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# Editorial: An overview of Applied Artificial Intelligence in Power Grids

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**Abstract.** Power grids are networks of lines and equipment used for electrical power generation, transmission, distribution, and consumption. Power grids are undergoing a process of digital transformation based on emerging information and communication technologies, with the aim of optimising the operation of power systems, increasing efficiency, reliability, sustainability, security, and quality of service, while reducing CO2 emissions. In this process of digital transformation, Artificial Intelligence (AI) has become a strategic element within power grids. This paper provides an overview of AI applications in power grids and how they can improve the efficiency, reliability, and availability of their processes. It analyses the main challenges and prospects for the future application of AI in power grids. AI applications help process large volumes of data and generate insights, with a focus on two primary functions: supporting operations and aiding strategic decision-making. These factors highlight the significant potential for AI application in power grids and solidify AI as a strategic key to the development of smart grids.
**Keywords: artificial intelligence, machine learning, applied intelligence, power grids**.

Article Info

## 1 Introduction

The growth that Artificial Intelligence applications have had in our daily lives and in society in general has been significant. Almost everywhere there is some smart device that makes life easier, frees us from repetitive activities, extends our capabilities and provides information for decision-making. In different fields, AI applications have emerged with systems capable of assisting in planning, in operational and strategic decision-making. The challenges that AI addresses are related to the management of data to generate useful information (knowledge) that allows supporting the solution of complex problems associated with reasoning, perception, planning, and the ability to make appropriate and timely operational decisions.

In the power grids domain, the challenges that drive the need to use AI can be summarized as follows: the increase in the complexity of the electrical grid by incorporating new types of intermittent renewable electricity generation and distributed generation; the optimal operation of networks immersed in an environment of environmental restrictions; the monitoring and control of the network through the digitalization of its processes, which brings with it an increase in the volume and complexity of structured and unstructured information; and the need to process information to generate knowledge for operational and strategic decision-making. IA models can analyze large amounts of data collected from sensors, smart meters, and systems of every process of power system, such as power generation, power transmission, power transformation, power distribution and power consumption, to extract valuable insights and optimize system operation. By harnessing the power of data analytics and predictive modeling, machine learning algorithms can optimize generation, predict and prevent outages, integrate renewable energy sources, and improve overall system performance. The Generative AI offers innovations in the network optimization, predictive maintenance and advanced energy management. The objective is to have robust and reliable systems capable of taking action in the face of sudden changes, with the ability to predict and optimize the future to operate the network assets to their full potential, in a context of great uncertainty.

In the future, the complexity of the electrical grid will grow to the point that it can no longer be modeled by conventional physical models, so it is essential to have reliable computing tools based on AI algorithms. The goal of this paper is to show an overview on IA applications of the power grids and how they can improve efficiency, reliability, and availability of their processes. The remainder of this paper is organized as follows. Section 2 presents AI applications to improve efficiency. Section

3 presents AI applications to improve reliability. Section 4 presents AI applications to improve availability. Section 5 presents the challenges and prospects of AI application in power grids. Finally, the conclusions are drawn in Section 6.

