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Artificial Intelligence And Iot In Power Systems: A Survey On Smart Protection And Electrical Machine Management

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The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) is revolutionizing modern power systems, especially in the domains of smart protection and electrical machine management. This survey provides a comprehensive overview of current methodologies, applications, and advancements in applying AI and IoT technologies for enhancing reliability, safety, and efficiency in power systems. Smart protection schemes using AI offer predictive maintenance, fault diagnosis, and adaptive control, while IoT facilitates real-time monitoring and decentralized decision-making. The paper reviews the state-of-the-art in neural networks, fuzzy logic, deep learning, and hybrid AI models for intelligent fault detection and load forecasting. Additionally, it discusses the role of IoT-enabled sensors and communication protocols in machine condition monitoring and grid automation. Challenges such as cybersecurity, data handling, interoperability, and real-time processing are also highlighted. The survey concludes by identifying potential research directions and emphasizing the importance of AI-IoT synergy for future smart grids.

Keywords: Artificial Intelligence (AI), Internet of Things (IoT), Power System Monitoring, Smart Grid, Electrical Energy Management.

1. Introduction

The majority of power plants around the world still rely on fossil fuels to generate electricity. However, these fossil fuel resources are being used up quickly and are expected to run out in the near future. To ensure the survival and progress of human life, we must maintain a steady and reliable supply of electricity. This is where the concept of the smart grid becomes very important.

A smart grid is considered the best solution to the current problems faced by traditional power grids. Unlike the old systems, smart grids not only transmit electricity but also actively monitor and manage how energy is used. Since the discovery of electricity, power grids have gone through regular improvements. While the basic structure of traditional grids has stayed almost the same, many modern technologies have emerged that can improve their performance [1].

One of the biggest challenges today is how to use modern Information and Communication Technologies (ICTs) to make the power grid more reliable, stable, and energy-efficient, while also meeting the changing needs of electricity consumers. Nowadays, there's a growing interest in renewable energy sources like solar and wind, as well as small-scale home energy production [2]. These types of energy sources are less centralized than traditional power plants and may be more sustainable in the long term. However, they also pose new challenges for power grid performance, which creates a need for advanced ICTs to ensure effective monitoring and control.

Today's electricity infrastructure is becoming digital, forming what we call a smart grid. Earlier power systems were centralized, meaning all the generation and control happened at a single place. The old system's main job was to generate, transmit, and deliver electricity to consumers. It didn't include any built-in security features. That model worked fine in the past, but times have changed [3].

Now, electricity demand is increasing, smart devices are being used in every home, and both physical and cyber security are essential. We also need systems that are highly reliable and energy efficient. Due to all these changes, the traditional grid is no longer enough, and that's why the smart grid was developed [4]. A smart grid allows for a two-way flow of electricity and data between electricity providers and consumers. It uses many types of devices to observe and control the grid in real time. This helps make energy delivery more flexible, secure, and responsive.

The issues of connectivity, automation, and real-time monitoring can be effectively addressed by using the Internet of Things (IoT) in smart grids. Devices like sensors, actuators, and smart meters are key parts of the smart grid system. These IoT devices help improve grid operations by detecting problems early, managing loads, and ensuring smooth operation even during natural disasters [5]. As a result, IoT helps reduce economic losses and makes electricity transmission more dependable.

Typically, there are three main steps in using IoT technologies in the power sector:

1. Digitalization of assets – This means converting physical electrical infrastructure into digital form so it can be monitored.

2. Data collection from assets – IoT devices collect data such as temperature, load, voltage, or fault status from machines and power lines.

3. Developing computational algorithms – Smart control systems use advanced algorithms, often running at the edge (close to devices) or in the cloud, to make decisions and manage the grid intelligently.

To support all these activities, the communication networks used in the smart grid must ensure a good quality of service (QoS) [6]. They also need to work well with industrial communication protocols and follow strong cybersecurity measures to keep the grid safe and efficient.

2. Literature Survey

Several recent research papers have made important contributions to the field of IoT-enabled smart grids, each focusing on different aspects such as architecture, energy efficiency, communication, and security. In the paper [7], the authors mainly focused on the architecture of IoT-based smart grids and discussed various security issues that can arise in such systems. They explored how smart grid components can be protected from cyber threats. The paper [8] provided a set of necessary steps and strategies for the successful development of IoT-enabled smart grids. It applied a layered industrial IoT architecture to explain the functions and roles of different technologies at each level of the system.

In paper [9], the study highlighted the concept of the energy internet, which is useful for utility energy services and demand-side energy management. It explained how smart technologies can help manage electricity more efficiently and reliably. Paper [10] focused on improving the energy efficiency of IoT systems, especially in terms of data communication and processing. It discussed how to reduce power consumption while maintaining good performance. In paper [11], the authors looked at the communication weaknesses in smart grids and explained how IEC 62351-6 security methods can improve time-sensitive networking, which is essential for real-time energy management.

