International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2024 | Issue 61 | Volume 16 | Number 4 | Pages 302-311

OPTIMIZING POWER ELECTRONICS WITH AI: A LOOK AT CURRENT SUCCESSES, CHALLENGES, AND FUTURE DIRECTIONS

W.O. Falana [1]   S.N. Tackie [1,2]   B. Bilgehan [1,2]

1. Electrical and Electronic Engineering Department, Near East University, Nicosia, Northern Cyprus
falanaayode1@gmail.com, samuel.niitackie@neu.edu.tr, bulent.bilgehan@neu.edu.tr
2. Centre for Science, Technology and Engineering (BILTEM) Researchers, Department of Electrical and Electronic Engineering, Near East University, Nicosia, Northern Cyprus

Abstract- This paper presents an overview of several artificial intelligence (AI) technologies used in power electronics applications. Power electronics and artificial intelligence are growing technical research disciplines that have significantly contributed to better voltage conditioning and computing. This paper looks at the use of AI in power electronics, highlighting three significant applications and the obstacles faced. Power electronics is an area of power systems engineering that deals with medium-to-high voltage conditioning, mostly through the use of converters. The power circuit of these converters needs sophisticated control to ensure effective power switch switching. This is where the high computational capabilities of AI technologies are used. To increase the control capabilities of power electronic converters, new AI technologies are required. As a result, this analysis looks at the accomplishments and problems of applying AI to power electronics, as well as providing a roadmap for bridging the AI-power electronics divide.

Keywords: Power Electronics, Power Electronics Systems, Artificial Intelligence.

1. INTRODUCTION

Power electronics plays one of the most important roles in our modern world of today. It involves power conversion and energy control applications. Most of the roles and application of power electronics ranges from power systems, renewable energy, motor control systems, industrial automation, and much more. It is said that power electronic systems and devices are part of our everyday lives [1]. Artificial intelligence is a branch of computer systems and technology that can solve complex problems. As of today, AI has a wider range of applications. One of the main importance of AI in power electronics which has attracted a wide range of interest is its ability to automate complex problems and systems more efficiently and reliably [2].

AI viewed from an angle has been a powerful tool for improving the performance of power electronics systems. In recent research, it has been noted that AI systems can achieve improved energy management, fault detection, maximum efficiency, and reliability. With the implementation of AI into power electronics, it creates system capabilities that are self-aware and can self-adapt which then gives room for improved system autonomy, which is the future goal of power electronics systems [3]. Several branches of AI are commonly used in power electronics which are neural networks, fuzzy logic, genetic algorithms, machine learning, and reinforcement learning [4]. A neural network is a branch of AI that involves learning complex relationships and retrieving patterns between inputs and output in power electronics system applications.

Fuzzy logic is another branch of AI applications that handles nonlinearities and uncertainties in power electronics systems [5]. Genetic algorithms are a branch of AI that deals with tuning controller parameters, modeling designs, and optimization of power electronics systems. Machine learning is also another branch of AI that has a variety range of applications in power electronics systems, it involves analyzing complex data and the relationship between this data with the mindset of improving the performance and efficiency of power electronics systems [6]. Reinforcement learning is also a branch of AI widely adopted in power electronics which involves the development of adaptive control methods for applications in a dynamic environment. The major goal of AI in power electronics is to create systems that are efficient, reliable, and adaptable but this goal has been met with several challenges.

In this investigation, we will examine in depth the types of literature on AI applications in power electronics, as well as the issues that come with them. As a consequence, numerous research publications were examined, the majority of which were journal articles. Papers related to the topic of interest. The next part will discuss (i) AI applications and problems in fault diagnosis and condition monitoring. (ii) AI applications and challenges in modeling, control, and design of power electronic converters. (iii) AI uses and problems for wireless power transfers and future power electronics technologies.

