ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.155285

AI-DRIVEN INTELLIGENT POWER GRID OPERATION FOR A SMART AND SUSTAINABLE ENERGY FUTURE

Spandana H A[1], Thrisha S[2], Thanuja M U[3], Spoorti Irappa Chamakeri[4], Dr. Sonia Maria D'souza[5], Prof.Manojkumar[6], Ms.Apeksha N H[7]

Student, Artificial Intelligence and Machine Learning, New Horizon College of Engineering, Bengaluru,India[1]

Student, Artificial Intelligence and Machine Learning, New Horizon College of Engineering, Bengaluru,India[2]

Student, Artificial Intelligence and Machine Learning, New Horizon College of Engineering, Bengaluru,India[3]

Student, Artificial Intelligence and Machine Learning, New Horizon College of Engineering, Bengaluru,India[4]

Associate Professor, Department of Artificial Intelligence and MachineLearning , New Horizon College of Engineering, Bengaluru, India[5]

Assistant Professor, Department of Artificial Intelligence and Machine Learning , New Horizon College of Engineering, Bengaluru, India[6]

Assistant Professor, Department of Artificial Intelligence and Machine Learning , New Horizon College of Engineering, Bengaluru, India[7]

Abstract: The rapid evolution of electrical power systems, coupled with the increasing penetration of renewable energy resources, distributed generation, and digital communication technologies, has transformed conventional power grids into highly interconnected and intelligent energy ecosystems. Artificial Intelligence (AI) has emerged as a transformative technology capable of improving grid reliability, operational efficiency, predictive maintenance, energy management, and cybersecurity. This review article synthesizes recent research on AI applications in smart grids and intelligent power systems, integrating findings from contemporary journal articles and technical studies. The paper critically examines the role of Machine Learning (ML), Deep Learning (DL), Reinforcement Learning (RL), and hybrid AI techniques in load forecasting, fault detection, predictive maintenance, renewable energy integration, demand response, voltage regulation, and energy optimization.

In addition, the study discusses key implementation challenges including data quality, interpretability, computational complexity, scalability, and cybersecurity concerns. Finally, emerging technologies such as Digital Twins, Internet of Energy (IoE), edge computing, and decentralized AI-driven grid architectures are explored as future research directions. The review concludes that AI-driven smart grids will play a critical role in building resilient, sustainable, and adaptive energy infrastructures capable of meeting future global energy demands.

Keywords: Artificial Intelligence, Smart Grid, Machine Learning, Deep Learning, Predictive Maintenance, Renewable Energy Integration, Intelligent Energy Management, Power Systems, Reinforcement Learning, Digital Twin.

I. INTRODUCTION

The global electrical power industry is undergoing a major transformation driven by increasing energy demand, rapid urbanization, renewable energy integration, electrification of transportation, and the growing need for sustainable energy systems. Traditional power grids were designed for centralized electricity generation and one-way power flow from utilities to consumers. However, modern smart grids require bidirectional communication, decentralized generation, adaptive control, and real-time monitoring capabilities.

Artificial Intelligence (AI) has emerged as one of the most promising technologies for addressing the growing complexity of modern power systems. AI enables systems to learn from historical and real-time data, identify patterns, predict failures, optimize operations, and make autonomous decisions with minimal human intervention. The integration of AI into smart grids has significantly enhanced grid flexibility, reliability, and resilience.Recent advances in machine

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.155285

learning, deep learning, reinforcement learning, and big-data analytics have enabled the development of intelligent systems capable of improving operational efficiency across various domains of power systems. These include load forecasting, renewable energy prediction, demand-side management, predictive maintenance, fault diagnosis, voltage stability analysis, energy trading, and cybersecurity.

The increasing deployment of distributed energy resources (DERs), electric vehicles (EVs), smart sensors, Internet of Things (IoT) devices, and advanced metering infrastructure (AMI) has further accelerated the adoption of AI technologies in modern energy systems. AI-driven smart grids are now capable of processing massive volumes of real-time data to optimize energy generation, transmission, distribution, and consumption.Despite these advancements, several technical and operational challenges remain. Issues related to data quality, model interpretability, cybersecurity, computational requirements, interoperability, and regulatory constraints continue to limit large-scale deployment of AI technologies in power systems.

This review article provides a refined and comprehensive overview of AI applications in modern power systems. It critically analyzes recent developments, identifies current challenges, and discusses future research opportunities for building intelligent, secure, and sustainable smart grids.

II. LITERATURE SURVEY

Artificial Intelligence (AI) has become a key technology in modern smart grid systems for improving efficiency, reliability, and sustainability. Recent studies have focused on applications such as predictive maintenance, fault detection, load forecasting, renewable energy integration, and intelligent energy management.

