



Paper Type: Original Article

Smart Grid Energy Management Using IoT and AI

Arpit Kumar Mantra^{1,*} , Bhumika Diwan²

¹ Department of Computer Science, KIIT University, Bhubaneswar, India; 22051929@kiit.ac.in.

² Manav Rachna University, Haryana, India; bhumikadiwankhatri@gmail.com.

Citation:

Received: 09 February 2026

Revised: 19 April 2026

Accepted: 12 Jun 2026

Kumar Mantra, A., & Diwan, B. (2026). Smart grid energy management using IoT and AI. *Smart Internet of Things*, 3(2), 101-108.

Abstract

The introduction of the Internet of Things (IoT) and Artificial Intelligence (AI) has ushered in a new era of smart grid energy management, fundamentally altering the distribution, use, and optimization of energy. This review article explores the state of smart grid technology today, emphasising how IoT devices help with real-time data collection and monitoring, which makes it possible to use AI algorithms to make better decisions. Using case studies that demonstrate their usefulness in real-world scenarios, we examine important IoT and AI applications such as Demand Response (DR), predictive maintenance, and energy efficiency optimisation. We also discuss important implementation issues for these technologies, like data privacy issues, cybersecurity flaws, and the requirement for robust communication systems. Finally, we suggest future research avenues that seek to improve smart grids' resilience and adaptability in order to satisfy changing energy consumption demands and tackle climate change's concerns. This thorough synthesis of recent developments creates the framework for future smart grid technological improvements, supporting the development of sustainable energy. By improving efficiency, dependability, and sustainability, the combination of IoT and AI technologies in smart grid energy management is changing the direction of energy systems in the future. In order to optimise energy distribution and consumption, this review article looks at the latest developments in smart grid systems, highlighting how IoT devices provide real-time data collection, monitoring, and analysis. With the use of pertinent case studies that demonstrate their efficacy in actual situations, we examine a range of IoT and AI applications, such as DR systems, predictive maintenance plans, and energy efficiency optimisation.

Keywords: Energy optimization, Real-time data collection, Monitoring, Decision-making, Demand response, Predictive maintenance.

1 | Introduction

By improving efficiency, dependability, and sustainability, the combination of Internet of Things (IoT) and Artificial Intelligence (AI) technologies in smart grid energy management is changing the direction of energy systems in the future. In order to optimise energy distribution and consumption, this review article looks at

 Corresponding Author: 22051929@kiit.ac.in

 <https://doi.org/10.48313/siot.v3i2.264>



Licensee System Analytics. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0>).

the latest developments in smart grid systems, highlighting how IoT devices provide real-time data collection, monitoring, and analysis. With the use of pertinent case studies that demonstrate their efficacy in actual situations, we examine a range of IoT and AI applications, such as DR systems, predictive maintenance plans, and energy efficiency optimisation. Real-time data exchange offers previously unheard-of insight into grid functioning, operational efficiency, and patterns of energy consumption. In order to optimise energy distribution, utilities can monitor grid conditions, identify outages, and apply DR methods by integrating IoT devices [1].

Predictive analytics, automated decision-making, and sophisticated modelling approaches are made possible by AI algorithms, which also make it possible to analyse the massive volumes of data produced by IoT devices. By anticipating demand variations, allocating resources optimally, and improving maintenance plans, these AI-driven insights enable energy suppliers to improve grid efficiency and dependability overall. The combination of IoT and AI technology creates a framework for energy management that is more flexible and adaptable, opening the door for creative solutions to today's energy problems.

The goal of this review paper is to present a thorough summary of the most recent developments in IoT and AI-powered smart grid energy management. We will examine the many uses of these technologies, such as energy efficiency optimisation techniques, DR systems, and predictive maintenance programs. We will also discuss the difficulties and impediments to implementation, including the need for strong communication infrastructures, cybersecurity threats, and data privacy issues.