Registered: 240502 | Article Info: 1926 | Accepted: 241101
Reserved: 240818 | Available: 241231

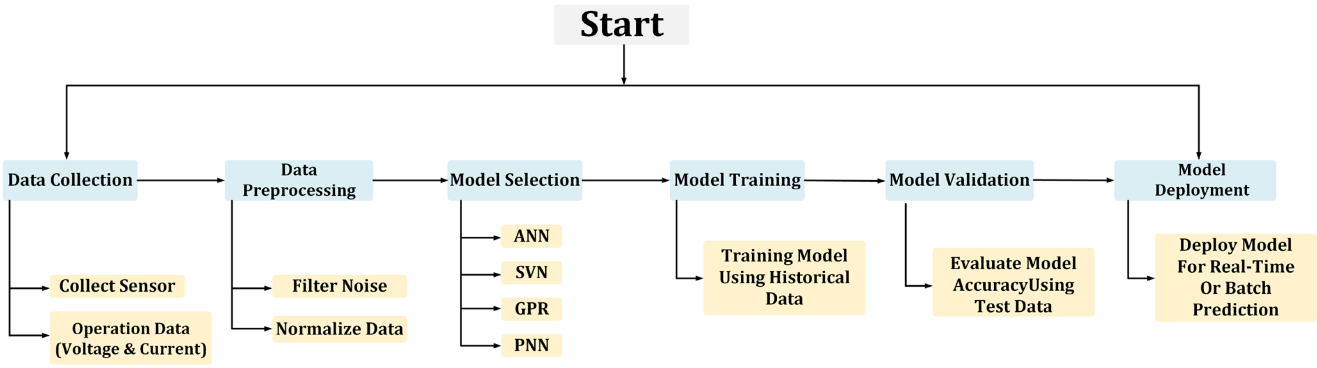

Figure 1. AI technique in modeling of power electronic converter

2. AI TECHNIQUES IN POWER ELECTRONICS

AI has emerged as one of the most prominent and powerful technologies. The primary purpose of AI is to execute activities that human brainpower can or cannot do but in a far superior manner. Nonetheless, the scope of AI has begun to broaden over time, with one such expansion aimed at improving systems in a more efficient, dependable manner. This is also consistent with the purpose of power electronics, which is to create power electronics systems and devices that are efficient, dependable, and deliver high-quality results. As a result, the use of AI may be extremely beneficial to power electronics systems and technology. Figure 1 shows AI techniques in the modeling of power electronics converters.

2.1. Machine Learning

Machine learning is a branch of AI that is aimed at developing statistical models and algorithms to enable machines and systems to perform tasks and duties without explicitly being programmed or instructed. Figure 2 shows the various categories of machine learning. These statistical models and algorithms can learn or make predictions from trends and sequences of events. There are three ways and methods of application of learning in power electronics. These are (i) supervised learning (ii) unsupervised learning and (iii) Reinforcement learning.

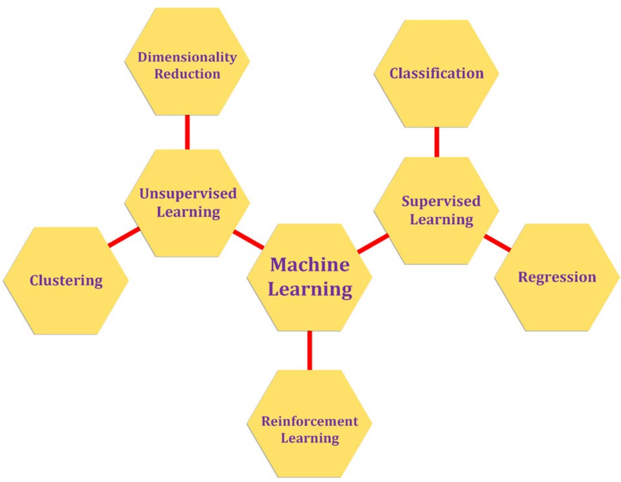

Figure 2. Machine learning process

2.1.1. Supervised Learning

This is when a machine is trained on input data and output data such that the machine can identify the patterns and relation between the input and output. Supervised learning applications in power electronics can be in two major forms which are (i) Classification and (ii) Regression.

i) Classification: this method of application is principally used for fault detection in power systems and devices by classifying different types of faults.

ii) Regression: this method of application is mainly used to predict power electronics system behaviors, especially in situations like load forecasting. This is done by modeling the relationships between the input data and output data.

