INNOVATIONS AND APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING

Editors
Mohammed WADI
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Innovations and Applications of Artificial Intelligence in Electrical and Electronics Engineering

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PREFACE

Artificial Intelligence (AI) has revolutionized various engineering disciplines, providing innovative solutions to complex challenges. *Innovations and Applications of Artificial Intelligence in Electrical and Electronics Engineering* delves into the transformative impact of AI in these fields, highlighting cutting-edge research, advanced methodologies, and practical implementations.

This book comprehensively explores AI-driven advancements, encompassing intelligent control systems, fault detection, predictive maintenance, renewable energy forecasting and optimization, and automation in electrical and electronic systems. The chapters focus on enhancing system efficiency, reliability, and sustainability by integrating AI techniques such as machine learning, deep learning, and optimization algorithms.

Targeted at researchers, academics, engineers, and professionals, this book bridges the gap between AI theory and real-world applications. It presents fundamental concepts and advanced developments, providing insights into AI-powered engineering solutions' latest trends and future directions.

We sincerely appreciate the contributors whose expertise has enriched this first volume. We hope this book is a valuable resource, inspiring further innovation and research in AI-driven electrical and electronics engineering.

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CONTENTS

CHAPTER I

AI APPLICATIONS IN ELECTRICAL AND ELECTRONICS ENGINEERING: REVIEW

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1. Introduction

Artificial Intelligence (AI) has emerged as a transformative technology of the 21st century, transforming industries from healthcare to finance, including engineering. In Electrical and Electronics Engineering (EEE), artificial intelligence has emerged as a fundamental element for innovation, facilitating the creation of more advanced, efficient, and adaptive systems. Integrating AI into EEE has improved conventional approaches and created new opportunities for research and application, tackling complicated challenges that were once insurmountable.

EEE comprises multiple areas: power systems, control systems, signal processing, electronic design automation, and embedded systems. Every domain has experienced substantial progress by integrating AI methodologies, including machine learning (ML) (Wadi, Elmasry, TAMYİĞİT, et al., 2024), deep learning (DL), neural networks, and reinforcement learning as given in Figure 1. These technologies have empowered engineers to evaluate extensive data, enhance system performance, and execute unprecedented and efficient real-time decisions.

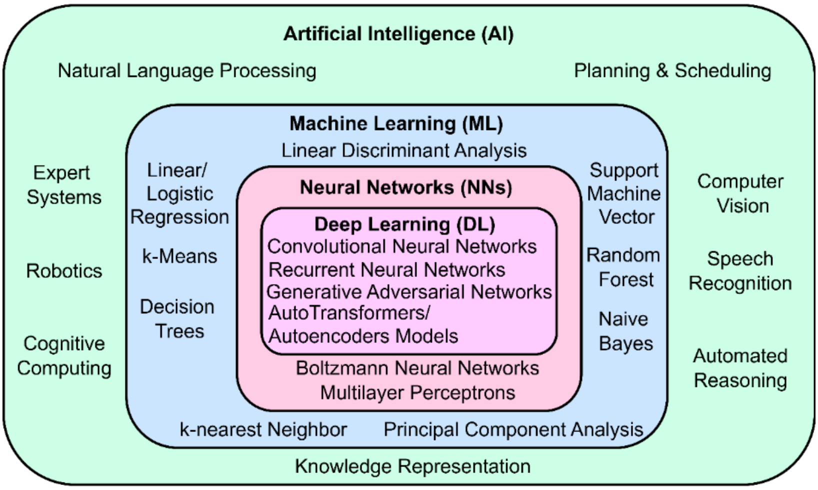

Figure 1. Categories of AI.

The escalating complexity of contemporary systems is a primary catalyst for integrating AI in EEE. Power systems are transforming into smart grids incorporating renewable energy sources, necessitating sophisticated algorithms for load balancing, fault detection, and energy distribution management. In control systems, AI has facilitated the creation of adaptive and predictive control strategies that enhance the efficacy of industrial automation and robots. Artificial intelligence approaches have transformed data analysis in signal and image processing, facilitating noise reduction, feature extraction, and computer vision applications. Moreover, in electrical design automation, AI-powered technologies optimize the design and verification of intricate circuits, decreasing time-to-market and enhancing reliability.

