditional meters that measure cumulative energy use periodically, IoT-based SEMS continuously tracks energy data, offering a detailed breakdown of consumption at any given moment. Real-time monitoring allows for instantaneous calculations of energy units, giving users and energy providers an up-to-date view of consumption patterns. This dynamic calculation capability is especially useful for industries and businesses with complex, high-energy systems, as it helps to identify inefficiencies or excessive energy drains promptly, enabling quick corrective actions.

C. Energy Cost Calculation and Time-of-Use Pricing

With accurate energy units calculation, IoT-based SEMS can also calculate energy costs based on time-of-use [1] pricing models. Time-of-use pricing involves charging different rates for electricity based on the time of day, with higher rates during peak demand periods and lower rates during off-peak hours. IoT-based SEMS continuously calculates energy units and maps this data to real-time pricing, giving users a clear view of the costs associated with their energy consumption.

D. Integration with Renewable Energy Sources

Energy units' calculation in IoT-based SEMS is crucial for facilities utilizing renewable energy sources, as it helps manage both consumption and generation. In cases where buildings or industrial sites have solar panels or wind turbines, SEMS calculates the energy generated by these sources in addition to traditional consumption data. This dual calculation enables SEMS to balance the load dynamically, prioritizing renewable energy when available and supplementing with grid power as needed.



Fig: 3

11. Challenges in Energy Units Calculation within IoT-Based SEMS

While energy units' calculation within IoT-based SEMS brings numerous benefits, challenges remain. High-frequency data collection and real-time calculation require substantial data storage and processing power, which can increase infrastructure costs. Ensuring the accuracy of energy units' calculation also depends on the reliability of IoT sensors, which may be susceptible to issues like calibration drift or communication failures. Additionally, energy units' calculations must be secured against tampering, as unauthorized alterations could affect billing and demand response participation. Addressing these challenges is crucial for the consistent and reliable operation of IoT-based SEMS, particularly as these systems expand to include more devices and users.

12. CONCLUSION

In conclusion, the integration of IoT into Energy Management Systems represents a transformative step toward smarter, more efficient, and sustainable energy usage. By enabling real-time monitoring, automation, and advanced data analytics, IoT-powered systems optimize energy consumption, reduce costs, and minimize environmental impact across residential, commercial, and industrial domains. These systems also facilitate the integration of renewable energy sources, enhancing sustainability efforts while ensuring reliability and adaptability in energy management.

Despite challenges such as high initial investment, data security concerns, and interoperability issues, the long-term benefits—ranging from cost efficiency and operational optimization to reduced carbon emissions—make IoT-based energy management a vital innovation. As IoT technology continues to advance, it will play a critical role in addressing global energy challenges, promoting sustainable practices, and building a future that prioritizes energy efficiency and environmental stewardship.

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