2.1.2. Unsupervised Learning

This is when a machine or device is given input data for it to learn and determine the outcome of the output. Application of unsupervised learning in power electronics are:

i) Clustering: this method of application is done by identification of patterns in data and groups with similar or close data points, which can be used to distinguish different operating modes of power electronics systems and most times identification of abnormal patterns.

ii) Abnormality detection: this method of application is done by identification of deviations of power electronics systems behavior from normal operations, this helps to detect faults or inefficiencies in power electronics systems and devices.

2.1.3. Reinforcement Learning

This is when a machine or device does not require the training process but rather it's able to adapt suitable strategies and decisions to get a desirable outcome. This is used in designing and modeling controllers that can adapt to changing conditions in real-time. This helps to improve the efficiency and performance of power electronic systems and devices without the need for a predefined model. This applies to adaptive control of inverters, converters, and power electronics devices intending to improve efficiency and response time.

2.2. Neural Network (NN)

NN is an aspect of AI and a branch of neural network that can model and understand complex relationships in data. In cases like this large-scale data is usually involved. The application of neural networks to power electronics is:

- System modeling and complex pattern recognition: Due to the ability of deep learning models to understand complex relationships between data, it is usually and, in most cases, used in creating models that are accurate for power electronics systems. An example of such an application is used in predicting system failures and improving designs and models for power electronics systems.

2.3. Convolutional Neural Network (CNN)

CNN system uses three-dimensional data for image analysis and classification. This is mostly used or suitable for image data. The application of CNN to power electronics is

- Image-based monitoring and analysis: due to the ability of CNN to be able to handle image-based data, it can be applied to areas like condition monitoring in situations where the health performances of power electronics devices and component is a concern.

2.4. Recurrent Neural Network (RNN)

RNN system is a type of AI that uses sequential data or time series data. This is mostly used when data are sequential or when components are interrogatable based on semantics rules. The application of RNN to power electronics is predicting future behaviors of power electronics systems and devices based on available and historical data. This helps in effectively controlling systems with temporal dependencies such as load forecasting and real-time control of power grids.

2.5. Fuzzy Logic Systems

A fuzzy logic system can be explained as a type of reasoning and computing that is able to handle uncertainty and imprecision by replication of how humans make judgments. The application of fuzzy logic to power electronics is in areas of modeling of power electronics controllers that are robust and can handle this type of uncertainty and imprecise data and information.

2.6. Genetic Algorithms

Genetic algorithms are used in the designing and operation of efficient power electronic systems and device. This is done by determining the optimal size and component rating, selecting the configuration of efficient circuit elements, and tuning parameters of control algorithms for power electronic systems. Also, it can be applied in situations like adjusting operational parameters to maximize energy distribution of loads among multiple power electronics systems, to create a balance in performance, and also helps in creating robust power electronic systems that are efficient in detecting faults and performing correcting mechanisms.

2.7 Generative Adversarial Networks (GANs)

GANs can create artificial fault data by learning the pattern of distribution of real-world fault patterns. These artificial datasets can then be used to supplement training data, allowing machine learning models to detect problems that may not occur frequently in real-world operations. GANs, for example, could replicate failures like as short circuits, overloading, and component degradation in power converters or inverters, allowing them to train more resilient AI models.

2.8 Swarm Intelligence

For decentralized optimization and decision-making, swarm intelligence approaches are employed, which draw inspiration from natural phenomena such as ant colony optimization or bird flocking. These techniques can be used in power electronics for improving distributed systems, such as microgrid inverters, where local decisions are made according to local conditions. In large-scale power systems, swarm intelligence can assist in the simultaneous optimization of several goals, including cost, efficiency, and dependability.

3. APPLICATION OF NEURAL NETWORK TO POWER ELECTRONICS IN A PREDICTIVE CONTROL CIRCUIT

One of the applications of neural networks in power electronics circuits is in the case of predictive control of a power electronics circuit. A neural network-based predictive control system designed to reduce the error between the actual and estimated outputs of a power electronic circuit. In this case, by using the capabilities of adaptive learning strategies, it can predict the output of a given power electronics circuit at very high accuracy and adjust the parameters in such a way that the system can adjust in real-time so has to produce an efficient result.