The increasing demand for intelligent and autonomous systems highlights the significance of AI in EEE. The expansion of the Internet of Things (IoT) and embedded systems has necessitated AI algorithms capable of functioning at the edge, delivering real-time insights and decision-making abilities. These advances enhance the efficiency and efficacy of current systems. Nevertheless, they also facilitate the emergence of novel technology, such as driverless vehicles, intelligent urban environments, and sophisticated healthcare devices.

Although it has numerous advantages, incorporating AI into EEE presents several hurdles. Concerns such as data privacy, algorithmic bias, and the necessity for robust and explicable AI models persist as key issues. Furthermore, the computational demands of AI algorithms frequently present difficulties for resource-limited systems, requiring the creation of lightweight and efficient models. Confronting these issues necessitates a multidisciplinary strategy integrating electrical engineering, computer science, and data science skills.

This chapter thoroughly examines the applications of AI in EEE. This chapter seeks to underscore the revolutionary influence of AI on the field by examining critical domains such as power systems, control systems, signal processing, electronic design automation, and embedded systems. Additionally, it aims to delineate existing obstacles and prospective opportunities, offering a framework for researchers and practitioners.

Further, AI is transforming the field of EEE by providing novel answers to enduring difficulties and facilitating the advancement of next-generation technology. The ongoing evolution of the field will undoubtedly see AI integration as a crucial factor in advancing growth and innovation. This chapter seeks to elucidate the present landscape of AI applications in EEE, acting as a significant resource for students, researchers, and industry practitioners.

The chapter is organized as follows: Section 2 delineates the methodology for investigating AI applications in EEE. Sections 3 to 6 explore AI applications in specific fields of EEE, examining the contributions, limitations, and future directions of AI in each field. Section 7 presents a comprehensive analysis of the results, emphasizing significant findings and their ramifications. Section 8 finishes the chapter by summarizing the principal insights and suggesting future avenues for research and advancement.

2. Methodology

This chapter's methodology examines AI applications in EEE, ensuring a systematic and organized method to understand the subject thoroughly. The methodology assumed for this chapter comprises the research framework, data collection methods, and tools used for analysis. Figure 2 shows the methodology of the chapter.

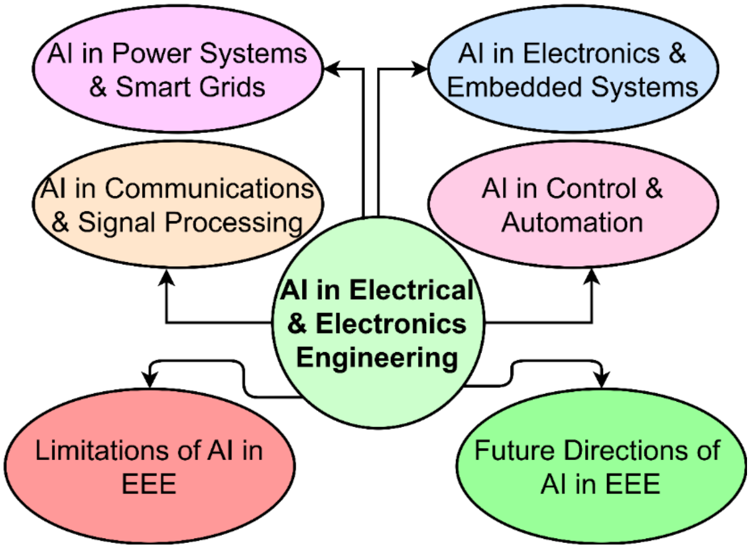

Figure 2. The methodology of the chapter.

2.1 Research Framework

This chapter's study structure integrates a literature review, case studies, and practical examples to offer a comprehensive perspective on AI applications in EEE. The structure is structured to:

- **Principal Contributions:** Explain the notable advancements that AI has facilitated in EEE.
- **Assessing the Influence:** Determine the AI methodologies on system performance, efficiency, and innovation.
- **Identifying the Obstacles:** Identify the constraints related to the incorporation of AI in EEE.
- **Future Directions:** Suggest prospective proposals for the research and development of artificial intelligence in electrical and electronic engineering.

2.2 Data Collection Methods

A comprehensive data-gathering strategy is employed in Figure 3 and comprises the following stages.