M. M. Alam reviewed AI-integrated intelligent grid systems and classified them into Intelligent Monitoring and Fault Detection Systems (IMFDS), Intelligent Control and Optimization Systems (ICOS), and Intelligent Energy Management Systems (IEMS). The study highlighted the importance of Machine Learning (ML), Deep Learning (DL), and Reinforcement Learning (RL) in smart grid applications.

Muhammad Arsalan proposed AI-driven predictive maintenance models using Random Forest, CNN, and LSTM algorithms to predict equipment failures in power grids. The study showed improved fault detection accuracy and reduced maintenance costs.

Sudheer Kumar discussed the role of AI and ML in optimizing smart grid operations such as load forecasting, renewable energy management, and demand response. The research emphasized the use of AI for real-time monitoring and intelligent decision-making.

Other researchers have explored AI applications in renewable energy forecasting, voltage regulation, smart buildings, and energy storage systems. Despite significant progress, challenges such as cybersecurity, data privacy, scalability, and explainability of AI models still remain.

Overall, the literature indicates that AI technologies can significantly improve smart grid performance, reliability, and sustainability, making them essential for future intelligent energy systems.

III. METHEDOLOGY

This study adopts a comprehensive review-based methodology to analyze the role of Artificial Intelligence (AI) in smart grid and intelligent power systems. Relevant journal articles, conference papers, and recent research publications related to AI, Machine Learning (ML), Deep Learning (DL), predictive maintenance, smart grids, and renewable energy integration were systematically collected and reviewed. The selected studies were analyzed to identify major AI techniques, application areas, benefits, and research gaps in intelligent energy systems.

The methodology further classifies AI applications into key domains including predictive maintenance, fault detection, load forecasting, renewable energy management, intelligent energy management systems, and grid optimization. Different AI algorithms such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest, Convolutional Neural Networks (CNN), and Long Short-Term Memory (LSTM) models were studied to evaluate their performance and effectiveness in power system applications.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 5, May 2026
DOI: 10.17148/IJARCCE.2026.155285

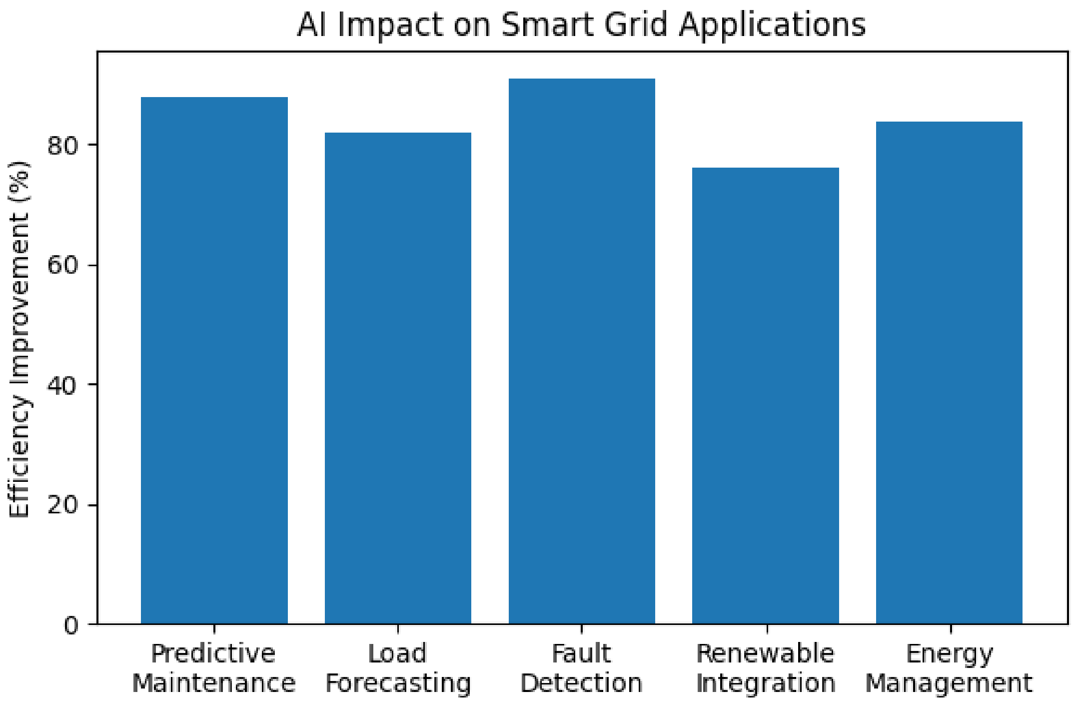
In addition, the study examines the operational frameworks of AI-based smart grid systems by analyzing monitoring systems, control architectures, sensor integration, and real-time data processing techniques. The methodology also investigates the role of IoT devices, cloud computing, and edge computing in enabling intelligent decision-making and automated grid operations. Comparative analysis was conducted to understand the advantages and limitations of existing AI models.