Additionally, we will present real-world case studies that show how well IoT and AI technologies work in smart grid systems and how they have the potential to completely transform energy management techniques. In order to help the creation of a more resilient and sustainable energy future, this study aims to add to the continuing conversation on smart grid innovations by analysing the existing literature and suggesting future research possibilities [2].

1.1| Context and Background

The pressing demand for sustainable energy solutions in the face of growing consumption and environmental concerns is causing a paradigm change in the global energy sector. The intricacies of contemporary energy demands are becoming too great for traditional power systems, which are typified by centralised energy generation and minimal interactivity. Consequently, smart grids have become a paradigm-shifting framework that incorporates cutting-edge technologies to improve sustainability, dependability, and energy efficiency [3].

1.2| IoT's Function in Smart Grids

The development of smart grid systems is significantly influenced by the IoT. IoT allows for real-time data gathering and monitoring of grid performance, operational metrics, and patterns in energy usage by connecting a wide range of devices and sensors. It can quickly identify outages and put DR plans into action. Instantaneous data collection and analysis opens the door to better-informed decision-making by offering previously unheard-of insights into how energy systems operate [4].

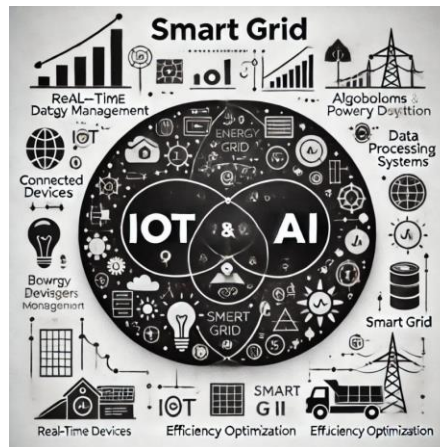


Fig. 1. Power grid modernization by integrating IoT and AI; a step towards a connected, stable, and efficient grid.

1.3 | How AI Affects Energy Management

By handling the massive amounts of data produced by IoT devices, AI further expands the possibilities of smart grids. Energy companies may anticipate changes in demand, optimise resource distribution, and enhance maintenance procedures by utilising AI algorithms through machine learning and predictive analytics. In addition to improving operating efficiency, this astute analysis makes it easier to take preventative action to deal with possible problems before they become more serious, which raises the grid's overall reliability.

1.4 | Review Objectives

The purpose of this review paper is to offer an extensive examination of how the combination of IoT and AI technology has improved smart grid energy management. We will investigate a number of uses for these technologies, including energy efficiency optimisation, predictive maintenance, and DR systems. The study will also discuss the difficulties in putting these technologies into practice, such as the need for robust communication infrastructures, cybersecurity threats, and data privacy issues.

1.5 | Significance of the Research

This study aims to emphasise the enormous potential of IoT and AI technologies in transforming energy management practices by synthesising existing literature and presenting real-world case studies that prove the efficacy of these applications in smart grids.

2 | Smart Grid Technologies

The development of smart grid technologies signifies the progression from traditional electrical grids to advanced systems that utilise digital communication, automation, and data analytics to optimise electricity generation, distribution, and consumption. This evolution aims to improve the efficiency, reliability, and sustainability of energy systems while meeting the increasing demands of modern society. This section offers an outline of the primary technologies that characterise smart grids, their functions, and their influence on energy management. Smart grid technologies are transforming the generation, transmission, and utilisation of electricity. By incorporating digital communication, advanced sensors, and analytical tools, smart grids enhance operational efficiency, reliability, and sustainability. This section explores the fundamental elements of smart grid technologies, their functions, and their impacts on energy management [5].