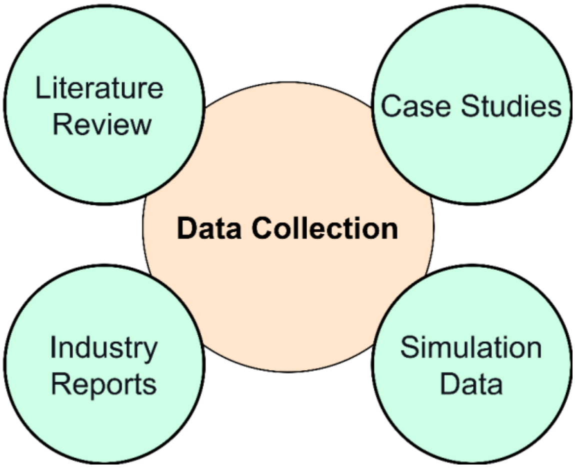

Figure 3. The data collection mechanism.

2.2.1 Literature Review:

A comprehensive examination of peer-reviewed journal articles, conference proceedings, and academic publications was undertaken to ascertain the most recent developments in AI applications for EEE. Additionally, databases, including IEEE Xplore, ScienceDirect, and SpringerLink, were employed to obtain high-quality research papers.

2.2.2 Case Studies:

Empirical case studies were examined to illustrate the actual application of AI in EEE. Examples encompass AI-enhanced smart grid optimization, predictive maintenance in industrial automation, and AI-facilitated image processing in medical electronics.

2.2.3 Industry Reports and Whitepapers:

Analyses of reports from central technology firms and academic institutions were conducted to acquire insights into industry trends and issues. Examples contain reports from corporations such as Siemens, General Electric, and NVIDIA regarding AI uses in power and embedded systems.

2.2.4 Simulation and Experimental Data:

Simulation findings and experimental data from AI-based systems were reviewed, where appropriate, to verify theoretical principles. MATLAB, Simulink, and Python-based frameworks (e.g., TensorFlow, PyTorch) were employed to simulate AI algorithms and assess their efficiency.

2.3 Tools and Technologies

The tools and technologies examination of AI applications utilized in EEE includes an array of tools as described in Table 1.

Table 1. AI tools and technology utilized in EEE

Item	**Tools and Technology(s)**
Machine Learning Frameworks	Widely utilized machine learning frameworks, including TensorFlow, PyTorch, and Scikit-learn, were employed to create, and evaluate artificial intelligence models. These frameworks were utilized to execute algorithms for load forecasting, fault detection, and picture classification activities.
Simulation Software	MATLAB and Simulink were utilized to simulate electrical and electronic systems, facilitating the assessment of AI-driven control techniques and signal-processing methodologies. Simulation tools for power systems, including ETAP and PSCAD, were employed to evaluate AI applications in smart grids.
Data Analytics Platforms	Platforms such as Python, utilizing libraries including Pandas, NumPy, and Matplotlib, were employed for data preprocessing, analysis, and visualization. These tools facilitated the analysis of extensive datasets produced by IoT devices and embedded systems.
Hardware Platforms	Embedded systems and IoT devices were utilized to evaluate AI algorithms in real-time settings. Examples comprise NVIDIA Jetson for edge AI applications and Raspberry Pi for prototype IoT solutions.

2.4 Limitations

The methodology offers a thorough framework for investigating AI applications in EEE, although it possesses certain limitations:

- **Data Availability:** Access to proprietary datasets and sector-specific information was restricted.
- **Scope Limitations:** This chapter concentrates on specific domains of EEE and does not encompass all potential applications of AI within the discipline.
- **Dynamic Discipline:** The swift progression of AI research indicates that certain developments may not be comprehensively represented in this study.

3. AI in Power Systems and Smart Grids

Many applications of AI in reliability evaluation, load forecasting, predictive maintenance, fault detection, grid stability, energy management, and its role in optimizing smart grid operations and integrating renewable energy have been documented in the literature (Wadi et al., 2024; Tur et al., 2024).

An AI-based power consumption and load forecasting model in smart grids was suggested (Aljarrah, 2024). Blockchain employs smart energy trading via the adaptive volt-VAR optimization algorithm in real-time, which is also suggested. A framework for intrusion detection to prevent unwanted access, data manipulation, and cyber-physical attackers on Electric Vehicle (EV) charging stations within smart grids was introduced in (Singh et al., 2025). A model was presented to predict and optimize energy use in real-time using AI, considering operational sensors and anomalies in electrical grid equipment (Santhosh Krishna et al., 2024).

