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Artificial Intelligence for Power System Protection and Fault Diagnosis

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Abstract: The growing complexity of modern power systems, driven by the integration of renewable energy sources, distributed generation, and evolving grid structures, has highlighted the limitations of traditional protection methods. Artificial Intelligence (AI) presents a revolutionary approach to increase power system protection and fault detection. In this paper, the use of different AI techniques, including machine learning, deep learning, expert systems, and fuzzy logic in optimizing fault detection, fault classification, localization, and adaptive protection schemes will be reviewed. The use of AI-based systems allows a more precise, real-time fault detection, predictive maintenance, and dynamic coordination of protection relays, which is beneficial in grid stability and reliability. Nonetheless, the AI solutions to power system protection are not supported, and there are problems with data quality, computational complexity, the proper work with existing systems, and security issues. These challenges are also discussed in this paper, and the future of AI with respect to developing smarter and more resilient power systems. The future use of AI in power system protection is set to transform the industry because of the promise of quicker, more flexible, and effective fault handling.

Keywords: Power System Protection; Fault Diagnosis; Artificial Intelligence; Machine Learning; Adaptive Protection Systems

1. Introduction

Robot Having reliable and stable power systems is important in terms of providing the necessary electricity supply to homes, industries, as well as important services [1]. The fault detection and isolation play a large role in the efficient operation of power systems as they aim to reduce service interruptions, damage to equipment, and grid stability. The protection mechanisms in the power systems have, traditionally, depended on time-proven practices, like overcurrent relays, differential protection, and distance relays that identify and handle the fault to minimise the amount of damage. Although these techniques have worked adequately in the industry, they tend to become insufficient when the challenges are about complex and modern power systems characterized by distributed power generation, renewable energy, and a dynamic grid system. In addition, considerations of quick fault detection and more precise protection systems are of greater necessity as grids become complex and larger [2].

In that regard, Artificial Intelligence (AI) has become an effective solution when it comes to the power system protection and fault detection. Techniques to revolutionise monitoring, analysis, and management of power systems are the AI incorporates a variety of techniques such as machine learning (ML), deep learning (DL), fuzzy logic, and expert systems. Utilization of AI in power systems has the potential to introduce major improvements to real-time fault diagnosis, classification, localisation, isolation, predictive maintenance, and decision-making procedures. Machine learning algorithms can be used to analyse huge sets of data in real-time, detect complex patterns and tendencies that would have been overlooked by conventional methods, and dynamically respond to changing system conditions in order to guarantee optimal performance [3-4].

The use of AI in the power system protection is particularly notable in the age of Smart Grids. Such intelligent grids require protection schemes that not only are fast, reliable but also flexible and able to respond to the new nature of faults due to renewable energy sources or other dynamic components. Within this situation, AI has the elasticity to build dynamic protection structures which would adapt their conduct in real-time according to the data given by the grid, enhancing the competence of the system as well as the precision of fault diagnosis. Moreover, there is an increased application of AI and predictive maintenance models, which means that operators can predict when a piece of equipment will fail to work and avoid costly downtimes [5].

Nevertheless, although the benefits of AI in power system protection cannot be overestimated, many issues have to be dealt with [6]. Such issues as the complexity of the power system, the necessity of large volumes of high-quality data, and the integration of AI into existing protection and control systems are only some of the many hurdles that should be addressed. In addition, when implementing AI models in actual time protection, their computing requirements, particularly when they rely on deep learning, may pose a problem in becoming widely adopted. The strength and soundness of the AI-based protection systems, their resistance to the possible weak points and attacks of adversaries, is the issue of great concern, too. Moreover, standardization can also be discussed; it can be argued that numerous AI methods do not have any universal rules and regulations, and this presents a challenge in implementing the method in various power systems infrastructures [7].

The role of AI in power system protection and fault diagnosis is the subject of the review provided in this paper to summarise the present state of applications, techniques, and solutions applicable to real life, and the challenges that are still waiting to be addressed. Discussing the potential of AI in modernizing the protection systems and diagnosing operational faults, as well as boosting the resilience of systems in general, this paper will provide a great opportunity to better understand how AI can reinvent the current way of protection and maintenance of power systems in the coming years. It aims to provide an unbiased image of AI potential, at the same time notifying about the spheres that should be the target of additional research and development activities in order to achieve the full potential of AI in the power sector [8].

Secondly, Framing Principles of protection of the power system, key AI methods developed in the field, and the way they can be applied to fault detection and diagnosis, and the issues of implementation of AI into the power system will be discussed. Finally, the conclusion determining the prospects of the field and future research orientations will be carried out. After this review, the reader will understand more fully how AI has the potential to add innovation to the current trajectory of power system protection and how this will eventually enhance grid stability, reliability and performance against the backdrop of an ever more complex energy environment [9-11].