Paper [12] studied IoT applications in business and smart energy systems. It explained how IoT can help improve data handling, energy production, and overall efficiency in energy-related industries. The paper [13] reviewed the technologies, applications, and security issues related to IoT-based smart grids. It gave a complete overview of how IoT is being used and the problems that still need to be solved. In paper [14], the study focused on energy harvesting systems used with IoT devices. It discussed storage methods, control systems, distribution techniques, and the challenges in building efficient energy-harvesting smart grids. Paper [15] compared different energy frameworks and measured how IoT technologies are being adopted in the energy sector. It offered updated insights into how these technologies are used at different system levels.

Lastly, in paper [16], the authors discussed the role of 5G technology in supporting IoT-based power systems. It covered the benefits, issues, and structure of combining 5G with power grid communication systems. Although each of these papers provides useful information, most of them focus on specific topics like architecture, energy, or security.

In contrast, our survey presents a complete and unified view of IoT-enabled smart grids. We cover architecture, communication technologies, integration methods, applications, prototypes, and the main challenges. Our work also highlights future research areas and aims to be a valuable guide for both researchers and engineers working in this field.

3. Need of AI & IoT in Power Systems

The use of Artificial Intelligence (AI) in power systems offers major advantages compared to traditional methods. As power systems become more complex and large-scale, conventional approaches like state estimation and optimal power flow (OPF) struggle to handle the massive data and intricate dependencies within modern grids [17]. On the other hand, AI techniques, such as neural networks and machine learning, can process large datasets efficiently and detect hidden patterns that traditional methods often miss.

Another key benefit of AI is its ability to make decisions in real time. Traditional control techniques like PID control and automatic generation control (AGC) rely on predefined rules that may not respond fast enough to rapid changes in the grid [18]. In contrast, AI approaches, including deep learning and reinforcement learning, can quickly adapt to new conditions, helping to maintain system stability and control.

Prediction and forecasting is another area where AI excels [19]. Traditional strategies, such as load shedding and frequency response analysis, usually react to problems after they happen. AI tools like predictive analytics and time series analysis allow for accurate forecasting of future grid conditions, helping operators take action before issues arise.

AI's ability to learn and improve continuously is a big advantage. Traditional systems use fixed rules and settings, which may not be effective under changing conditions. Reinforcement learning algorithms can learn from new data and adjust their behavior over time, improving performance as conditions change.

Dealing with uncertainty in power systems is another important challenge. Grid operations must cope with variable electricity demand and unpredictable outputs from renewable energy sources like wind and solar. AI techniques such as fuzzy logic and Bayesian networks can model and handle such uncertainties better than fixed-rule-based methods [20].

AI also offers advanced optimization capabilities. Using metaheuristic algorithms like particle swarm optimization (PSO) and genetic algorithms (GAs), AI can find efficient solutions to complex problems—such as optimizing control strategies, protection settings, or power flows—which are often difficult to solve using traditional techniques.

Lastly, the combination of AI with smart sensors and IoT devices improves real-time monitoring and control. These tools collect detailed data from the grid, which AI systems analyze to make smarter, faster decisions [21]. This leads to improved system stability, reliability, and fault prevention.

Many research studies and surveys have been done in the area of IoT-enabled smart grids. These surveys usually focus on different aspects, such as system architecture, technologies used, various applications, and the challenges involved. However, most of the existing surveys do not cover all important areas together. For example, in some papers, the authors have not discussed earlier related research. In others, there is very little explanation of the technologies used, and some surveys do not talk about the challenges faced in IoT-enabled smart grids.

In paper [22], the author studies how IoT is used in energy systems. This includes the use of cloud computing and data analytics platforms. The paper also talks about privacy and security problems that may arise when IoT is used in the energy sector, and it suggests solutions like blockchain technology. In another paper [23], the author gives an overview of smart grid technology, but it lacks proper discussion about the role of IoT in smart grids and does not explain the different layers of its architecture. Paper [24] gives a good summary of earlier research and talks about the benefits and uses of IoT in smart grid systems. It also explains how IoT works at each level of the architecture and shows how the different technologies are connected.

Paper [25] reviews past research related to IoT-based smart grid systems and covers existing architectures, applications, and prototypes. In paper [26], the author studies how IoT is used in business and smart energy systems. This includes communication networks, energy production, and devices at the end-user level. Paper [27] introduces the concept of an energy internet, which supports energy services and demand-side management. It also explains the main parts and difficulties of this system and shows what further research is needed in this area.