2.1| Definition and Components of Smart Grids

Smart grids consist of various elements, including Advanced Metering Infrastructure (AMI), communication networks, and Distributed Energy Resources (DERs), all working together to enable real-time monitoring and control of energy systems. The evolution of traditional electrical grids is represented by smart grids, which incorporate advanced communication, control, and information technologies to improve the efficiency, reliability, and sustainability of electricity distribution. Smart grids are characterised by their ability to enable two-way communication between utilities and consumers, allowing for real-time monitoring and management of energy flows. Key components of smart grids include smart meters that provide real-time energy consumption data to consumers and utilities, sensors and actuators spread throughout the grid to monitor system health and performance, and advanced communication networks that facilitate data exchange among various grid components. DER, such as solar panels and wind turbines, play a vital role by enabling localised energy generation and consumption. The inclusion of Energy Management Systems (EMS) and DR technologies further improves grid responsiveness by enabling utilities to effectively manage demand and encouraging consumers to adjust their energy usage based on supply conditions. Together, these components create a resilient, flexible energy ecosystem that can accommodate renewable energy sources, enhance grid stability, and give consumers greater control over their energy use.

2.2| IoT Devices in Smart Grids

Crucial for gathering data and gaining insights into energy usage patterns, IoT devices such as smart meters, sensors, and actuators play a significant role in improving operational efficiency and enabling proactive issue response for utilities. The way energy systems operate is being fundamentally transformed by the integration of the IoT in smart grids. Real-time data collection, monitoring, and management are enabled by IoT devices, which enhance the efficiency and reliability of energy distribution. This section delves into the different types of IoT devices used in smart grids, their functions, and their influence on energy management.



Fig. 2. IoT Devices in Smart Grids: Enabling real-time data, smarter energy management, and more reliable power distribution.

2.3| AI Technologies in Smart Grids

AI technologies, such as machine learning and data analytics, are utilized to process data collected from IoT devices, enabling predictive modeling and optimization of energy management strategies. The use of AI technologies in smart grids is transforming energy management, making operations more efficient, reliable, and adaptable. By analysing large volumes of data from IoT devices and other sources, AI boosts the capabilities of smart grids, enabling advanced analytics, decision-making, and automation. This section delves

into the different AI technologies employed in smart grids, their practical uses, and their influence on energy management.

3 | Applications of IoT and AI in Smart Grids

The smart grid has been transformed by the integration of IoT and AI technologies, allowing for real-time data analysis, improved decision-making, and efficient resource allocation in energy management. This section examines key applications of IoT and AI in smart grid systems, demonstrating how they can optimise energy distribution, enhance reliability, and promote sustainability. Integrating IoT and AI in smart grids is reshaping the energy sector by enabling advanced monitoring, control, and optimisation of energy systems. These technologies not only boost the operational efficiency of the grid but also enable consumers and utilities to make data-driven decisions. This section delves into the various uses of IoT and AI in smart grid applications, emphasising their importance and advantages [6].

3.1 | Demand Response Management

IoT and AI are employed in Demand Response (DR) programs to optimize energy consumption during peak demand periods, enhancing grid stability through real-time data provision and incentivizing consumers to reduce or shift their energy use. Grid operators encounter difficulties in maintaining balance as renewable energy sources like wind and solar become more common due to their unpredictable nature. The variability of these energy sources poses challenges for grid stability. DR offers a solution by adjusting energy consumption to match the fluctuating supply, thereby improving grid reliability and stability.

3.2 | Predictive Maintenance

AI algorithms analyze data from IoT sensors to predict equipment failures, thus reducing downtime and operational costs while enhancing the reliability of energy systems through proactive maintenance. The use of data analytics, IoT devices, and AI algorithms in predictive maintenance (PdM) allows for the anticipation of equipment failures before they happen as an advanced maintenance strategy. When applied to smart grids, predictive maintenance improves the reliability and efficiency of the electrical grid by reducing downtime, cutting operational costs, and prolonging the lifespan of critical assets. This section explores predictive maintenance, its significance, approaches, and the technologies used to implement it in smart grids.