2. Fundamentals of Power System Protection and Fault Diagnosis

Power system protection is an important area in electrical engineering that addresses the stability, reliability, and safety of power systems. This section prepares the ground on which the least general principles of the workings of power system protection and fault diagnosis are to be understood and, thus, frames the role that Artificial Intelligence (AI) can bring to enhancing its functionality. The part is subdivided into two important aspects, that is, the main principles of fault diagnosis and protection, and the comparison of the traditional protection techniques with AI-based tools [12].

2.1 Significant Protection and Fault Diagnosis Ideas

2.1.1 What are protective relays?

Protective relays in power systems are important devices which monitor the normal condition in the system (e.g. to detect a fault situation in the system) and take the necessary actions to break the connection in the affected area. Such relays track the electrical values (e.g. current, voltage, frequency) on the system, and when a fault is detected, they send a trip signal to circuit breakers, disconnecting the faulty component of the system. The relays used depend on the nature of the fault as well as the protection requirement applied to different applications. An illustration is that overcurrent relays are applied on a circuit to come out of line when current on the circuit reaches a preset limit, and are relays applied to find faults between two points by comparing current at two locations [13].

2.1.2 Classes of Faults in a Power System

Power system faults are some ways of defining it as abnormal electricity conditions that interfere with the normal conduct of electricity. These may be divided into two types:

- Transient faults: Temporary faults, lightning strikes, switching operations, etc. They usually resolve themselves after the cause is eliminated.
- Permanent faults: The long-term faults that can be caused by intermediate interventions, such as cable damage or short circuits.

Short circuits (e.g., line-to-ground, line-to-line and three-phase faults) are the most common types of faults that, when not sensed and cleared within a short time, can result in major damage. System stability is also threatened by open circuit faults (e.g. broken transmission lines) [14].

2.1.3 FDI

Detecting the fault is the method of determining the location and occurrence of the fault. Conventional approaches to fault detection are used to monitor the electrical signals and detect their deviations from normal operating conditions. After a faulty situation has been identified, the isolation strategy, as developed by the protection system, must then determine the mode of operation that would effectively isolate the affected section of the system to avoid any further damage or interruption in service [15].

Isolation of faults is important as it constrains the effect of the fault on the rest of the system. As an example, in case of a fault in each part of the grid, this error should be isolated as soon as possible to prevent the interference of this error with other parts of the grid.

2.2. The Conventional vs Artificial Intelligence

2.2.1. Conventional Protection Procedures

- Time-Overcurrent Protection: This is one of the simplest schemes of protection, where a relay connects after a fixed interval following the occurrence of a certain level of current. Although this is effective pertaining to overcurrent conditions, it is not precise and can therefore not differentiate various types of faults.
- Differential Protection: In this protection scheme, the current going in and coming out of a device (e.g. a transformer) is compared, and the breaker is operated in the event the difference is greater than a specified amount. It is dependable, however needs complicated configuration and integration of equipment.
- Distance Protection: This method is mostly applied in the transmission lines, and the method measures the difference in impedance between the relay and the fault location. The calculated impedance is used to calculate the fault-to-distance at which the protection system trips. It is more advanced but may not give as precise results in complicated grid formations [16].

Although conventional techniques, such as these, have served as the pillars of power system protection since the 20th century, they are not suitable in a complicated grid network. These are mostly based on simple threshold-based rules, which do not readily respond to dynamic situations or fault combinations. Furthermore, they usually involve a lot of coordination among the relays, and they may lack flexibility in response to unforeseen or new faults since this is based on preset settings [17].

2.2.2 Why Chatbots are Needed

The upgrading of the Smart Grids with their complex networks and varying power quality production (including renewable energy) requires more advanced forms of protection. Solutions that apply artificial intelligence (AI) and, most notably, laboratory methods of artificial intelligence, such as machine learning (ML) and deep learning (DL), have the potential to supplement conventional protection plans by learning from large volumes of data and making immediate decisions based on fluctuating circumstances [18].

The AI-based protection systems have the potential of:

Enhance the detection and classification of faults with better accuracy because the protection schemes can identify patterns in data that may not be identified in the traditional protection schemes. The AI models can also be trained to identify the difference among different kinds of faults, e.g. identifying the difference between short and transient faults.

- Be ready to change within real-time conditions. The dynamic and responsive nature of protection mechanisms can be provided by AI that constantly learning based on system performance and refines its protection algorithms based on it.
- Increase or enhance the accuracy of locating the faults through the application of AI models that interpret the non-small amount of data inputs from diverse sources to reveal the fault location with

accuracy.
- Facilitate predictive maintenance with the analytics of the equipment breakdowns by time and being able to determine when the items will malfunction and so being able to replace or repair and before it happens.