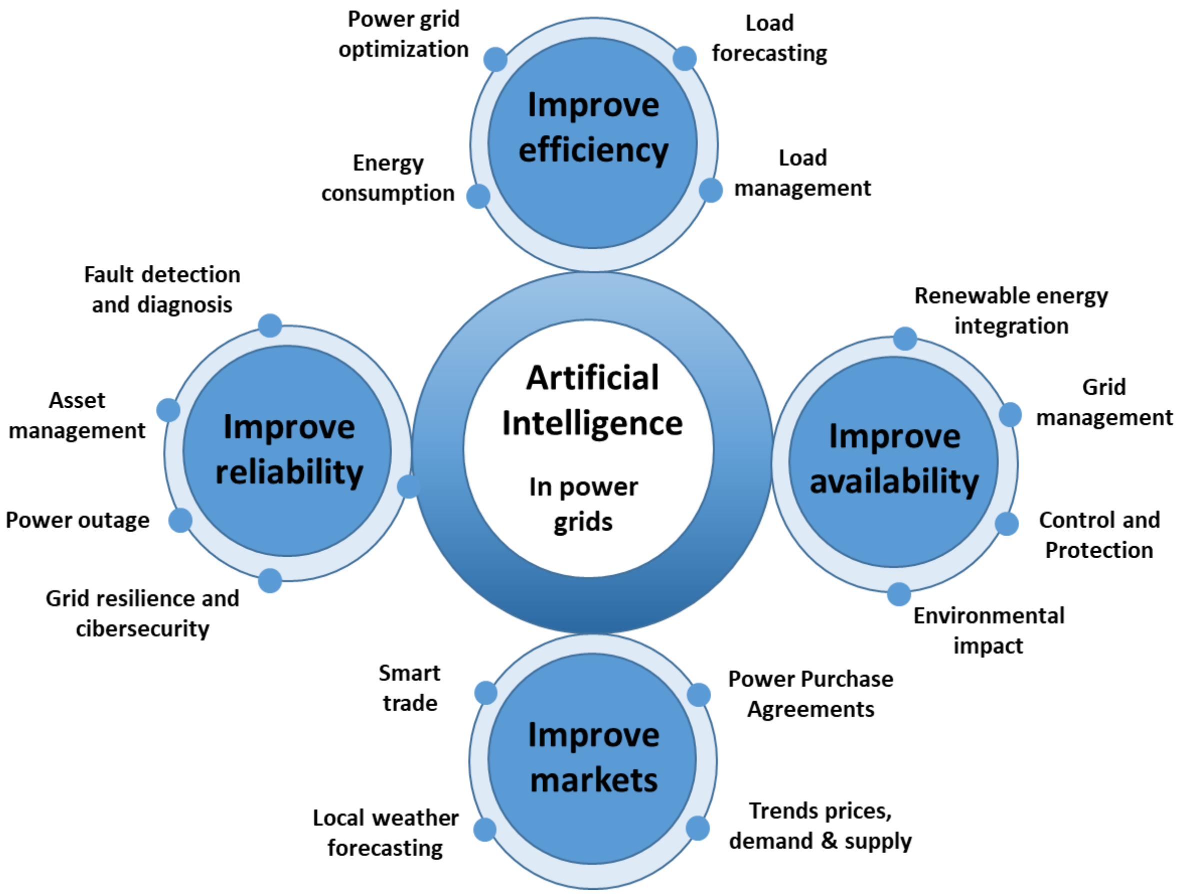


**Fig. 1.** Some AI applications in power grids.

## 2 AI applications to improve efficiency

Improving efficiency is a key goal in power grid as it directly impacts operating costs and resource utilization. AI models play a key role in optimizing power generation by analyzing historical data, weather patterns, and market conditions for strategic decision-making. By doing so, utilities can optimize their generation resources, adjust generation schedules, and manage load balancing efficiently. These data-driven insights enable electrical industry to reduce energy waste, minimize operating costs, and improve overall system efficiency.

### 2.1. Power grid Optimization

Power grid optimization is the process of optimizing the design, operation, and control of power grid, which are electrical networks that use advanced technologies and communications to enable bidirectional flows of electricity and information between all components of the grid. Smart grid optimization aims to improve the performance, resilience, and sustainability of the electrical system by helping to integrate distributed generation, storage, and demand resources, improve situational awareness and fault recovery, and enable dynamic pricing and market participation. AI models can assist power grid optimization by using artificial neural networks, evolutionary algorithms, and reinforcement learning that can optimize power flow, voltage control, state estimation, and grid reconfiguration (Akkara & Selvakumar, 2023).

### 2.2. Load management

Load management refers to the process of balancing the supply and demand of electrical energy by controlling and optimizing energy consumption. This is crucial for maintaining grid stability, especially as renewable energy sources are integrated into the grid, leading to fluctuations in power generation and consumption patterns. Effective load management strategies can mitigate peak demand, enhance energy efficiency, and support energy storage requirements. AI models enable advanced load management strategies that improve efficiency in power systems. (Akhtar, Sujod, & Rizvi, 2022).

### 2.3. Energy consumption

The clustering and identification ability of machine learning in AI can be utilized to analyze the power consumption behavior of users, detect abnormal power consumption and non-invasive load monitoring. For example, based on the data of power, voltage and current measured by smart meters, AI clustering and data mining can be used to identify the characteristics of electricity consumption behavior of different user groups, realize scientific segmentation of customers, and then provide personalized marketing and services. AI models can analyze energy consumption data collected by smart meters, sensors, and other devices to identify energy saving opportunities (Eddaoudi et al., 2024).