A model was developed to examine the deficiencies of AI concerning photovoltaics (PV) in smart grids. AI offers significant benefits for predicting and integrating intermittent renewable energy sources (Lamnatou et al., 2024). Estimation of solar power systems based on different machine learning models includes linear regression, Artificial Neural Networks (ANN), and Convolutional Neural Networks (CNN) proposed in (Salemdeeb & Wadi, 2024).

A concise study was presented to explain the effect of parameters such as solar irradiance, humidity, temperature, and others based on two approaches: deterministic and machine learning (Wadi, Jouda, Salemdeeb, & Husain, 2024).

A study based on different optimization methods with different distribution functions targets increasing renewable energy sources in smart grids

(Wadi, Elmasry, Colak, et al., 2024). The particle swarm optimization and genetic algorithms offered high performance in selecting the parameters of each distribution.

A review article to investigate the recent developments and limitations of load frequency control in smart grids was presented in (Wadi, Shobole, Elmasry, & Kucuk, 2024). Many issues were considered, including machine learning, cyber-attacks, communication failure, and the challenges associated with LFC in modern power systems.

Five distinct include Rayleigh, Weibull, Inverse Gaussian, Burr Type XII, and Generalized Pareto distributions to model the wind pattern was proposed (Wadi & Elmasry, 2023). In addition, five innovative optimizations, including Grasshopper, Grey Wolf, Moth-Flame, Salp Swarm, and Whale Optimization, were utilized to determine the optimum parameters per distribution. A new study based on different distribution functions such as Rayleigh, Weibull, Gamma, Burr type XII, and generalized extreme value and different optimizations like genetic algorithm, gray wolf, particle swarm, and whale algorithm were introduced in (Wadi, 2023). Similar studies also related to the wind potential evaluation in smart grids based on different optimization methods were studied in (Wadi, 2021b; Wadi, Elmasry, & Tamyiğit, 2023; Wadi, Elmasry, et al., 2021; Wadi & Elmasry, 2021a, 2021c).

Many studies have considered the reliability and dependability of smart grids, which have appeared in the literature (Wadi, Baysal, et al., 2022; Wadi, Baysal, Shobole, & Rida TUR, 2021; Wadi, Baysal, Shobole, & Tur, 2018; Wadi, Elmasry, et al., 2022; Wadi et al., 2017; Wadi & Baysal, 2017; Wadi & Shobole, 2020.) An integrated method based on reliability block diagram (RBD) and the Monte Carlo simulation (MCS) techniques to evaluate reliability in modern power systems was proposed (Wadi, Elmasry, et al., 2022). Employing fuzzy logic to handle the uncertainties of the evaluated parameters was optimized to perform the sensitivity analysis. A novel paper was proposed to evaluate the closed-ring grids' reliability using the total loss of continuity and the MCS techniques (Wadi, Baysal, et al., 2022). The proposed technique was tested on reliability test systems Bus-2 and Bus-4, and the sensitivity investigation utilizing fuzzy logic was also applied to determine variabilities related to the reliability parameters. An innovative method called modified Monte Carlo simulation was proposed to evaluate the reliability of open and closed-ring power systems (Wadi et al., 2018). It confirmed its applicability on radial semi-ring and ring systems.

Many research works have considered the fault detection of smart grids using different models of AI (Elmasry et al., 2022; Elmasry & Wadi, 2022a, 2022b, 2022c; Wadi & Elmasry, 2021b). An innovative approach was presented to detect fault detection in real-time power systems based on Support Vector Machines (SVM) and Principal Component Analysis (PCA) techniques (Elmasry & Wadi, 2022a). The article used a real VSB dataset, and the obtained outcomes verified the high performance of the presented approach. A new approach utilizing ensemble deep learning was proposed for detecting faults in power smart grids (Elmasry & Wadi, 2022b). It was tested on an accurate and new VSB dataset. Many tests and techniques were used to assess the performance of the proposed approach, including Friedman, receiver operating characteristic curves, data balancing, data preprocessing, pretraining, chunk numbers, and hyperparameter optimization. A helpful article employing binary classification machine learning to enhance the fault in modern power systems was proposed (Wadi, 2021a). It utilized the Technical University of Ostrava real dataset. Data balancing and preprocessing approaches were used to improve the classifier's performance.

4. AI in Control Systems and Automation

This section examines the application of AI in industrial automation and robotics control, sophisticated control techniques (e.g., predictive control, adaptive control), and IoT-enabled devices.