At its essence, Artificial Intelligence may bring needed flexibility and intelligence to the power system protection. It has the potential to be used as an addition or even a substitute for conventional measures because it also makes them more flexible, accurate, and considers the growing complexity of today's power grids [19].

3. AI Techniques for Power System Protection

In this part, the attention is devoted to the Artificial Intelligence (AI) methods that have been utilized to enhance fault diagnosis and protection of the power systems. Innovative approaches AI provides to complement the traditional protection systems include the ability to better detect faults, real-time flexibility, and foresight: AI methods such as machine learning (ML), deep learning (DL), fuzzy logic, and expert systems can be used. In this section, we are going to discuss major AI techniques that have worked out in the process of power system protection [20].

3.1. Machine Learning and Deep Learning

Overall, in a supervised learning problem, labelled information is given to train an algorithm, input data can be seen, such as current and voltage values and the ground truth data, such as the type of fault, or no fault. This method is employed in the construction of models that can be used to classify the various types of faults (e.g. short circuits or open circuits) and fault condition prediction. Fault classification and fault detection utilizing machine learning algorithms are commonly done using decision trees, support vector machines (SVMs) and k-nearest neighbours (KNN). These models can generalize on past fault data to forecast fault events in the future or for real-time identification of fault types [21].

Unsupervised learning permits it to be done without labelled data, unlike supervised learning. Rather, it determines trends and rare occurrences in data, as per the ways to define the grouping or the decrease in the number of dimensions. This comes in at times when there is little labelled data. To detect faults that may appear but have not been seen before, methods of unsupervised learning, commonly k-means clustering or principal component analysis (PCA), can be trained to recognise anomalous or faulty scenarios within the system so that subsequent faults that have not been observed previously can trigger an appropriate response within the system [22].

The subset of machine learning, Deep learning, is the study of multi-layered neural networks and the ability to model complicated relationships in massive data. It can find a particular use in feature extraction, the classification of faults, and future fault prediction. Deep learning techniques: This is one of the most widespread methods used, and Artificial Neural Networks (ANNs) are applied to emulate the operation of the human brain in the form of detecting and classifying faults. They form quite powerful tools for modelling complex fault conditions in power systems because they can process non-linear relationships in data. Convolutional Neural Networks (CNNs) are computational models initially used on image-recording scenes but modified to apply to time-series information that includes power system signs. It can automatically identify useful features (such as waveforms in currents of a power system) without having to extract the feature manually. The Recurrent Neural Networks (RNNs) can manipulate sequential data and be applied in power system protection when other events that occurred in the past are vital in the sense of system activity. As an example, RNNs may be used to forecast faults in time-series sensor data concerning a sensitive duration of time.

It is the case because deep learning methods are more suitable in complex cases where other algorithms cannot find patterns, which is frequent when it comes to real-world power systems, as the data is quite noisy or very volatile [23].

3.2 Fuzzy Logic and Expert Systems

An expert system is an artificial intelligence computer-based system whose purpose is to simulate the decision capabilities of a human expert in a specialised field. These systems are based on a set of knowledge and inference rules which are used in the decision-making process or even solving problems. Expert systems are applied in power system protection in detecting the fault, detecting its type and providing the most suitable suggestion. Their operation is based on the rules established based on the experience of human experts and on the experience of the work of the system. To give an example, the expert system may recommend what protective relays need to be tripped or what action can be taken so that the part of the grid that has tripped is isolated in the event of a fault [24,25].

Fuzzy logic is a mathematical theory addressing uncertainty, imprecision, so it is appropriate in the real world where precise values cannot be found in all cases, or the data is imprecise or erroneous naturally. Situations may also occur when the fault conditions are not so obvious or when any method generally available may probably break down; in this situation, one may utilize fuzzy logic in modelling such a condition. To use another example, when trying to detect a fault, fuzzy logic will be able to process imprecise data (readings of a sensor becoming neither regular nor faulty) and react in a different way that is determined by the situation (or context). Relay coordination on complex relaying applications is also done using fuzzy systems, whereby multiple relays should be able to communicate with each other using fuzzy behaviour to isolate faults without causing any interference to the whole system [26].

3.3. Mixed AI Methods

Although every AI approach has its advantages, integrated AI approaches can develop a more comprehensive and reliable protective system. The hybrid AI solutions use the mutually complementary capabilities of multiple models to address the nature of complexities in power system protection. Neuro-fuzzy systems are the systems that merge artificial neural networks (ANNs) with fuzzy logic to enjoy the joint advantages of the two, a learning potential of neural networks and the processing of uncertain data in fuzzy logic. The reservoir-based systems can be applied in the detection as well as classification of faults, with the neural network being trained on how the system behaves and the fuzzy logic handling ambiguous or fuzzy data. The ensemble method of learning, which integrates several models of machine learning, can be used very well in the diagnosis of faults in a power system, whereby each algorithm can concentrate on a specific factor of the information to give the entire system a better capability of identifying and learning faults.