### 2.4. Load forecasting

Load forecasting is essential for planning and operating power systems, helping to balance supply and demand, optimize generation scheduling, reduce costs, and avoid blackouts. Load forecasting is the process of predicting future electricity demand based on historical data, weather conditions, calendar events, and other factors. Machine learning can improve the accuracy and flexibility of load forecasting by using advanced algorithms and models that can capture complex patterns and relationships in data, adapt to changing conditions, and incorporate new information (Jain and Gupta, 2024).

## 3 AI applications to improve reliability

Reliability is one of critical aspect of power grid. Power outages can cause substantial economic losses and inconvenience to consumers. IA models can analyze historical power outage data, weather patterns, and asset performance metrics to predict potential failures and identify maintenance requirements. By providing early warning systems, IA models can enable utilities to proactively address problems, prioritize maintenance activities, and prevent power outages. This proactive approach improves system reliability, reduces downtime, and enhances customer satisfaction.

### 3.1. Fault detection and diagnosis

Fault detection and diagnosis is the process of identifying and locating faults or anomalies in power systems, such as short circuits, line faults, or transformer breakdowns. Fault detection and diagnosis are important for maintaining power system reliability and security by helping to prevent or mitigate the impacts of faults, reduce downtime, and facilitate repairs. AI models can analyze real-time sensor data, historical fault records, and system performance metrics to improve fault detection and diagnosis by using data-driven methods and techniques that can detect and classify faults more quickly and accurately, learn from historical data and online measurements, and provide actionable insights and recommendations. detect and diagnose faults in power assets and systems (Santamaria-Bonfil et. al., 2024).

### 3.2. Asset management

Asset management is seen as one of the most crucial functions in developing and operating today's transmission and distribution systems. Power grids have been pushed to find the best ways to manage installed capacity while minimizing the cost of current components throughout their useful lives by a tendency to increase power system reliability. AI models are crucial to optimizing asset management in electrical systems. Predictive maintenance is a proactive approach to maintenance that aims to prevent equipment failures and optimize maintenance schedules (Rajora et. al, 2024).

### 3.3. Power outage prediction and management

Outage management is a critical component of maintaining customer satisfaction, as customer complaints and dissatisfaction can intensify when power is not restored promptly or when communication is lacking about the duration of an outage. AI models can analyze historical power outage data, weather patterns, and system performance data to predict and manage power outages (Ghasemkhani, et al., 2024).

3.4. Grid resilience and security

The power grid is a complex system with real-time perception, information service, and dynamic control. The deep interaction of information flow will make the power system face more potential threats. The attack on the power grid has the characteristics of strong concealment and long incubation period. Although the primary equipment is not directly damaged, the secondary system may be destroyed to attack the physical power grid. Deep learning can automatically identify the characteristics of network attacks, detect malware and intrusions, and provide network security protection for power systems. The probability of the power system being attacked is much lower than that of normal operation, so the abnormal sample data of the power grid being attacked is much smaller than that of normal sample data. The training process of deep learning does not require sample labels, which can mitigate the impact of insufficient sample size. AI models can improve the resilience and security of power systems by detecting and mitigating cybersecurity threats and physical attacks (Arroyo, 2023).

## 4 AI applications to improve availability

Availability is a pressing concern in the energy sector as the transition to clean, renewable energy sources gains momentum. IA applications play an important role in enabling the integration and management of renewable energy sources into the grid. By analyzing weather patterns, historical data, and other relevant factors, IA models can accurately predict renewable energy generation. This information enables utilities to optimize the integration of solar, wind, and other clean energy sources, reduce reliance on fossil fuels, and minimize greenhouse gas emissions. Additionally, IA models can optimize energy storage systems, such as batteries, by predicting energy demand and optimizing charge and discharge cycles, thereby improving overall system availability.