A hybrid method integrating deep learning with bee colony optimization was suggested to improve voltage control and regulation in smart grids, considering EVs (Karthikeyan et al., 2025). A comprehensive overview of buildings' automation and control systems was presented in (van Roosmale et al., 2024). Strategic decisions were made based on actual collected data considering the building conditions and technical systems.

A good review article delves into the details of AI in smart grids, considering PV design and optimization, integration of renewable energy, risk management, and others (Lamnatou et al., 2024). Many advantages and disadvantages of renewable energy, such as PV systems integration into power systems, were discussed. Important suggestions for practical energy storage, plans, and forecasting were provided.

An optimized controller based on AI for electrical automation control was presented (Sami, 2022). It showed that the controller is robust to interference with about 0.02 failure under 20.1% load interference and 2Hz frequency interference conditions.

Many works benefit from adaptive, self-tuning, and intelligent systems appeared in the literature (M.S. Jouda & Kahraman, 2019, 2022).

A self-tuning controller based on H-infinity and tuning the parameters via an artificial bee colony algorithm to maintain voltage and frequency stability in microgrids was introduced in (M.S. Jouda & Kahraman, 2022). The method was implemented in Simulink/ MATLAB, and many comparisons with droop control and particle swarm optimization were performed.

5. AI in Electronics and Embedded Systems

This section explores the applications of AI in electronics, power electronics, embedded systems, and edge computing. Additionally, it analyzes AI applications within sensor networks and IoT technologies (Jouda et al., 2024).

The implementation of vehicle-to-grid (V2G) technology in smart grids, considering various types of bidirectional converters to enhance DC power flow and voltage regulation, was proposed (Munusamy & Vairavasundaram, 2024).

A boost DC-DC switching converter utilizing Luo topology via one switch for smart grids was introduced (M. Jouda & Wadi, 2024a). These converters have higher voltage gains, good efficiency, and lower ripple than conventional boost converters. An indoor air quality monitoring system was introduced using IoT and LoRa communication technology for different buildings. The advantages of the system are that it can be monitored wirelessly within 10 km and for large ventilation areas (M. Jouda & Wadi, 2024b). A review paper about EVs considering modern, fast, wireless, and innovative charging technologies was discussed. (Wadi, Elmasry, Jouda, et al., 2023). Moreover, innovative solutions, optimal techniques, and continued research initiatives were critically investigated.

6. AI in Communication and Signal Processing

This section examines AI methodologies for signal processing, communication systems, and multimedia applications, including noise reduction and feature extraction. Furthermore, it examines the uses of AI in image and video processing for electronics, including computer vision and medical imaging.

A novel approach utilizing black-box fake data injection attacks utilizes measurement modules in smart grids to improve the effectiveness of communication security, overcoming data manipulation within conventional communication networks (Liu et al., 2024). A character recognition model based on CNN deep learning was proposed to detect Latin and Arabic handwritten alphanumeric characters (Salemdeeb & Ertürk, 2021). The proposed technique was applied to three different datasets and many error metrics were used to test the performance of the proposed classifier. A novel model using CNN to detect national and multilanguage based on a license plate detection approach was presented (Salemdeeb & Erturk, 2020). The presented approach achieved an average detection accuracy and precision of more than 99%.

7. Results and Discussion

This section outlines the primary findings of each domain presented in the current review. Additionally, a comparative analysis of AI methods and their effectiveness across many applications. The challenges, limitations, and constraints of AI in Electrical and Electronics Engineering, prospective trends, and emerging research opportunities are also examined. Table 2 concisely reviews AI applications in power systems and smart grids, considering main fields such as forecasting, fault detection, grid security, management and monitoring, and integrating renewable energy and electric vehicles.

Table 2. AI in power systems and smart grids main field applications.