Hybrids are applied in more accurate fault localization where the advantage of different techniques is multiplied to determine the accurate localization of a fault with more reliability than an individual method. Hybrid models can also adaptively learn and adjust protection settings in real time, with changing grid conditions and fault situations, and, thus, hybrid models can be more responsive to changing grid conditions and fault scenarios with adaptive protection schemes [27].

The section has talked about several AI methods that can have major contributions to power system protection and fault diagnosis. To detect, classify and predict the faulting, the machine learning and deep learning models are powerful tools to help, and the certainty of the faults is dealt with by the expert systems and fuzzy logic. Moreover, hybrid AI solutions, which use several techniques of AI, are contributing to the elimination of the weaknesses of a single model and ensuring more safety of the security systems. Such AI methods hold an exciting future in the context of the next generation of power system protection, to be more precise, they will be more precise, more flexible, and smarter in responding to system faults and anomalies [28].

4. Applications of AI in Power System Protection and Fault Diagnosis

The field of AI has a myriad of feasible applications in improving the capability of power system protection and fault diagnosis. The conventional protection practices tend to be narrowed down by the fact that some of them cannot accommodate the new complex relational and dynamic behaviours of contemporary power systems that might entail distributed energy resources, renewable sources, and a changing grid topography. The limitations are solved by AI technologies, which are more intelligent and adaptive. Over here, we will delve into the main ways in which AI is changing power system protection and fault diagnosis [29].

4. 1 corresponding to Fault Detection and Classification

The AI-based systems have been proven to be specifically useful in enhancing fault detection classification. Detection of faults in the conventional protection systems is done by monitoring some aspects of the system, like current and voltage, but in many cases, it might not be able to distinguish between the categories of faults or might not detect any faults under some circumstances. This process can be tremendously simplified with the help of AI models, like the ones based on machine learning or deep learning, that may locate and classify the faults in a much more accurate way.

Large datasets including fault conditions can be used to train the machine learning algorithm so that the model will learn about the specific peculiarities of various types of faults (e.g., line-to-line faults, ground faults, and open circuit faults). These AI models can identify complicated patterns that may not be identified using conventional means, thus making the process of detecting the faults more accurate and faster. As an example, an AI system could identify the fault type by the shape of the current and voltage waveforms and possibly pick up some transient faults that would not have been detected by conventional means.

Moreover, the changes in the grid might be real-time, and AI models could learn to adapt to those situations; this can be especially helpful in grids with a high share of renewable sources. Since these sources cause the introduction of variability and unpredictability of the grid, AI will enable identifying faults in these circumstances with greater precision and speed [30,31].

4.2 Adaptive protection systems

Adaptive protection is one of the most promising technologies for using AI in power systems. They are intended to provide a reaction to the current situation in real-time to dynamically change the protection parameters per the current system conditions, grid settings, or terminology of the fault characteristics. Older protection systems have fixed settings, which are not optimal in every case. An example would be that settings of fault detection and clear times may not be appropriate to all fault conditions and loading conditions, which results in unnecessary interruptions or slow isolations of faults.

With each new and changing system-related data, AI can be used to increase protection systems, automatically toning down protection settings in response to change. As an example, a protective relay might have its trip times adjusted dynamically by an AI model during or after a fault event, depending on the operating load and fault conditions (or local environment conditions). By doing that, this adaptive solution enables the system to maximize protection without involving human interference and, therefore, there is a decreased risk of unwanted shutdowns and enhanced grid stability. Next, the AI can also assist in coordinating the protection of several devices in the system in such a way that the isolation of faults becomes efficient as well as fast enough to prevent the impact on follow-up protections [32].

4.3. Predictive Maintenance and Fault Diagnosis

Predictive maintenance is a process of forecasting equipment breakdown before it happens, and therefore, the application of AI is crucial in this process. The traditional approaches to maintenance are usually either time-based or reactive, wherein maintenance is only done when a defect appears in the system or when the machinery's performance levels drastically decline. Predictive maintenance, however, leverages AI in order to examine history, sensor measurements, and other factors to predict when one such component is most likely to break down.

By using data on wear and tear, operating performance and records, machine-learning models can forecast the possible fault in things like transformers, circuit breakers or generators. Such predictive models will allow detecting the early signs of the deterioration when repairing can be conducted based not on the failure but rather on the upcoming failure before it can manifest in unusual vibrations, temperature, or changes in electricity. This curbs the downtime, increases reliability and cuts down on maintenance expenses as repairs can be carried out at the most convenient times. Besides, AI can assist in performing fault diagnosis in real-time conditions and suggest effective remedial measures to the operators based on the nature of the fault. To give an example, in the case of a fault being detected, the AI models will be able to process information about the grid in a relatively short period to determine whether the fault was caused by equipment failure, congestion in the network or exogenous factors. This will assist operators to make better decisions faster and will also diminish the repeat failures [33-35].

