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Application of Artificial Intelligence Technology in Electrical Automation Control

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Abstract. Against the backdrop of industrial digital transformation and the construction of new-type power systems, electrical automation systems are widely deployed in production lines, substations, new-energy power generation and other scenarios. Conventional electrical automation relies on pre-set fixed programs for control, which suffers from poor adaptability, delayed fault warnings, insufficient control accuracy, and high operation and maintenance costs. This paper discusses the development of artificial-intelligence technology and its applications in electrical automation. A literature review shows that AI can improve the adaptability and operational stability of electrical systems, realise equipment fault diagnosis, load forecasting, and operation optimisation, and reduce the operation and maintenance workload. Nevertheless, challenges including poor hardware compatibility, weak model interpretability, inconsistent data quality and cybersecurity risks remain at the current stage. This study concludes that artificial intelligence serves as an effective supplement to traditional electrical control systems and cannot completely replace the original control framework. Further efforts are required to improve data acquisition systems, optimise lightweight algorithms and strengthen security protection to facilitate the practical implementation of intelligent transformation.

Keywords: Artificial Intelligence, Electrical Automation Control, Neural Network, Fuzzy Control, Fault Diagnosis

1. Introduction

With the advancement of industrial digital transformation and the construction of new-type power systems, electrical automation systems have been widely applied in factory production lines, substations, new-energy power generation and other scenarios. Most conventional electrical automation control is implemented based on pre-set fixed programmes. When confronted with complex and variable operating conditions, it exhibits poor adaptive capacity, accompanied by drawbacks such as delayed fault detection, limited control accuracy and heavy manual operation-and-maintenance workload, and thus can hardly meet modern industrial requirements for safe, energy-saving and stable operation. In recent years, AI technologies such as machine learning, expert systems, and fuzzy control have matured rapidly. They lay a technical foundation for electrical control systems to break through existing technical bottlenecks and realise autonomous perception and intelligent decision-making. The integration of artificial intelligence and electrical

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automation has become a vital trend in industrial development. This study focuses on the applications of artificial-intelligence technology in electrical automation control. It analyses how AI technologies—expert systems, neural networks, and fuzzy control—are applied to intelligent regulation of electrical systems, equipment fault diagnosis, load forecasting, and operation optimisation. It also discusses the advantages brought by AI technologies and sorts out existing problems in practical engineering implementation, so as to provide references for the intelligent transformation of electrical automation control systems.

2. Principles of core artificial intelligence technologies

2.1. Fuzzy control

Fuzzy control imitates human fuzzy reasoning thinking. It does not rely on precise mathematical models and is suitable for controlled objects in electrical systems that are nonlinear, subject to strong interference, and difficult to model accurately. The fuzzy controller converts precise signals such as voltage, current, and temperature into fuzzy quantities, performs inference according to predefined rules, and outputs clear control signals to dynamically regulate motors and power distribution equipment.

2.2. Neural networks

Artificial neural networks realise nonlinear fitting through a multi-layer network structure and possess autonomous learning capability. Models are trained using historical operational data of equipment to mine hidden correlations between electrical parameters and equipment conditions, which can be applied to load forecasting and fault identification. When real-time electrical data are received, the well-trained neural network can rapidly identify abnormal features and predict potential faults.

2.3. Expert systems

Expert systems transform expert experience in the electrical engineering field into computer knowledge bases and inference rules to simulate expert judgement logic. When abnormalities occur in electrical equipment, the system quickly identifies the fault type and location by consulting the knowledge base and provides remedial recommendations. It is widely used for fault diagnosis in substations and large-scale industrial power-distribution equipment.

3. Advantages of artificial-intelligence technology

3.1. Practicality

Conventional electrical control depends on manual tuning of PID parameters. Optimal parameters are difficult to obtain for nonlinear, strongly coupled electrical systems. Artificial-intelligence optimisation algorithms can automatically search for optimal control parameters, improve the response speed and anti-interference capability of controllers, and reduce the workload of manual debugging [1].

Artificial intelligence can build a full-process operation-and-maintenance system of "monitoring-diagnosis-maintenance-review", promoting the transformation of electrical equipment from periodic

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maintenance to predictive maintenance. It can identify latent faults in advance and reduce production losses caused by unexpected shutdowns [2].

With AI-based online condition monitoring, electrical equipment shifts from traditional periodic maintenance to condition-based maintenance. Frequent manual on-site inspections are no longer required. The system automatically outputs fault-handling recommendations, shortening manual troubleshooting time and reducing labour costs.