3.3 | Energy Efficiency Optimization

IoT devices monitor energy usage patterns, with AI algorithms analyzing this data to identify opportunities for energy savings, promoting more efficient energy consumption across residential and commercial sectors. Optimising energy efficiency is crucial in modern smart grid systems, aiming to decrease energy usage while preserving or improving service quality. Smart grids can achieve optimal efficiency by utilising advanced technologies like the IoT and AI to dynamically monitor, analyse, and manage energy flows. This section delves into the importance of energy efficiency optimisation in smart grids, the methods used, the technologies employed, and the obstacles and future prospects in this field.

4 | Challenges in Implementation

The advancement of smart grid technology brings great promise for improving energy management and sustainability, but it also encounters several significant obstacles. Integrating new technologies with existing legacy systems presents a major challenge. Outdated infrastructure in many electrical grids makes it hard to implement advanced IoT and AI solutions without substantial upgrades and investment. Additionally, cybersecurity concerns pose a significant risk. As smart grids become more interconnected, they also become more vulnerable to cyberattacks, which can disrupt operations and compromise sensitive data. It is crucial to prioritise robust security measures to mitigate these risks. Furthermore, the collection of vast amounts of personal consumption data by smart meters and IoT devices raises data privacy issues. This data must be

handled responsibly to protect consumer privacy and comply with regulatory standards. The need for a resilient communication infrastructure also presents a challenge. Effective communication networks are essential for real-time data exchange and decision-making, yet many regions lack the necessary infrastructure to support these requirements. Finally, regulatory and policy frameworks need to evolve to facilitate the transition to smart grids. Policymakers must develop regulations that encourage innovation while ensuring equitable access to the benefits of smart grid technologies. Addressing these challenges is crucial for realising the full potential of smart grids and fostering a more sustainable energy future [7].

4.1| Cybersecurity Concerns

The increasing reliance on connected devices raises concerns about cybersecurity threats, making the protection of sensitive data and ensuring the integrity of energy systems a top priority. The incorporation of intelligent grid systems, which combine cutting-edge communication technologies, IoT devices, and AI algorithms, offers substantial advantages in terms of effectiveness, dependability, and environmental friendliness. Nevertheless, these developments also make the grid susceptible to numerous cybersecurity threats and difficulties. This segment examines the crucial cybersecurity issues linked to the implementation of intelligent grids, the possible repercussions of cyber threats, and the methods for bolstering cybersecurity in intelligent grids.

4.2| Data Privacy Issues

The collection and analysis of consumer data through IoT devices raise privacy concerns, emphasizing the need to ensure compliance with data protection regulations and maintain transparency for consumer trust. The use of smart grid technologies, making use of the IoT and AI, has transformed energy management through the ability to monitor and control energy consumption in real time. Nevertheless, this evolution presents substantial data privacy hurdles that need to be dealt with in order to safeguard consumer data and uphold public confidence. This section will explore the primary data privacy concerns related to the implementation of smart grids, the consequences of these challenges, and approaches to improving data privacy [8].

4.3| Communication Infrastructure Needs

The effectiveness of IoT and AI in smart grids hinges on robust communication networks, emphasizing the need for reliable connectivity and low-latency communication to facilitate real-time data processing. A strong and efficient communication infrastructure is crucial for the successful implementation of smart grid technologies, serving as the foundation for data exchange, real-time monitoring, and energy resource control. With the integration of advanced communication technologies in smart grids, it is important to cater to the unique communication requirements that guarantee the efficient operation, reliability, and security of these systems.