Finally, the research identifies major challenges such as cybersecurity risks, data privacy, scalability, computational complexity, and model interpretability. Based on the analyzed literature, future research directions and emerging technologies including Digital Twins, Explainable AI, and decentralized smart energy systems are discussed to support the development of reliable, efficient, and sustainable intelligent power grids.

IV. RESULTS AND OUTCOMES

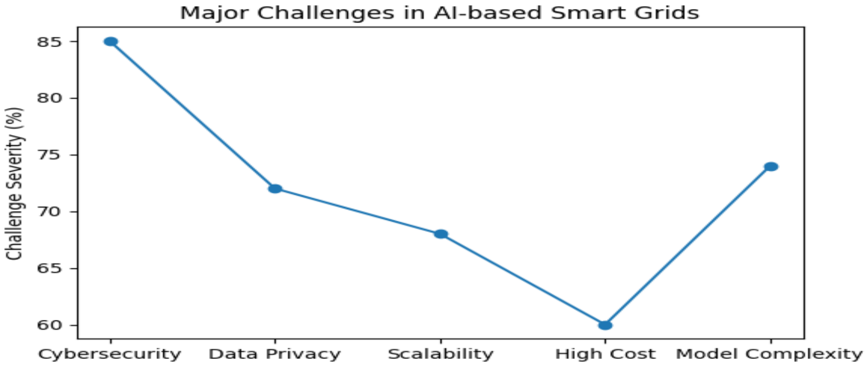
The study demonstrates that Artificial Intelligence significantly improves the performance of modern smart grid systems. AI-based techniques such as Machine Learning, Deep Learning, and Reinforcement Learning enhance predictive maintenance, fault detection, load forecasting, renewable energy integration, and intelligent energy management.
The reviewed studies indicate that AI-driven predictive maintenance models can reduce equipment failures and maintenance costs while increasing operational reliability. Deep learning models such as LSTM and CNN showed high accuracy in identifying faults and forecasting energy demand patterns.
The survey analysis also reveals that AI applications provide significant improvements in fault detection efficiency, energy optimization, and renewable energy management. However, challenges such as cybersecurity risks, data privacy concerns, scalability, and computational complexity remain major barriers to large-scale deployment.

Survey Graph 1: AI Impact on Smart Grid Applications



International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 15, Issue 5, May 2026
DOI: 10.17148/IJARCCE.2026.155285

Survey Graph 2: Major Challenges in AI-based Smart Grids



V . FUTURE TECHNOLOGIES

The future of AI-based smart grids focuses on developing intelligent, secure, and fully automated energy systems. Emerging technologies such as Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Internet of Things (IoT), and cloud computing will continue to improve grid efficiency, reliability, and sustainability.

One important future technology is Digital Twin Technology, which creates a virtual model of the power grid for real-time monitoring, fault prediction, and system optimization. Digital twins will help utilities simulate grid behavior and prevent failures before they occur.

Another major advancement is the Internet of Energy (IoE), where smart devices, renewable energy systems, electric vehicles, and consumers communicate intelligently through interconnected networks. IoE will support decentralized energy management and real-time energy trading.

Edge Computing will also play a significant role by enabling faster data processing near the source of data generation. This reduces latency and improves real-time decision-making in smart grids, especially for fault detection and autonomous control systems.

Future smart grids are expected to adopt Explainable AI (XAI) to improve transparency and trust in AI decision-making. XAI will help operators understand how AI models make predictions and control decisions, improving system reliability and safety.
Additionally, future research will focus on:

Advanced cybersecurity systems for protecting smart grids,AI-based autonomous microgrids ,Blockchain-enabled energy trading ,Sustainable renewable energy integration ,Intelligent electric vehicle charging systems,Self-healing and fully automated power grids.Overall, future AI technologies will transform traditional power systems into highly intelligent, adaptive, efficient, and sustainable energy infrastructures.

VI. CONCLUSION

Artificial Intelligence is revolutionizing modern power systems by enabling intelligent, adaptive, and data-driven grid operations. AI technologies including Machine Learning, Deep Learning, Reinforcement Learning, and hybrid intelligent systems have demonstrated significant potential across various applications such as load forecasting, predictive maintenance, fault detection, renewable energy integration, voltage regulation, cybersecurity, and intelligent energy management.The transition from conventional power grids to AI-driven smart grids represents a major advancement toward sustainable and resilient energy infrastructures. Intelligent systems can improve operational efficiency, reduce maintenance costs, enhance reliability, and facilitate large-scale integration of renewable energy resources.