3.2. Stability

Fuzzy control and neural networks do not require accurate mathematical models of equipment. They are suitable for industrial electrical control systems with variable operating conditions, enabling adaptive adjustment of motor speed and torque and effectively reducing energy consumption [3].

Expert systems can store electrical-engineering expert experience in knowledge bases. When abnormalities arise in electrical equipment, they rapidly locate fault positions and identify fault types, provide remedial recommendations, and greatly shorten troubleshooting time.

4. Applications of artificial-intelligence technology in electrical automation

4.1. Applications of artificial-intelligence technology in routine operations of electrical systems

Routine operations of electrical systems include regular tasks such as equipment start-stop, parameter inspection, load regulation, condition monitoring, and daily operation-and-maintenance record-keeping. Under the conventional mode, numerous operations rely on manual on-site duty. Operators are required to check meters at fixed intervals, record operating parameters, and manually adjust operating parameters of power distribution and motor equipment. Such work is repetitive and cumbersome with a high risk of human error.

With the introduction of AI, routine operations of electrical systems can be managed automatically and intelligently [4]. Firstly, real-time online monitoring: AI continuously collects operating data such as voltage, current and temperature, automatically identifies parameter anomalies, replaces manual periodic meter-reading and inspection, and pushes equipment condition information in real time. Secondly, it assists in regular regulation operations. Based on fuzzy control and machine-learning algorithms, operating parameters of motors and power-distribution equipment are adjusted automatically according to load variations to complete daily control operations such as voltage regulation and speed regulation without frequent manual intervention. Thirdly, operation assistance and intelligent prompting: expert systems store electrical operation specifications. When tasks such as switching equipment on and off or switching circuits need to be performed, operating workflows and safety precautions are sent to operation and maintenance personnel to reduce misoperations. In addition, AI automatically saves operation logs, generates daily operation reports and completes statistical data processing, eliminating manual ledger compilation work.

Meanwhile, AI can realise load forecasting and assist staff in arranging daily operational tasks such as power-distribution dispatching in advance to achieve peak-load shifting. In routine inspections, combined with image-recognition technology, cameras can automatically identify meter readings on switchgears and visible defects of equipment to fulfil on-site inspection tasks.

In summary, for routine operations of electrical systems, artificial intelligence enables automatic monitoring of equipment operating parameters and adaptive parameter adjustment for motors and power-distribution equipment. Guided by expert systems, it supports operations such as equipment switching. Machine vision is adopted to assist on-site inspections. AI automatically records

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operating data and generates reports, reducing repetitive work such as manual meter reading and ledger sorting, lowering the risk of human error, and improving the management efficiency of daily electrical system operation.

4.2. Applications of artificial-intelligence technology in accident and fault diagnosis

Electrical equipment faults are often characterised by concealment, sudden occurrence and cascading propagation. Conventional fault diagnosis mainly depends on human experience together with fixed-threshold judgement. Alarms are triggered only when operating parameters exceed limits obviously, resulting in insufficient capability to identify early degradation and weak potential hazards. After an electrical accident occurs, operation and maintenance personnel must inspect circuits and equipment one after another. Fault localisation consumes substantial time, which may delay disposal and lead to expanded fault scope [5].

Based on multi-source sensor data, artificial-intelligence technologies deploy algorithms such as neural networks, fuzzy control and expert systems for electrical fault and accident diagnosis. On the one hand, neural networks and convolutional neural networks perform feature mining on multi-dimensional monitoring data including current, temperature, vibration and partial discharge. They capture subtle early abnormal signals that are hard for conventional methods to detect, realise early fault warning, and shift maintenance modes from post-fault emergency repair to predictive maintenance. On the other hand, expert systems construct knowledge bases with electrical-fault cases, relay-protection logics and equipment maintenance experience. When faults or even accidents such as short-circuit, overload and insulation ageing take place, the system rapidly locates fault positions, identifies fault types and provides disposal schemes by integrating protection-action information, shortening fault-troubleshooting time. Fuzzy control is suitable for scenarios with ambiguous fault-feature boundaries and noisy signals, reducing false alarms and missed alarms.