Application(s)	References	Contribution(s)
Forecasting	(Xie et al., 2019) (You & Zhu, 2023)	• Short-term load predictions were made using a new ordinary differential equation solver based on deep learning. • A combined approach of modified mutual information and Boltz man machine to extract data and forecasting loads was proposed.
Fault detection	(Xia et al., 2021) (Dhibi et al., 2021)	• A fault detection model was proposed utilizing a digital twin-based deep transfer learning approach with a sparse denoising autoencoder model. • The study addressed fault detection in microgrids, encompassing four steps and utilizing three integrated decision tree classifiers, K-nearest neighbor, and support vector machine ensemble learning methodologies.
Security of grid	(Xie et al., 2019)	• Establish a physical test bed to evaluate the scalability and enhancement of a smart

	(Sayghe et al., 2020)	grid's physical configuration, aimed at improving the cyber security of physical systems through various training and testing of cyberattack simulations. • Implemented diverse machine-learning methodologies to address false data injection in smart grids, utilizing real data gathered from hundreds of sensors integrated into the systems.
Management and monitoring	(Zhaoyun & Linjun, 2022) (O'Dwyer et al., 2020)	• Introduced a real-time monitoring framework comprising a five-layer structure for human interface, inspection, condition investigation, and deductive simulation. • Developed an advanced energy management system utilizing machine learning and model predictive control for the optimal control and coordination of interconnected energy systems.
Integration of renewable energy	(Mohammadi & Mohammadi, 2024) (Mohamed et al., 2015)	• Machine learning techniques to handle the uncertainties associated with integrating renewable energy in smart grids. • Introduced machine learning to enhance energy efficiency, execute real-time pricing, maximize economic load dispatch, manage power flow, and perform load prediction and management.
Electric vehicles	(Bhatti et al., 2021) (ZHANG et al., 2021)	• Electric vehicles in smart grids include self-navigating control, enhanced driver support systems, vehicle inspection, battery management, and vehicle power electronics. • Developed a model utilizing a data-driven digital twin to improve the energy consumption framework in electric vehicles, considering motor efficiency, compactness, and optimal torque-to-weight ratio.

This section explores AI-driven solutions for smart grids. A deep learning-based differential equation solver enhances short-term load forecasting, while a hybrid mutual information and Boltzmann machine method improves data extraction. Fault detection integrates digital twins, deep transfer learning, and ensemble classifiers. A physical testbed evaluates cybersecurity, addressing cyberattacks. Machine learning mitigates false data injections, optimizes energy management, and enhances renewable energy integration. A five-layer real-time monitoring framework improves system oversight. Electric vehicles benefit from AI-driven self-navigation, battery management, and energy optimization using a data-driven digital twin model for efficiency and performance improvements.

Table 3 provides many applications and contributions of AI in combination with traditional and advanced controllers. AI enhances traditional and advanced controllers by improving adaptability, efficiency, and decision-making in complicated systems. AI-driven models optimize control strategies, enabling predictive maintenance, fault detection, and real-time system adjustments. AI dynamically tunes parameters for optimal performance by enhancing PID, fuzzy logic, and model predictive controllers. Additionally, AI-based reinforcement learning enables autonomous control in robotics and industrial automation. By integrating AI with conventional controllers, systems accomplish greater accuracy and stability, leading to advancements in smart grids and automated manufacturing processes.

This section investigates various AI-driven security measures for network and system security. Machine learning-based security protocols enhance SDN controllers by mitigating small security risks. A hybrid SVM-Genetic Algorithm approach optimizes anomaly detection through feature selection. Malware detection integrates data mining for centralized firewall security, while web shell detection employs feature clustering and PCA for IoT server protection. Intrusion detection utilizes stacked autoencoders with ANN to maintain high classification performance. Network traffic classification benefits from stacked autoencoders with CNN techniques. A restricted Boltzmann machine effectively detects false data injections, and insider threats are addressed using a combination of DFNN, RNN, CNN, and GNN for anomaly detection, temporal analysis, user information precision, and graphical data modeling. These AI-based approaches enhance cybersecurity across diverse attack patterns and threat landscapes. Table 4 provides valuable research focusing on AI applications for electronic information security. Figure 4 illustrates the cyber-threats general taxonomy.

Table 3. AI in control and automation applications.