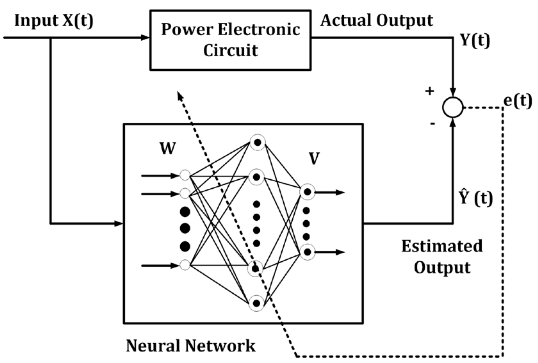

Figure 3. Neural network-based predictive control for power electronic circuits

In Figure 3, the control system is made up of a neural network that processes the same input signal as the power electronic circuit and also processes an estimated output. The difference between the actual output of the power electronic circuit and the approximated output from the neural network forms an error signal. This error signal is used to update the neural network, allowing it to learn and improve its predictions continuously. The parameters of Figure 3 are defined as:

- $X(t)$ is the input into the power electronic circuit
- $Y(t)$ is the processed $X(t)$ by the power electronic circuit which is now the actual output.
- Neural network (NN) is taken in the same $X(t)$ and processes it using weights and biases represented by W and v and then predicts an estimated output $\widehat{Y}(t)$
- $e(t)$ is the error signal which is the variance between the actual output $Y(t)$ and the approximated output $\widehat{Y}(t)$, This is computed by Equation (1):

$$e(t) = Y(t) - \widehat{Y}(t) \quad (1)$$

3.1. Feedback Loop

The error signal $e(t)$ is feedback to the neural network. In such a way the feedback loop is necessary for training and adjusting the neural network to minimize the error over time. This is done by continuously adjusting its weights and biases which allows the NN to learn and to predict output of power electronic circuit more efficiently.

3.2. Neural Network Structure

The neural network in this diagram (Figure 3) has various layers comprising input, hidden, and output layers. The weights W and V represent the connections between the neurons in these layers. the neural network processes the input $X(t)$ through these layers to produce the estimated $\widehat{Y}(t)$. The primary goal of this system is to minimize the error $e(t)$ by training the neural network to generate an estimated output $\widehat{Y}(t)$ which approximately matches the actual output $Y(t)$ This is one of the practical applications of neural networks in power electronics where the exact mathematical model of the power electronic circuit is complex or unknown, and a data-driven model like a neural network can provide a good estimation.

3.3. Applications

This system can be used in various power electronics control system applications such as motor drives, inverters, and converters. It helps to improve the performance, efficiency, and reliability of these systems by providing accurate control signals based on the neural network's predictions. Figure 4 shows an AI application in a power electronic converter. Which include 3 major phases which are data collection, modeling, and design optimization.

4. AI APPLICATIONS IN POWER ELECTRONICS

4.1. AI Application and Challenges in Fault Diagnosis, Condition Monitoring

Fault diagnosis and condition monitoring are critical in power systems, particularly in related fields such as rotating equipment, in order to ensure the machines' safety, dependability, and availability. Several research publications have demonstrated the effectiveness of AI in various domains. In [7], an AI vibration application is described that uses CC (correlation coefficient), EEMD (ensemble empirical mode decomposition), and SVD (singular value decomposition) to find defects. In [8], an AI application to vibration and current was utilized to diagnose numerous defects and anticipate mechanical and electrical failures under various operations utilizing a statistical feature known as support vector machines (SVM).

In [9], an application of AI in vibration analysis using deep learning demonstrated automated defect identification and diagnosis using frequency distribution without the use of standard feature extraction methods. In [10], deep learning is used to monitor induction motor bearings via stator current analysis under various load circumstances. AI has been used in a variety of applications to improve fault identification and diagnosis across a wide range of machines. For example, AI has been utilized to detect and diagnose bearing faults using acoustic emission analysis and a transfer learning-based convolutional neural network. AI solutions for vibration analysis include a multiscale deep learning network that can handle a variety of operating situations, as well as a hybrid deep signal processing approach that uses auto encoders.