5| Future Research Directions

The evolution of smart grids presents several key research directions to improve their effectiveness and sustainability through the integration of IoT and AI. One area with great potential is the advancement of machine learning algorithms to enhance the prediction of energy consumption and renewable energy generation, especially in varying climate conditions. These developments involve exploring deep learning techniques to improve the accuracy of forecasting and grid operations optimization. Furthermore, there is a need for research focused on strengthening cybersecurity measures tailored for smart grids to address vulnerabilities associated with interconnected devices. Such research may involve developing AI-driven anomaly detection systems capable of autonomously responding to potential threats in real time. Another important direction is the exploration of decentralised EMS, utilising blockchain technology to enhance transparency, security, and efficiency in peer-to-peer energy trading among consumers. Additionally, studying the impact of consumer behaviour on energy usage and integrating behavioural analytics into smart grid

systems can lead to more effective DR strategies. Finally, research into regulatory frameworks and policy implications is crucial to facilitate the integration of these technologies while ensuring equitable access and addressing privacy concerns. By focusing on these areas, future research can significantly advance the capabilities of smart grids, leading to a more resilient, efficient, and sustainable energy landscape [9].

5.1 | Enhancing Cybersecurity Measures

Future research should concentrate on developing advanced cybersecurity protocols tailored specifically for smart grid systems to safeguard against evolving threats. In the progression of smart grids, the incorporation of innovative technologies like the IoT and AI underscores the growing significance of dependable cybersecurity measures. The interlinked structure of smart grids exposes them to diverse cyber risks, encompassing data breaches, malware attacks, and denial-of-service attacks. This segment delves into the fundamental elements of elevating cybersecurity measures in the execution of smart grids, the obstacles encountered, and tactics for constructing a robust security framework.

5.2 | Exploring Data Privacy Solutions

Research is needed to establish frameworks that balance data collection for analytics with consumer privacy rights, ensuring ethical practices in data handling. The collection of extensive data from smart meters and linked devices offers potential for improved energy management while also posing privacy challenges. This part delves into viable data privacy remedies for incorporation into smart grid systems, dealing with the distinct requirements for safeguarding data, adhering to regulations, and fostering consumer confidence.

5.3 | Advancing AI Algorithms

Continued innovation in AI algorithms can enhance predictive analytics and decision-making processes, leading to more efficient and adaptive energy management solutions. The way energy is managed, distributed, and consumed has been revolutionised by the incorporation of AI into smart grid systems. By analysing large volumes of data from IoT devices, AI algorithms empower utilities to make informed choices, streamline operations, and improve overall system efficiency. This section delves into the progress made in AI algorithms designed specifically for smart grid applications, their advantages, and the obstacles linked to their deployment.

6 | Conclusion

The integration of IoT and AI technologies in smart grid energy management holds considerable potential to enhance efficiency, reliability, and sustainability. By addressing the associated challenges and exploring future research directions, the energy sector can progress towards a more resilient and adaptive framework capable of meeting evolving consumer and environmental demands. The incorporation of IoT and AI technologies into smart grid energy management is a significant advancement towards efficient, reliable, and sustainable energy systems. Smart grids with IoT and AI capabilities provide transformative solutions to address rising energy demands and the increasing need for environmental sustainability.

This paper has emphasised the crucial role of IoT devices in enabling real-time data collection and monitoring, which is vital for understanding and optimising energy consumption patterns. The utilisation of AI algorithms further improves decision-making processes, allowing for predictive analytics and automated responses that enhance operational efficiencies and reduce costs. Case studies have demonstrated the practical effectiveness of these technologies in applications such as DR management, predictive maintenance, and energy efficiency optimisation. However, the integration of IoT and AI in smart grids comes with its challenges. Issues related to cybersecurity, data privacy, and the necessity for robust communication infrastructures must be tackled to fully realise the potential of these technologies. It is crucial for stakeholders, including policymakers, utility companies, and technology providers, to collaborate on developing comprehensive strategies that mitigate these risks while promoting innovation [10].