Controller(s)	References	Contribution(s)
Dual-loop controller (DLC)	(Quan et al., 2020)	• Proposed a controller to control DC AC voltage with the power synchronization in fuel cell/electrolyzer systems.
Fractional order proportional integral derivative (FOPID) controller	(Khokhar et al., 2021)	• Introduced a fractional order proportional integral derivative using a second-order derivative controller to load frequency control in power systems.
Super-twisting sliding mode control (ST-SMC)	(Li et al., 2021)	• Provided a more accurate controller considering the boundary estimation and parameters uncertainty compared to PID for fuel cells systems.
Particle swarm optimization (PSO) - PID (PSO-PID) controller	(Ahmadi et al., 2017)	• Presented a controller to improve the efficiency of fuel cell systems in combination with a maximum power point tracking controller.
PID- Ziegler-Nichol	(Swain & Jena, 2015)	• Introduced PID controller combined with Ziegler-Nichol for controlling the complex nonlinear proton exchange membrane system.
Model prediction control (MPC)	(Xu et al., 2023)	• Presented a self-tuning energy management strategy for fuel-cell hybrid electric vehicles utilizing MPC.
Fuzzy logic controller (FLC) - PID	(Tur et al., 2018)	• Introduced comparisons between fuzzy logic and PID controllers to maintain the frequency fluctuations in one and two areas of an interconnected power system.
Linear quadratic regulator (LQR) – Legendre Wavelet	(Elaydi & Wadi, 2015)	• Proposed an optimal controller combining Legendre wavelet function and LQR to control load frequency in single-area power systems.

Table 4. Summary of AI applications for electronic information.

Security-Category(ies)	References	Contribution(s)
Attack Patterns	(Nanda et al., 2016)	• Presented security protocols on the Software-Defined Networking (SDN) controller utilizing machine learning considering Impact of small security risks on SDN security.
Anomaly Detection	(Shon' et al., 2005)	• Proposed a combined SVM approach with Genetic Algorithms (GA) utilizing the principal feature selection methodology to choose more appropriate packet fields.
Malware Detection	(Singhal, 2012)	• Introduced a machine learning and data mining model to establish a centralized solution for industry security that operates at the firewall level.
Webshell Detection	(Yong et al., 2022)	• Analyzed many real datasets, including malicious and web shells, employing feature clustering and PCA techniques for Internet of Things (IoT) server security.
Intrusion Detection Systems	(Aminanto & Kim, 2016)	• Proposed stacked autoencoder with ANN to reduce the feature dimension while maintaining high-performance classification.
Network Traffic Identification	(Lotfollahi et al., 2020)	• Suggested stacked autoencoder with one-dimensional CNN techniques to improve the traffic classification by extracting the best features.
False Data Injection	(He et al., 2017)	• Presented a restricted Boltzmann machine model that can detect highly accurate false data regardless of the number of attacked data.
Insider Threat	(Yuan & Wu, 2021)	• Utilized a synthesis of methodologies including Dynamic Fuzzy Neural Networks (DFNN) for anomaly detection, Recurrent Neural Networks (RNN) for temporal user information analysis, CNN to improve the precision of user information detection in image format, and Graph Neural Networks (GNN) for graphical data modeling.

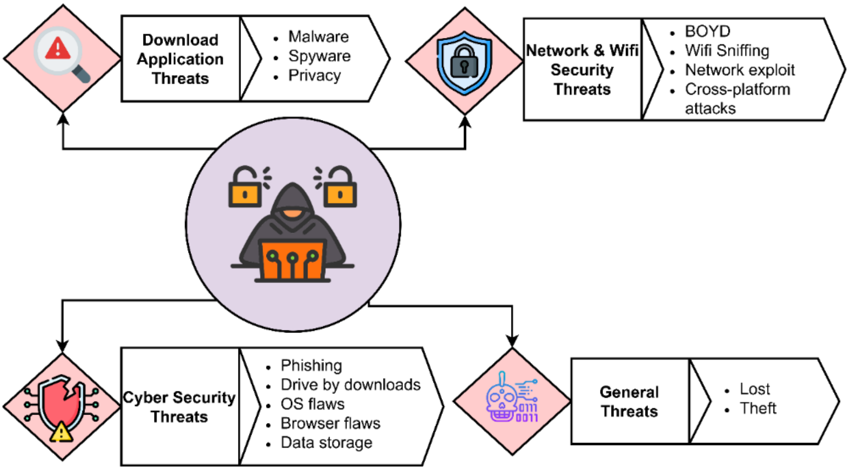

Figure 4. The cyber-threats general taxonomy.

8. Future Directions of AI in Electrical and Electronics Engineering

AI has provided many advances in EEE. This review mainly investigates AI contributions in power systems and smart grids, control and automation, communication and signal processing, and electronics and embedded systems. Figure 5 depicts the future directions of AI in the main fields of EEE.

Future AI uses in smart grids and power systems will concentrate on grid resilience enhancement, renewable energy integration optimization, and real-time monitoring improvement. Through predictive maintenance, problem detection, and self-healing systems, advanced machine learning algorithms will enable reduced downtime and increase productivity. Furthermore, improving energy consumption predictions and guaranteeing more reliable and sustainable grid operation will be achieved through AI-driven demand-side management and dynamic pricing models.