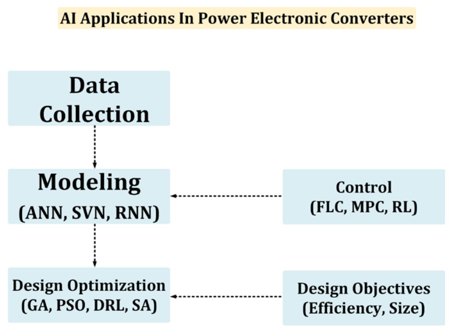

Figure 4. AI technique in modeling of power electronic converter

AI has also been used to diagnose rolling bearing faults using feature extraction approaches and to detect faults in real time using deep belief networks (DBN) paired with impulse signal uniformization. Early defect detection was accomplished using an improved deep-gated recurrent unit and complex wavelet packet energy moment entropy. AI has also been used to enhance defect identification on unbalanced datasets via generative adversarial networks (GAN) [11-13]. [14] Describes an AI application for extracting multiscale features from raw vibration signals with the purpose of achieving acceptable performance under varied working situations. In [15], AI was used to identify defects in anchor rods of electricity transmission lines using machine learning.

4.1.1. Challenges

AI application in fault diagnosis and condition monitoring has been an area of great interest however there are still some challenges associated with it. Some of these downsides are:

1. Imbalance dataset: most of the data used cannot be generalized because they are far from the big data that is required. However, there were instances where some experiments were done to cover up for an imbalanced

dataset but this is far from reality when it comes to fault diagnosis and condition monitoring. It is worth noting that the application of other AI techniques such as self-learning and a combination of other learning techniques can be considered to bridge this gap.
2. Transfer learning: most of the transfer learning algorithms are not comprehensive enough to encompass all the aspects of fault diagnosis and condition monitoring making it complex to juxtapose results and also assumptions in this regard can be very dangerous for concluding.
3. Environmental variability and noise: In most power electronics systems in most cases, measurements can differ from the environment for example factors such as temperature and electrical interference can result in noise.

4.2. AI Applications and Challenges to Modelling, Control, and Design of Power Electronic Converters

Power converters are devices that can process and control the flow of current or voltage to meet the load requirements. AI has shown to be quite effective in boosting efficiency, design control, and overall power converter maintenance. There are various evidence of this in the previously conducted studies. The purpose of [16], an artificial intelligence application in a converter-based actuation system, was to improve electronic converter control. In [17], AI was used as a DC-DC bulk converter to increase transient response performance.

AI has also been used to improve the performance of many power electrical systems and controllers. For example, AI has been used to modify the voltage output of PID-controlled DC-DC converters, monitor average switching current, and optimize load sharing. It has also been used to calibrate PID controllers and simulate predictive control (MPC) for grid-connected systems. Furthermore, AI aids in decreasing torque and current ripples in DC-DC buck converters, addressing training data, accuracy, and robustness issues in these converters, and enabling real-time optimization of power electronic converters employing dual active bridge technology [18-21].

The use of AI for power sharing and efficient control on DC microgrids is discussed in [22], while in [23], three-phase rectifiers are used to perform a voltage prediction. AI has been used in several important fields to enhance grid management and power electronics. It has been applied to forecast demand in power grids, improve transient responses in DC-DC converters, and handle disturbances in three-phase grid converters. AI has also been used to improve power electronics systems' overall performance and efficiency by optimizing their control [24-25].

4.2.1. Challenges

AI application in power converter designs, modeling, and control systems and techniques is also a serious area of interest because of the importance of efficiency which is one of the leading criteria in power systems, electronic converters, and control systems. But here are the challenges that are been faced in this area:
1. Immature AI technology: most of the AI techniques that are been tested in these areas are not matured yet to be deployed in real-life situations. Although experiments show how promising these technologies could be.
2. Dataset: The dataset that most of the AI technology relies on to predict the control of power systems in most of the research are already available datasets that have been collected over time, however in real-time and real-life applications there will be the need for data gathering from live control and power converters for AI to be more efficient. There will be a need for active sensors to gather this data in real-time for AI to make accurate and more efficient decisions.
3. Multi-objective optimization: in designing and modeling power electronics systems there are always multiple conflicting objectives like complexity of tradeoffs, computational demands, scalability and flexibility, and integration with control systems.