4.4. Fault Localization

The precise localization of the fault, particularly in bigger and multifaceted transmission and distribution networks, is one of the more difficult issues of power system protection. Fault localization using impedance-based methods has generally been done through distance relays, which may not always be accurate or quick enough, especially where the fault is intermittent or transient. Fault localization can be enhanced by AI analysing the data recorded by different sensors distributed in different groups within the system. Through the AI algorithm, e.g. machine learning or deep learning, the system will be able to process the data fast and identify the location of the fault significantly accurately. As an example, AI models will have the capability to assess the voltage and current courses in various areas of measurement, as well as recognise the precise location in a transmission line where the fault occurred, and will know where repair teams can find and identify the fault to repair it.While the other application of AI, including the use of wide-area monitoring, can also be integrated to improve fault localization in real-time, subsequent quick fault detection using AI results in reduced disturbances in the grid. This online response enhances power system protection response aspects and prevents needless power switch-offs offs thus leading to improved grid stability [36].

To conclude, AI will significantly change the process of power system protection and fault diagnosis. AI increases the reliability, efficiency, and flexibility of modern power systems by allowing more accurate fault detection, adaptive protection strategies, predictive maintenance and precise fault localization. These applications not only guarantee faster recovery times and less downtime but also facilitate the management of the increasing complexity of power networks that already include alternative energy resources, distributed generation, and smart grid technologies. By combining the use of AI-based methods within the protection schemes, a stronger approach towards the modern needs of the power systems can be achieved [37].

5. Challenges and Limitations

Although Artificial Intelligence (AI) is a strong contribution to power system protection and fault diagnosis, there exist some challenges and limitations to the integration of Artificial Intelligence (AI) with current power systems. These include data-related problems, computational complexity, system integration issues, reliability concerns, and security threats. These challenges should be addressed to make full use of AI in power systems. This part is devoted to the primary threats and drawbacks related to protection systems based on AI.

5.1 Data difficulties

The quality and availability of data are one of the main challenges in the implementation of AI to protect power systems and diagnose faults. Machine learning and deep learning algorithms (models) of AI need much data to learn and perform correct predictions, especially when the data is of high quality. Such data in the power systems is usually sensor data consisting of measurements of current, voltage, temperature, and status by different grid elements. Nevertheless, a few data-related problems may slow down the achievement of AI systems:

1. **Data scarcity and imbalance:** In most power systems, there might be limited quality data surrounding faults, and this is particularly true when it comes to rare fault instances. Any AI models trained using little data or unbalanced data is not likely to perform very well since they will be skewed towards the non-fault conditions, given that they are much more common than the fault conditions. This may lead to erroneous identification of faults or even new types of fault failures to be identified.
2. **Noisy/Incomplete Data:** Power systems produce massive data, which day often noisy, corrupted or incomplete due to malfunctioning of sensors, transmission faults, etc. Unless properly pre-processed or filtered, AI models might fail to make any sense of such data.
3. **Real-Time Data:** A lot of protection systems based on AI require input in real-time to provide them with data to identify faults and react as soon as possible. The real-time data can, however, be difficult to get and process, pertaining to its latency of bandwidths, delays in communications and infrastructural monitoring of the grid continuously.

These difficulties in data must be overcome by developing more trustworthy data capture systems in addition to further preprocessing of data during the timeframe to make sure that the AI models can perform [38,39].

5.2. Computational complexity and Integration

Deep learning, in particular, AIs can be computationally expensive and may even demand high amounts of input processing power. This poses a difficulty in implementing AI-based protection systems in a real-time scenario:

1. **Heavy Computation:** Deep learning models, including convolutional neural networks (CNNs) or recurrent neural networks (RNNs), demand a rather large amount of computing resources to process huge quantities of data. This may be challenging in detecting and protecting a fault in real-time, more so in large power systems; there are limits in the number of sensors to be installed, and heavy information flow.
2. **Real-Time Processing:** Power system protection systems must act within milliseconds to guarantee quick fault location and reduce equipment damage. The frequency of data processing by AI models and reaching decisions must be quick, such that the decision process should be faster and not cause delay in

fault detection and clearance. Finding the balance between efficiency and the complexity of AI models remains an issue.

3. **System Integration:** A situation may be complicated by incorporating AI models into current power system protection systems. Conventional security methods that usually rely on rigid configurations and naive algorithms will have to be altered or enhanced to ones that rely on AI in protection. The process of integration may include considerable input in order to make it compatible with the available hardware and software systems in place, and even the operational procedure might have to be modified.