4.1. Renewable energy integration

Renewable energy integration is the process of incorporating renewable energy sources, such as wind, solar, hydroelectric, or biomass, into power systems. Renewable energy integration is beneficial for reducing greenhouse gas emissions, diversifying energy sources, and increasing energy independence. However, renewable energy integration also poses challenges to the stability, operation, and control of power systems, as renewable energy sources are intermittent, variable, and uncertain. IA models can facilitate renewable energy integration by using data analysis and optimization tools that can forecast renewable energy production, optimize renewable energy dispatch and storage, and coordinate renewable energy resources with conventional ones. AI models play a crucial role in optimizing the integration of renewable energy sources, such as solar and wind, into the power grid. The accurate prediction of renewable energy generation is of great significance to the stable, efficient and economical operation of the power system (Bennagi et al., 2024).

4.2. Grid management and demand response

Demand response management is the process of managing and adjusting electricity demand in response to supply conditions, market prices, or grid events. Demand response management is useful for improving the efficiency, reliability, and economics of the electric system by helping to reduce demand peaks, avoid congestion, improve flexibility, and reduce costs. IA models can model and predict customer behavior, preferences, and responsiveness, design and implement effective demand response programs and incentives, and evaluate and monitor demand response performance and impacts AI models enable smart grid management and demand response programs that promote sustainability (Khan et al., 2023).

4.3. Control and protection

Equipment based on power electronics technology can be regarded as flexible power equipment. There is flexible power equipment in alternating current transmission, direct current transmission, renewable energy generation, power storage, power distribution system, micro grid and other fields. Fault diagnosis and protection of flexible equipment in power system is the defense line to ensure the safety of equipment, which plays an important role in quickly isolating faults, avoiding equipment damage and fault expansion. The fault characteristics of flexible equipment in power system are affected by its own variable structure, strong coupling, uncertain control variables and other factors, so it is difficult to carry out fault diagnosis (Alhamrouni, et al., 2024).

### 4.4. Environmental impact assessment

Artificial intelligence (AI) has emerged as a powerful tool with the potential to significantly contribute to mitigating climate change and achieving the ambitious goal of net-zero carbon emissions AI models can help assess, forecast, and mitigate the environmental impact of power systems (Olawade et al., 2024).

## 5 Challenges of AI application in power grids

Four main challenges stand out that the power grids industry faces for the application of AI.

### 5.1. Data availability

The main challenge is the use, availability and reliability of the data obtained from the processes of the power grids. The unordered growth of information technologies in power grids, mainly in the development of operational information systems, has generated a lack of data governance, so much of the information lacks clear and precise semantics; additionally, the data is often not captured and operational databases have instances with missing values or with unreliable values. The power grids require robust technology platforms with data governance to have available, reliable and timely data and information to develop robust and reliable AI applications.

### 5.2. Technology platforms

Another important challenge is the robustness and maturity of the technology platforms that collect operational data. This includes devices and sensors that collect data, the communications infrastructure so that they can be managed by operational information systems, and the technological capacity for storing and processing large volumes of data. Technology platforms with a Big Data and data lake structure are required, with the ability to implement AI algorithms and real-time processing capacity.

### 5.3. Intelligent system

The challenge is to build robust and reliable real-time AI applications, which must consider the joint participation of process specialists, AI specialists and IT specialists. The construction of intelligent systems should not be based solely on data, it must incorporate the knowledge of experts in the process where the application is required, this will help to build an intelligent model that is useful from an operational point of view. The participation of IT specialists is important to make the AI application work in the technological infrastructure of the power grids.

### 5.4 Information security

A challenge associated with the digital data management of data and information in the power grids is the increase in the attack surface of intruders who can steal information and operationally manipulate the assets of the power grids, which is why it is important to have cybersecurity mechanisms that allow the confidentiality, integrity and availability of information, to guarantee that the information used by AI applications is reliable and secure and that the knowledge generated is also reliable and secure.

## 4 Conclusions

The prospects for the application of AI in the power grids are growing. Today is the time of AI, as it has more and better computing capabilities and increasingly robust and efficient technological platforms. We are one step away from having large volumes of reliable and secure data. Application prototypes have had good results, but operational implementation in real time is lacking. AI algorithms are becoming more robust and well-known with the ability to be combined, generating hybrid or assembled algorithms that provide better results. In the power grids there is a great openness and desire to have AI applications. The new power grid cannot really be conceived without the use of intelligent systems. All these factors make the prospects for the application of AI in the power grid are high and make AI its strategic key.

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