Nevertheless, artificial-intelligence-based fault diagnosis still has limitations. Diagnostic performance of models heavily relies on high-quality labelled fault samples; identification accuracy degrades when samples for rare accidents are insufficient. Deep-learning models are black boxes whose diagnostic results are difficult to interpret. In the event of severe electrical accidents, operation-and-maintenance personnel cannot directly verify the reasoning logic of models. Sensor noise and missing field data also impair the reliability of diagnostic outputs. Therefore, in engineering practice, AI diagnosis serves to support human decision-making, and major electrical accidents are not judged solely by artificial intelligence.

The core value of AI-based fault diagnosis is not to replace maintenance personnel completely, but to assign massive complicated signal-analysis work to algorithms, allowing maintenance staff to focus on fault disposal and risk assessment. In future, interpretable-AI algorithms can be adopted and the sample library for extreme accidents expanded to improve model performance for rare severe accidents. Working with traditional relay protection systems, they can jointly enhance the safety defence capability of electrical systems.

4.3. Applications of artificial-intelligence technology in electrical automation equipment

Existing studies indicate that embedding artificial-intelligence algorithms into electrical-automation equipment such as motors, frequency converters and switchgears enables real-time perception of equipment operating conditions and adaptive parameter tuning [6]. By adopting fuzzy control and neural-network approaches, the inherent nonlinear and strongly coupled characteristics of electrical equipment can be effectively mitigated, improving control accuracy and disturbance rejection [7].

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Deep-learning technology can be applied to condition evaluation and fault prediction for transformers, motors and complete power-electronic equipment. By fusing multi-source sensor data such as current, temperature and vibration, degradation features are extracted, promoting the transition from periodic to predictive maintenance and reducing the risk of unplanned equipment shutdown. Traditional electrical-automation equipment generally adopts fixed-logic control strategies [8], whose operating parameters cannot dynamically adapt to variable operating conditions. The integration of artificial intelligence with PLCs and field sensing devices endows electrical equipment with self-learning capability, optimises regular workflows such as equipment start-stop and load regulation, and improves the overall operational efficiency of automation systems [9].

Applications of artificial intelligence in electrical-automation equipment can be summarised into three major directions: intelligent control, on-line condition monitoring and intelligent fault diagnosis. However, outdated electrical equipment commonly suffers from hardware bottlenecks such as insufficient data-acquisition interfaces and limited computing-power resources, which prevent the direct deployment of complex AI models. It is thus recommended to adopt lightweight algorithms operating in coordination with original control systems. The intelligent transformation of electrical-automation equipment should not discard existing hardware systems and control loops. A hybrid architecture should be constructed in which traditional control is the main body and AI provides auxiliary optimisation. When the AI module malfunctions, the original basic-control logic can operate independently to guarantee continuous safe and stable operation of electrical equipment [5].

5. Conclusion

This paper investigates the applications of artificial-intelligence technology in the field of electrical automation control, and sorts out how artificial-intelligence technologies including fuzzy control, neural networks and expert systems are applied in intelligent regulation of electrical equipment, routine system operation, as well as fault and accident diagnosis. The study reveals that artificial-intelligence technology can make up for the limitations of fixed-logic control in conventional electrical automation. It enables adaptive tuning of equipment parameters, real-time monitoring of operating conditions and early fault warning, optimises routine operations such as load regulation, equipment inspection and operation-and-maintenance record-keeping, improves control accuracy and anti-disturbance capability of electrical systems, and promotes the transformation of equipment maintenance modes from periodic maintenance to predictive maintenance.

Meanwhile, this study also indicates that many constraints still exist for the engineering implementation of artificial intelligence in electrical-automation equipment. Issues such as missing hardware interfaces and insufficient computing power of legacy electrical equipment, high noise in field-collected data, imbalanced fault samples and poor model interpretability restrict the large-scale deployment of complex intelligent algorithms. Therefore, the intelligent transformation of electrical systems should not completely replace the original control architecture. A hybrid control framework should be adopted in which traditional control is primary and AI is auxiliary, ensuring safe and stable system operation even if the AI module fails.

Overall, artificial intelligence serves as an important tool for the digital transformation of the electrical-automation industry. With the continuous improvement of lightweight algorithms, sensor-acquisition technologies and data governance systems, the integration depth between AI and electrical automation will become increasingly integrated. It will further enhance the operational efficiency of electrical systems, cut operation-and-maintenance costs, and guarantee the safe and

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reliable operation of industrial electrical equipment. Future research may focus on interpretable AI algorithms, model generalisation across multiple scenarios, and cybersecurity protection for control systems, so as to provide further support for the engineering application of artificial intelligence in electrical automation.

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