4.3. AI Applications and Challenges in Wireless Power Transfers & Emerging Power Electronics Technology

One of the promising and crucial technologies for future power mobility is wireless power transfers, which transfer electrical energy without the need for a physical connecting medium. AI applications for wireless power transmission will boost this system's performance by increasing its efficiency. An AI application to improve wireless power transfer systems' efficiency was shown in [26]. An application of AI to maximize EV system efficiency was shown in [27]. AI has been used in a variety of fields to improve energy management and wireless power systems. It has been used to optimize the design of wireless power transfer systems, detect stationary frequency components in electric signals within smart homes, and facilitate wireless energy trading, allowing individuals to trade energy packets on a microgrid. Furthermore, AI has been used in wireless PM DC motors to maintain energy security in multi-objective wireless power transfer systems, guarantee wireless energy security, and reduce the size of medical implants [28-30].

4.3.1. Challenges

AI applications in wireless power transfers and emerging power electronics technologies are part of the future of power systems. The application of these technologies will further enhance the safety and efficiency of these devices. However, there are several challenges associated with wireless power transfer in emerging power electronics technology
1. Complier of wireless power conversion: wireless energy conversion involves systems that convert energy from one form to another form however some of these AI and WPT technologies are not yet suitable for conversion and transmission due to factors like efficiency, heat dissipation, power density, and range.
2. Implementation of wireless power transfers-AI: The implementation of WPT and AI at these early stages is faced with problems associated with design and control which are in terms of signal interference, signal distortion, efficient power transfers, environmental changes, and design complexity.

5. COMPARATIVE ANALYSIS OF AI TECHNIQUES IN POWER ELECTRONICS

Power electronics deals with conversion, control, and management of electrical power, and artificial intelligence (AI) approaches are been integrated with power electronics due to their capacity to increase efficiency, dependability, and effectiveness in systems such as inverters, converters, and power electronics system at large

There was literature on several AI techniques that were considered and used to produce good insights into AI applications in power electronics. Most especially in fault detection and condition monitoring. Techniques that were used include Auto encoders, Support Vector Machines (SVMs), Graph Neural Networks (GNNs), and Convolutional Neural Networks (CNNs)

5.1 Auto Encoders

The autoencoder was one of the techniques that were mostly applied in fault detection and condition monitoring. Which was used for monitoring the functioning of power electronics systems. The autoencoder is trained using data that depicts typical functioning, such as current and voltage signals. When there are faults in the power electronics systems, the data from the power electronic device will depart from the learned usual patterns, causing the autoencoder to output a large reconstruction error. This irregularity may generate an alert requiring maintenance.

Diagnostic Accuracy: from the literature considered the accuracies varied from 89.90% - 100%. Autoencoders can achieve excellent diagnostic accuracy by learning representations of common operating patterns.

Medium Detection Speed: Auto encoders require data reconstruction to spot abnormalities, making them significantly slower than simpler models such as SVMs.

Adaptability to New Fault Types: Moderate adaptability refers to auto encoders' ability to notice variations from the typical pattern. They have little ability to identify new types of faults without being retrained but in cases where the fault looks similar to the previous fault.

5.2. Support Vector Machines (SVMs)

Support Vector Machines (SVMs) are a sophisticated machine-learning technique that is commonly used. SVMs were used to efficiently detect faults, classify data, anticipate maintenance, and monitor system states. SVMs can work with high-dimensional data, SVMs are very useful for assessing the complex signals found in power electronics systems.

Diagnostic Accuracy: from the literature, the accuracy on average was 96.8% SVMs excel in binary or multi-class classification, making them ideal for simple fault classification tasks, particularly with a well-labeled dataset.

Medium Detection Speed: SVMs have relatively fast detection times because they focus on identifying class borders rather than modeling complicated data structures. This makes them ideal for real-time applications.