The AI-based systems are computationally complex, and integrating such systems, including the means to integrate them, demands more efficient algorithms and hardware accelerators (e.g., GPU or edge computer) and light integration approaches to enhance real-time performance and scalability [40].

5.3. Reliability, Security and Standardization

AI in power systems raise critical issues concerning the reliability, security, and uniformity of the AI-based protection system.

1. **Reliability:** AI models, especially ones based on machine learning, are trained on past information and can generalize poorly when applied to novel or otherwise unseen examples of faults. This is a risk because the AI may be put in a situation of fault which was not in the training data. The system can respond in the wrong manner, leading to a delayed fault isolation or inappropriate actions being undertaken. The most important thing is to provide AI models that are resistant and stable in different fault circumstances.
2. **Security:** As AI penetrates our power systems even further, cybersecurity is a key question of concern. Constantly updating data and decisions are the key aspects of AI-based protection systems, and they are easily exposed to cyberattacks or adversary attacks. This phenomenon may also expose the system to potentially harmful admissions because malicious actors can falsify the input of the AI models into the system or influence the decision-making process. To protect AI-based protection systems against such threats, it is necessary to apply powerful encryption, detect anomalies, and mitigate attack measures.
3. **Standardization:** Implementation of AI in the sphere of power system protection is not very developed yet, and there is no common way to handle AI in the sphere of protection, tools and procedures. AI models may vary with power utilities, and thus, it might not be easy to have interoperability across systems. Moreover, it is possible that the lack of common standards will not allow granting the popularization of the AI-based solutions within the power sector effectively [41-44].

To resolve these problems, there should be additional studies and cooperation to establish standardized recommendations on the use of AI in power systems, protecting systems, and there should additionally be the requirement that AI systems adhere to the highest levels of reliability and security [45].

Although the potential of AI in enhancing power system protection and fault diagnosis is outstanding, several issues must be overcome to gain widespread application of AI. The problems related to the data, which include data scarcity, noise, and real-time data processing requirements, must be solved in the form of more efficient data capturing, data transformation, and data enhancement methods. The AI monitoring is more based on their computational complexity, and the challenges related to the integration of AI models into the existing systems imply the need to find more effective algorithms and hardware solutions. Moreover, to ensure safe and effective application of security-based protection systems on AI, it is necessary to ensure reliability, security, and standardization of such systems. Through these obstacles, AI has the potential to become a central mechanism of establishing next-generation protection in the power system, providing quicker, more responsive, and more precise fault detection and restoration actions [46,47].

6. Conclusions

The possibilities of Artificial Intelligence (AI) are great in protecting power systems and fault diagnosis. Even though the traditionally employed protection strategies performed well in most of the traditional situations, they are failing to keep up with the requirements of modern power systems which are increasingly becoming very complex in response to the integration of renewable energy sources and distributed generation coupled with the changing grid structures. The possible solutions introduced by AI applications, including machine learning, deep learning, expert systems, and fuzzy logic, will not only help better identify faults, classify, and localize them but also facilitate more flexible, predictive, and real-time protective measures.

Protection systems based on artificial intelligence increase the precision of fault detection, allow dynamic coordination of relays, and can support predictive maintenance through analysis of huge volumes of operating data. Utilizing the potential of AI, power systems will be able to move on toward proactive protection and minimize downtimes, equipment damage, and increase the overall stability of a grid. Also, the fact that AI can incorporate real-time changes in the grid makes it a highly asset when it comes to optimizing protection schemes in situations that are complex and unpredictable. Nevertheless, as much as it has numerous benefits associated with it, there are several issues that surround the integration of AI into power system protection. These comprise the quality and availability of data, intense computing requirements, intricacy of systems integration, as well as issues on reliability, security, and standardization. These difficulties will be surmounted through the ongoing developments of the data acquisition systems, AI algorithms, computing infrastructure, and industry standards. Additionally, working on cybersecurity risks will also be of utmost importance to guarantee the security and consistency of AI-based protection systems against rising cyber threats.

Conclusively, AI can revolutionise the area of power system protection as we will now be able to detect, diagnose faults intelligently, faster and more reliably. As the research and development discriminate the existing problems, AI will take an even more central position in the future of power system protection, helping to build stronger, more efficient and versatile grids. Properly developed and implemented, AI has the potential to enable power systems to adapt to technological, environmental and customer needs of an ever-developing energy market.

Reference

[1] National Academies of Sciences, Medicine, Division on Engineering, Physical Sciences, Board on Energy, Environmental Systems, Committee on Enhancing the Resilience of the Nation's Electric Power Transmission, Distribution System. Enhancing the resilience of the nation's electricity system. National Academies Press; 2017 Oct 25.