In paper [28], the author discusses energy-efficient communication and computing in smart grids and looks into the role of 5G technology and edge computing. Paper [29] focuses on recent developments in IoT-based smart grids and also talks about security threats. In [30], the author explains how current security standards can be extended to work with time-sensitive communication networks in the power sector. The surveys IoT and smart grids but doesn’t clearly explain different types of IoT-based smart grid architectures or the main technologies behind them.

Paper [31] reviews IoT technology in smart grids, covering architecture, applications, and security issues. The look at the use of IoT in smart homes and smart buildings, including software tools and communication methods, but not at the grid level. In paper [32], the author discusses key studies about IoT applications in smart grids and lists new approaches used in different areas. Paper [33] examines energy harvesting systems for IoT and their design, storage methods, and control mechanisms, along with future design challenges. It introduces a new way to measure how IoT is used in the energy sector and explains how each part of the system is organized. Paper [34] focuses on the influence of 5G networks on IoT and power systems, along with the architecture used in these systems.

From these surveys, we can see that some focus mainly on applications, some on architecture, while others are limited to security issues or computing technologies. Most of them do not cover the entire picture of IoT-enabled smart grids.

4. Application of AI & IoT in Power Systems

4.1. Application of AI in Power Systems

4.1.1. Machine Learning (ML)

Machine Learning is used to understand and predict how the power system behaves under different situations. It can predict when a fault or issue might occur. This helps in taking precautions before a failure happens. It is also used to automatically find faults in the system and apply protection without human involvement. In control operations, ML helps adjust system settings in real-time for smooth operation. Additionally, it helps in predicting power demand and managing the load on the system efficiently.

4.1.2.Neural Networks

Neural Networks are great for recognizing patterns and making predictions based on complex data. They can model how the system responds during faults or under changing conditions. These networks help detect and locate faults quickly and precisely. They are also useful in controlling system voltage and frequency, and in planning how to integrate renewable energy sources like solar or wind power. They manage how energy is stored and used efficiently.

4.1.3.Fuzzy Logic

Fuzzy Logic is used when the data is not clear or exact. It helps in making decisions even when there is uncertainty. For stability, it helps analyze unclear situations to maintain system balance. It adjusts protection settings automatically and makes the system tolerant to faults. It also controls systems that do not behave in a straightforward way and helps manage the electricity supply based on demand.

4.1.4.Reinforcement Learning

This technique allows the system to learn from experience. It figures out the best actions to keep the system stable over time. It creates protection systems that learn and adapt over time. It also helps systems take control actions without human input. In addition, it supports planning maintenance work and managing energy resources smartly.

4.1.5.Predictive Analytics

Predictive Analytics uses past data to forecast future situations. It predicts how stable the power system will be in the near future. It helps foresee faults before they happen so that protective measures can be taken in advance. It also predicts what kind of control actions will be needed soon. This helps in managing energy use and taking care of system equipment effectively.

4.1.6.Genetic Algorithms

These are used to find the best solutions among many options. They help optimize how control systems maintain stability and adjust parameters. They also help design the best settings for protection systems and analyze faults. In control, they solve complicated optimization problems like load distribution. They also plan how to use renewable energy sources and manage the grid efficiently.

4.1.7.Expert Systems

Expert Systems use human expert knowledge to make smart decisions. They assist in analyzing stability problems and support operators in taking the right decisions. They are also used to create protection systems that follow a set of rules and identify faults. These systems help in deciding control strategies and managing the smart grid effectively.

4.1.8.Deep Learning

Deep Learning deals with large amounts of data and can handle complex problems. It is used to model stability accurately and make predictions. It helps in identifying faults by learning patterns in data and can create smart protection systems. In control, it helps analyze complex situations and make predictive decisions. It is also useful in planning maintenance and forecasting demand.

4.1.9.Time Series Analysis

This method looks at data collected over time. It is used to study trends and predict how stable the system will be. It helps find fault patterns by analyzing past data and applies protective actions based on those patterns. It also forecasts what control actions may be needed and analyzes how energy is used over time.

4.1.10. Recurrent Neural Networks (RNNs)

RNNs are specialized in handling data that changes over time. They predict how the system's stability might change in the future. They can detect changing fault patterns and adjust protection systems dynamically. They also help in making control decisions based on ongoing data and support energy management and forecasting.

4.1.11. Long Short-Term Memory (LSTM)

LSTM is a type of RNN that is good at understanding long-term patterns. It forecasts stability over longer periods and handles sequences of data. It recognizes long-term fault patterns and adjusts protection based on them. It also helps create control strategies that depend on long-term changes in the system. LSTM is useful in forecasting energy demand and managing energy storage systems.

4.1.12. Data Mining

Data Mining helps discover hidden patterns in large datasets. It is used to find patterns that relate to system stability and detect potential risks. It helps identify fault patterns that are not easily visible and improve protection. In control, it finds useful patterns and helps optimize operations. It also helps in planning maintenance and managing system assets.