AI will allow more intelligent and flexible control tactics by utilizing model predictive control in control, automation, and reinforcement learning. Including artificial intelligence in conventional control strategies will improve accuracy in robotics, industrial automation, and autonomous systems. Furthermore, real-time system optimization made possible by AI-driven digital twin technology can help to enhance predictive control and anomaly detection in challenging industrial processes.

AI will be crucial in next-generation communication networks—including 6G and beyond— to maximize spectrum efficiency, interference control, and resource allocation. Applications include noise reduction, modulation classification, and channel estimation—which depend on signal processing—and deep learning models that will improve. Moreover, dynamic spectrum access made possible by AI-powered cognitive radio systems would increase wireless network adaptability and performance by employing improvement.

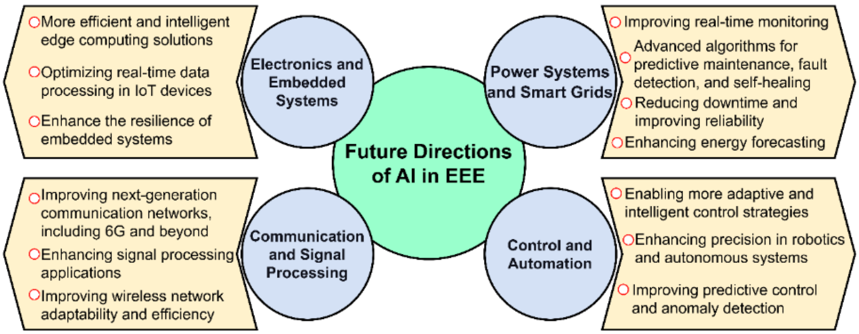

Figure 5. The future directions of AI in EEE.

Advances in embedded systems and AI-driven electronics will result in more intelligent and efficient edge computing solutions. Embedded processors driven by AI will maximize real-time data processing in IoT devices, enhancing computing capability and energy economy. AI-based hardware security solutions will also improve embedded systems' resistance to cyberattacks. Combining AI with neuromorphic computing will support the creation of energy-efficient AI hardware, allowing more advanced AI uses in settings with limited resources.

9. Conclusion

This chapter looks closely at how AI may be used in EEE. Examining important disciplines such as power systems, control systems, signal processing, electronic design automation, and embedded systems helps this chapter highlight artificial intelligence's revolutionary impact on the sector. It also seeks to define current challenges and opportunities, providing a structure for professionals and researchers. Moreover, AI is revolutionizing the area of EEE by offering fresh solutions for longstanding challenges and enabling the progress of next-generation technologies. The area's continuous development will depend on artificial intelligence integration as a significant determinant of the advancement of development and creativity. This chapter aims to clarify the recent background of AI applications in EEE, which is acting as a significant source of information for students, academics, and industry practitioners.

In conclusion, the future of AI in EEE will be characterized by increased automation, intelligence, and efficiency across multiple disciplines. By leveraging AI-driven innovations, power systems, industrial automation, communication networks, and embedded systems will achieve higher levels of optimization, security, and adaptability, paving the way for next-generation intelligent engineering solutions.

List of Abbreviations

Abbreviation	**Explanation**
AI	Artificial Intelligence
ANN	Artificial Neural Network
CNN	Convolutional Neural Network
DFNN	Dynamic Fuzzy Neural Networks
DL	Deep Learning
DLC	Dual-Loop Controller
EEE	Electrical and Electronics Engineering
EV	Electric Vehicle
FLC	Fuzzy Logic Controller
FOPID	Fractional Order Proportional Integral Derivative
GA	Genetic Algorithm
GNN	Graph Neural Networks
IoT	Internet of Things
LQR	Linear Quadratic Regulator
MCS	Monte Carlo Simulation
ML	Machine Learning
MPC	Model Prediction Control
PCA	Principal Component Analysis
PSO	Particle swarm optimization
PSO-PID	Particle swarm optimization - PID controller
PV	Photovoltaic
RBD	Reliability Block Diagram
RNN	Recurrent Neural Networks
SDN	Software-Defined Networking
ST-SMC	Super-twisting sliding mode control
SVM	Support Vector Machine
V2G	Vehicle-to-Grid

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