[2] Munasinghe M. The economics of power system reliability and planning. Baltimore; 1979 Jan.

[3] Folly KA. Artificial intelligence could revolutionise the education and training of the next generation of power and energy engineers and researchers. Journal of Energy in Southern Africa. 2025;36(1):1-3.

[4] Abdelaziz AY, Aleem SH, Yadav A, editors. Artificial Intelligence Applications in Electrical Transmission and Distribution Systems Protection. Boca Raton, FL, USA: CRC Press; 2021 Oct 21.

[5] Bakkar M, Bogarra S, Córcoles F, Aboelhassan A, Wang S, Iglesias J. Artificial intelligence-based protection for smart grids. Energies. 2022 Jul 5;15(13):4933.

[6] Alhamrouni I, Abdul Kahar NH, Salem M, Swadi M, Zahroui Y, Kadhim DJ, Mohamed FA, Alhuyi Nazari M. A comprehensive review on the role of artificial intelligence in power system stability, control, and protection: Insights and future directions. Applied Sciences. 2024 Jul 17;14(14):6214.

[7] El Rhatrif AB, Bouihi BO, Mestari MO. AI-based solutions for grid stability and efficiency: Challenges, limitations, and opportunities. Int. J. Internet Things Web Serv. 2024 Jan 11;9:16-28.

[8] Minakawa T, Ichikawa Y, Kunugi M, Shimada K, Wada N, Utsunomiya M. Development and implementation of a power system fault diagnosis expert system. IEEE Transactions on power systems. 1995 May;10(2):932-40.

[9] Drukker K, Chen W, Gichoya J, Gruszauskas N, Kalpathy-Cramer J, Koyejo S, Myers K, Sá RC, Sahiner B, Whitney H, Zhang Z. Toward fairness in artificial intelligence for medical image analysis: identification and mitigation of potential biases in the roadmap from data collection to model deployment. Journal of Medical Imaging. 2023 Nov 1;10(6):061104-.

[10] Awadallah MA, Morcos MM. Application of AI tools in fault diagnosis of electrical machines and drives-

an overview. IEEE Transactions on energy conversion. 2003 May 28;18(2):245-51.

[11] Raza A, Benrabah A, Alquthami T, Akmal M. A review of fault diagnosing methods in power transmission systems. Applied Sciences. 2020 Feb 14;10(4):1312.

[12] Alhelou HH, Abdelaziz AY, Siano P, editors. Wide area power systems stability, protection, and security. Springer; 2021.

[13] Elmore WA. Protective relaying: theory and applications. CRC press; 2003 Sep 9.

[14] Tleis N. Power systems modelling and fault analysis: theory and practice. Elsevier; 2007 Nov 30.

[15] Chen K, Huang C, He J. Fault detection, classification and location for transmission lines and distribution systems: a review on the methods. High voltage. 2016 Apr;1(1):25-33.

[16] Suliman MY, Ghazal M. Design and implementation of overcurrent protection relay. Journal of Electrical Engineering & Technology. 2020 Jul;15(4):1595-605.

[17] Kannuppaiyan S, Chenniappan V. Numerical inverse definite minimum time overcurrent relay for microgrid power system protection. IEEJ Transactions on Electrical and Electronic Engineering. 2015 Jan;10(1):50-4.

[18] Gandoman FH, Ahmadi A, Sharaf AM, Siano P, Pou J, Hredzak B, Agelidis VG. Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems. Renewable and sustainable energy reviews. 2018 Feb 1;82:502-14.

[19] Jiang JA, Chen CS, Liu CW. A new protection scheme for fault detection, direction discrimination, classification, and location in transmission lines. IEEE Transactions on power delivery. 2003 Jan 31;18(1):34-42.

[20] Singh A, Shankar R, Kumar A. A Comprehensive Review of Load Frequency Control and Solar Energy Integration: Challenges & Opportunities in Indian Context. Energies (19961073). 2025 Feb 15;18(4).

[21] Abdelgayed TS, Morsi WG, Sidhu TS. Fault detection and classification based on co-training of semisupervised machine learning. IEEE Transactions on Industrial Electronics. 2017 Jul 13;65(2):1595-605.

[22] Shakiba FM, Azizi SM, Zhou M, Abusorrah A. Application of machine learning methods in fault detection and classification of power transmission lines: a survey. Artificial Intelligence Review. 2023 Jul;56(7):5799-836.

[23] Bikku T. Multi-layered deep learning perceptron approach for health risk prediction. Journal of Big Data. 2020 Jul 23;7(1):50.

[24] Hunt VD. Artificial intelligence & expert systems sourcebook. Springer Science & Business Media; 2012 Dec 6.

[25] Krishnamoorthy CS, Rajeev S. Artificial intelligence and expert systems for engineers. CRC press; 2018 Apr 24.