4.1.13. Clustering Algorithms

Clustering Algorithms group similar types of data together. They help group similar stability situations and detect critical conditions. They can group faults with similar characteristics and improve understanding. In control, they help organize similar scenarios to improve decision-making. They are also used to manage customer behavior and demand response programs.

4.1.14. Bayesian Networks

Bayesian Networks use probabilities to make decisions under uncertainty. They help assess how stable the system is when data is unclear. They are used to diagnose faults in uncertain conditions and improve protection reliability. In control, they support decision-making with probabilistic reasoning. They are also used for predicting maintenance needs and managing risks.

4.1.15. Proportional–Integral–Derivative (PID) Control

PID Control is a classical method used to maintain stability by adjusting system parameters. It keeps the system balanced under changing conditions. It also helps maintain protection during varying system conditions. It ensures stable voltage and frequency and fine-tunes control actions. PID control is widely used in automation and control processes.

4.1.16. Model Predictive Control (MPC)

MPC looks ahead and plans control actions for the future. It manages system stability by predicting what may happen next. It also predicts when protection actions are needed and optimizes them. It anticipates future control requirements and creates the best strategies. MPC is used in energy management and optimizing industrial processes.

4.2. Application of IoT in Power Systems

The Internet of Things (IoT) plays a very important role in modern power systems by bringing smart monitoring, automation, and communication across all key areas—generation, transmission, distribution, and consumption. In power generation, IoT helps monitor the performance of different power plants such as those using coal, solar, wind, and biomass. It keeps track of energy output, gas emissions, fuel usage, and energy storage conditions. With the help of sensors and data collectors, IoT systems can give early warnings when equipment fails or environmental conditions change. This allows plant operators to take timely action, ensuring safety and efficiency. IoT can also help in monitoring pollution levels, tracking fuel consumption, and predicting power generation patterns.

In the transmission segment, IoT ensures the safety and smooth operation of transmission lines by monitoring environmental factors such as temperature, fog, snow, and wind. It uses sensors installed along the transmission network to detect mechanical stress, faults, or damages in towers, lines, and high-voltage equipment. The collected data is transmitted through wireless communication systems to control centers for real-time analysis. This helps in quickly identifying and fixing faults, thus minimizing power outages and improving reliability.

At substations, IoT is used to oversee the performance and environmental safety of all equipment. It allows grid operators to monitor electrical flows, identify abnormalities, and make sure that substations are working safely and efficiently. This real-time monitoring helps in quick decision-making and improves the coordination between substations and control centers.

In the distribution and utilization sections of the power system, IoT enables a wide range of smart applications. These include automatic power distribution, electricity load balancing, real-time data collection from consumers, and remote monitoring of home and industrial energy use. IoT also supports the integration of smart meters, electric vehicle charging stations, and distributed energy sources such as solar rooftops. These features make the grid more interactive and customer-focused, allowing users to manage their energy consumption better through intelligent systems and applications.

Smart metering is another major area where IoT proves highly beneficial. IoT-enabled meters can send real-time data to electricity providers, helping them understand usage patterns and detect faults instantly. This not only improves billing accuracy but also supports predictive maintenance by identifying potential issues before they lead to major breakdowns. The combination of IoT and cloud computing helps scale up the smart metering infrastructure and increases its efficiency, making the power system more intelligent, responsive, and sustainable. Overall, IoT enhances the efficiency, reliability, and intelligence of the entire power system by providing accurate, real-time data and enabling automated control across all levels of electricity management.

Conclusions

Artificial Intelligence (AI) and the Internet of Things (IoT) are transforming the modern power system by enabling intelligent monitoring, control, protection, and management. This survey has demonstrated how a wide variety of AI techniques including Machine Learning, Neural Networks, Fuzzy Logic, Deep Learning, and Model Predictive Control play a crucial role in ensuring system stability, enabling fault prediction and classification, optimizing control actions, and supporting efficient energy and asset management.

Each AI method has unique capabilities that contribute to different aspects of the power system. For instance, Machine Learning and Neural Networks provide predictive insights, Fuzzy Logic deals with uncertainties in real-time decisions, and Deep Learning and RNNs analyze high-dimensional, time-series data for fault diagnosis and future forecasting. Moreover, techniques like Reinforcement Learning and Genetic Algorithms help systems learn and optimize themselves over time.

The integration of these AI approaches with IoT devices enhances data acquisition, real-time processing, and adaptive responses, especially in smart grids and renewable energy setups. As power systems become more complex and dynamic, the synergy between AI and IoT will be fundamental for achieving smarter, self-healing, and energy-efficient grids. Future research should focus on improving interoperability, cybersecurity, and cost-effectiveness of AI-IoT based systems, as well as on developing lightweight and scalable models suitable for real-time embedded power applications.

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