Looking forward, future research should concentrate on enhancing cybersecurity measures tailored for smart grids, creating ethical frameworks for data privacy, and advancing AI algorithms to improve predictive capabilities and operational resilience. By prioritising these areas, we can pave the way for smarter, more adaptive EMS capable of meeting the evolving demands of consumers and the environment. In conclusion, the convergence of IoT and AI technologies in smart grid energy management not only offers a pathway to optimising energy distribution and consumption but also plays a crucial role in advancing a sustainable energy future. As we continue to explore and innovate in this field, we move closer to creating resilient energy systems that can adapt to the challenges posed by climate change and ensure a stable and sustainable energy supply for generations to come [11].

Acknowledgments

The authors sincerely appreciate the valuable contributions and support provided throughout this research.

Funding

No specific funding was received for this research.

Data Availability

The data used in this study are available from the corresponding author upon reasonable request.

References

- [1] Mahmood, M., Chowdhury, P., Yeassin, R., Hasan, M., Ahmad, T., & Chowdhury, N.-U.-R. (2024). Impacts of digitalization on smart grids, renewable energy, and demand response: An updated review of current applications. *Energy Conversion and Management: X*, 24, 100790. <https://doi.org/10.1016/j.ecmx.2024.100790>
- [2] Reham, A., Al-Soeidat, M., Ahmad, S., Omar, A., & Dah-Chuan, L. D. (2026). Artificial intelligence in smart grids and power-electronic-interfaced microgrids: A systematic literature review of energy management, optimisation, and cybersecurity. *Energies*, 19(15), 3643. 10.3390/en19153643
- [3] Powell, J., McCafferty-Leroux, A., Hilal, W., & Gadsden, S. A. (2024). Smart grids: A comprehensive survey of challenges, industry applications, and future trends. *Energy Reports*, 11, 5760–5785. <https://doi.org/10.1016/j.egyr.2024.05.051>
- [4] Qays, M. O., Ahmad, I., Abu-Siada, A., Hossain, M. L., & Yasmin, F. (2023). Key communication technologies, applications, protocols and future guides for IoT-assisted smart grid systems: A review. *Energy Reports*, 9, 2440–2452. <https://doi.org/10.1016/j.egyr.2023.01.085>
- [5] Dileep, G. (2020). A survey on smart grid technologies and applications. *Renewable Energy*, 146, 2589–2625. <https://doi.org/10.1016/j.renene.2019.08.092>
- [6] Mansour, D. E. A., Numair, M., Zalhaf, A. S., Ramadan, R., Darwish, M. M., Huang, Q., ... & Abdel-Rahim, O. (2023). Applications of IoT and digital twin in electrical power systems: A comprehensive survey. *IET Generation, Transmission & Distribution*, 17(20), 4457–4479. <https://doi.org/10.1049/gtd2.12940>
- [7] Kabeyi, M. J. B., & Olanrewaju, O. A. (2023). Smart grid technologies and application in the sustainable energy transition: A review. *International Journal of Sustainable Energy*, 42(1), 685–758. <https://doi.org/10.1080/14786451.2023.2222298>
- [8] Asghar, M. R., Dán, G., Miorandi, D., & Chlamtac, I. (2017). Smart meter data privacy: A survey. *IEEE Communications Surveys and Tutorials*, 19(4), 2820–2835. <https://doi.org/10.1109/COMST.2017.2720195>
- [9] Mololoth, V. K., Saguna, S., & Åhlund, C. (2023). Blockchain and machine learning for future smart grids: A review. *Energies*, 16(1), 528. <https://www.mdpi.com/1996-1073/16/1/528#>
- [10] Banad, Y. M., Sharif, S. S., & Rezaei, Z. (2025). Artificial intelligence and machine learning for smart grids: From foundational paradigms to emerging technologies with digital twin and large language model-driven intelligence. *Energy Conversion and Management: X*, 28, 101329. <https://doi.org/10.1016/j.ecmx.2025.101329>
- [11] Safari, A., Daneshvar, M., & Anvari-Moghaddam, A. (2024). Energy intelligence: A systematic review of artificial intelligence for energy management. *Applied Sciences*, 14(23), 11112. <https://doi.org/10.3390/app142311112>