[26] Celikyilmaz A, Türksen IB. Modeling uncertainty with fuzzy logic. Springer Berlin Heidelberg; 2009.

[27] Sarker IH. Multi-aspects AI-based modeling and adversarial learning for cybersecurity intelligence and robustness: A comprehensive overview. Security and Privacy. 2023 Sep;6(5):e295.

[28] Ferreira VH, Zanghi R, Fortes MZ, Sotelo GG, Silva RD, Souza JC, Guimarães CH, Gomes Jr S. A survey on intelligent system application to fault diagnosis in electric power system transmission lines. Electric Power Systems Research. 2016 Jul 1;136:135-53.

[29] Afridi YS, Ahmad K, Hassan L. Artificial intelligence based prognostic maintenance of renewable energy systems: A review of techniques, challenges, and future research directions. International Journal of Energy Research. 2022 Dec;46(15):21619-42.

[30] Gadde H. AI-Powered Fault Detection and Recovery in High-Availability Databases. International Journal of Machine Learning Research in Cybersecurity and Artificial Intelligence. 2024;15(1):500-29.

[31] Lang W, Hu Y, Gong C, Zhang X, Xu H, Deng J. Artificial intelligence-based technique for fault detection and diagnosis of EV motors: A review. IEEE Transactions on Transportation Electrification. 2021 Sep 3;8(1):384-406.

[32] Bittencourt AA, De Carvalho MR, Rolim JG. Adaptive strategies in power systems protection using artificial intelligence techniques. In2009 15th International conference on intelligent system applications to power systems 2009 Nov 8 (pp. 1-6). IEEE.

[33] Ucar A, Karakose M, Kırımça N. Artificial intelligence for predictive maintenance applications: key components, trustworthiness, and future trends. Applied Sciences. 2024 Jan 20;14(2):898.

[34] Cardoso D, Ferreira L. Application of predictive maintenance concepts using artificial intelligence tools. Applied Sciences. 2020 Dec 22;11(1):18.

[35] Keleko AT, Kamsu-Foguem B, Ngouna RH, Tongne A. Artificial intelligence and real-time predictive maintenance in industry 4.0: a bibliometric analysis. AI and Ethics. 2022 Nov;2(4):553-77.

[36] Panahi H, Zamani R, Sanaye-Pasand M, Mehrjerdi H. Advances in transmission network fault location in modern power systems: Review, outlook and future works. IEEE Access. 2021 Nov 22;9:158599-615.

[37] Baxevanos IS, Labridis DP. Implementing multiagent systems technology for power distribution network control and protection management. IEEE Transactions on Power Delivery. 2006 Dec 26;22(1):433-43.

[38] Chai E, Zeng P, Ma S, Xing H, Zhao B. Artificial intelligence approaches to fault diagnosis in power grids: A review. In2019 Chinese control conference (CCC) 2019 Jul 27 (pp. 7346-7353). IEEE.

[39] Wong SY, Choe CW, Goh HH, Low YW, Cheah DY, Pang C. Power transmission line fault detection and diagnosis based on artificial intelligence approach and its development in uav: A review. Arabian Journal for Science and Engineering. 2021 Oct;46(10):9305-31.

[40] Heaven D. Why deep-learning AIs are so easy to fool. Nature. 2019 Oct 1;574(7777):163-6.

[41] Islam R, Rivin MA, Sultana S, Asif MA, Mohammad M, Rahaman M. Machine Learning for Power System Stability and Control. Results in Engineering. 2025 May 17:105355.

[42] Mishra M, Singh JG. A Comprehensive Review on Deep Learning Techniques in Power System Protection: Trends, Challenges, Applications and Future Directions. Results in Engineering. 2025 Jan 7:103884.

[43] Ness S. Integrating AI Models for Voltage and Current Monitoring in Autonomous Mobile Robots to Prevent Power System Blackouts. IEEE Access. 2025 Apr 11.

[44] Ogbogu CE, Thornburg J, Okozi SO. Smart Grid Fault Mitigation and Cybersecurity with Wide-Area Measurement Systems: A Review. Energies. 2025 Feb 19;18(4):994.

[45] Shobeiry SM. AI-Enabled Modern Power Systems: Challenges, Solutions, and Recommendations. InArtificial Intelligence in the Operation and Control of Digitalized Power Systems 2024 Nov 16 (pp. 19-67). Cham: Springer Nature Switzerland.

[46] Gorjian A, Eskandari M, Moradi MH. Conservation voltage reduction in modern power systems: Applications, implementation, quantification, and ai-assisted techniques. Energies. 2023 Mar 6;16(5):2502.

[47] Khan S, Yairi T. A review on the application of deep learning in system health management. Mechanical systems and signal processing. 2018 Jul 1;107:241-65.