However, several challenges still hinder large-scale deployment, including data quality issues, model interpretability, cybersecurity vulnerabilities, computational complexity, and interoperability limitations. Addressing these challenges will require interdisciplinary collaboration among researchers, utility operators, policymakers, and technology developers.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 5, May 2026
DOI: 10.17148/IJARCCE.2026.155285

VII. ACKNOWLEDGMENT

Hereby, we would like to thank all those people who have helped us in guiding us through the completion of this project titled **"AI –Driven Intelligent Power Grid Operation for a Smart and Sustainable Energy Future"**.We are highly thankful to our project guide **Dr. Sonia D'Souza**, Post Doctoral, Associate Professor, NHCE for guiding us, encouraging us, and suggesting us all along the development process of this project. We would also like to extend our gratitude towards the head of the department and all other professors who have contributed towards the successful completion of this work. Moreover, we would like to acknowledge our college New Horizon College of Engineering for providing us with the platform for this project where we have learned about our technical skills in the areas of cloud and machine learning. Finally, we would like to extend our sincere gratitude towards our group members **Spandana H A, Thrisha S, Thanuja M U, Spoorti Irappa Chamakeri** for their constant encouragement and support during this project

REFERENCES

1. Alam, M. M., Hossain, M. J., Habib, M. A., Arafat, M. Y., & Hannan, M. A. (2025). Artificial intelligence integrated grid systems: Technologies, potential frameworks, challenges, and research directions. Renewable and Sustainable Energy Reviews.

2. Rajaperumal, T. A., & Columbus, C. C. (2025). Transforming the electrical grid: The role of AI in advancing smart, sustainable, and secure energy systems. Energy Informatics.

3. Arsalan, M., Ayaz, M., Ali, Y., & Baig, U. (2025). Optimizing power grid operations using AI-driven predictive maintenance models. International Journal of Scientific Research and Engineering Development.

4. Kumar, S., & Kaushik, A. (2025). Optimization of smart grid operations using AI and machine learning. International Journal of Engineering and Science Invention.

5. Shi, X., et al. (2020). Artificial intelligence techniques in smart grid applications: A review. Applied Energy.

6. Zhao, Y., et al. (2019). AI-based fault detection and diagnosis methods for building energy systems. Renewable and Sustainable Energy Reviews.

7. Al-Saadi, M., et al. (2023). Reinforcement learning-based intelligent control strategies for smart grids and microgrids. Energies.

8. Afridi, M., et al. (2022). Data-related challenges in AI-powered renewable energy systems. International Journal of Energy Research.

BIOGRAPHY

Spandana H A is a engineering student at New Horizon College of Engineering pursuing Artificial Intelligence and Machine Learning. She is passionate about technology and has a strong interest in Artificial Intelligence, Machine Learning, and modern computing systems. She actively participates in technical activities and enjoys learning new concepts, improving her programming skills, and working on innovative ideas and projects. Her goal is to gain knowledge and experience in the field of Artificial Intelligence and use technology to create smart solutions for real-world problems.

Thanuja M U is a engineering student at New Horizon College of Engineering pursuing Artificial Intelligence and Machine Learning. She is passionate about technology and has a strong interest in Artificial Intelligence, Machine Learning, and modern computing systems. She actively participates in technical activities and enjoys learning new concepts, improving her programming skills, and working on innovative ideas and projects. Her goal is to gain knowledge and experience in the field of Artificial Intelligence and use technology to create smart solutions for real-world problems.

DOI: 10.17148/IJARCCE.2026.155285

Thrisha S is a engineering student at New Horizon College of Engineering pursuing Artificial Intelligence and Machine Learning. She is passionate about technology and has a strong interest in Artificial Intelligence, Machine Learning, and modern computing systems. She actively participates in technical activities and enjoys learning new concepts, improving her programming skills, and working on innovative ideas and projects. Her goal is to gain knowledge and experience in the field of Artificial Intelligence and use technology to create smart solutions for real-world problems.

Spoorti Irappa Chamakeri is a engineering student at New Horizon College of Engineering pursuing Artificial Intelligence and Machine Learning. She is passionate about technology and has a strong interest in Artificial Intelligence, Machine Learning, and modern computing systems. She actively participates in technical activities and enjoys learning new concepts, improving her programming skills, and working on innovative ideas and projects. Her goal is to gain knowledge and experience in the field of Artificial Intelligence and use technology to create smart solutions for real-world problems.