Adaptability to New Fault Types: SVMs rely on predetermined classes and boundaries, making them less adaptive to new defect kinds without retraining.

5.3. Graph Neural Networks (GNNs)

GNNS is a type of neural network meant to operate on graph-structured data, with nodes representing entities and edges representing relationships between them. GNNs have been used in applications involving defect detection, and system monitoring.

Diagnostic Accuracy: from the literature considered the accuracies range from 89.45% to 99.72% GNNs are excellent in defect detection

Number of Layers: from the literature 1 – 4 layers were recorded. The layer level varies with the complexity of the network interactions being represented.

Medium Detection Speed: from the literature GNNs may be computationally demanding, particularly when dealing with bigger networks, hence they typically operate at a medium pace. They are quicker than certain deep networks when dealing with simpler graphs.

Adaptability to New Fault Types: GNNs are moderately adaptable, as they can simulate new defects when the network structure changes. However, spotting flaws outside of previously known patterns may still need retraining.

5.4. Convolutional Neural Networks (CNNs)

Convolutional Neural Networks (CNNs) are a deep learning architecture that does well in detecting patterns in data, notably pictures and grids. They have been used for analyzing waveform data, thermal imaging, fault detection signals, and sensor readings.

Diagnostic Accuracy: from the literature considered the accuracies ranged between 91% - 100% CNNs provide great accuracy, particularly when evaluating images (such as sensor array data) for defect detection.

Number of Layers: from the literature 1 – 6 layers were recorded. More layers can be captured but it will lead to more computation time although it will lead to more accurate results. However, the goal of this research paper was to compute them in the shortest time possible.

Medium Detection Speed: from the literature CNNs outperform certain deep learning models because they employ convolutional layers, which are effective in feature extraction.

Adaptability to New Fault Types: CNNs are extremely versatile since they learn from patterns in data. They are more adaptable to new defects than traditional models, although they may still require retraining for better results.

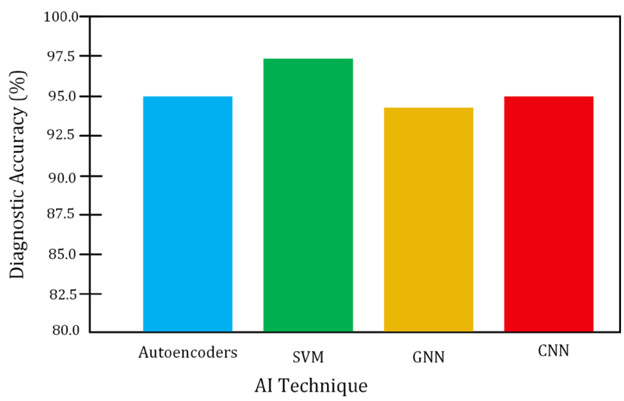

Figure 5. Diagnostic accuracy of AI techniques

Table 1 AI techniques used in various literature

AI Technique	Diagnostic Accuracy (%)	Detection Speed	Number of layers	Adaptability to New Fault Types
Autoencoders	89.90 - 100	Medium	-	Moderate
Support Vector Machines (SVMs)	96.8	Fast	-	-
Graph Neural Network (GNN)	89.45 - 99.72	Medium	1 - 4	Moderate
Convolutional Neural Networks (CNNs)	91-100	Medium-High	1 - 6	High

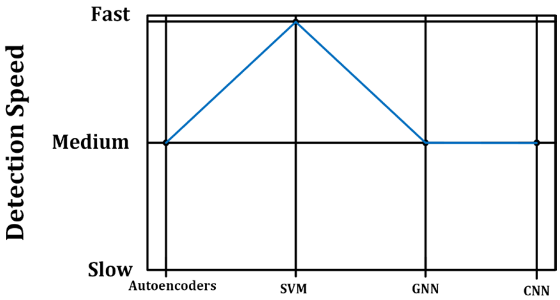

Figure 6. Detection speed comparison of AI techniques

Table 1 shows a summary of AI techniques used in the literature and their performance. Figure 5 shows the Diagnostic accuracy of AI techniques used in the literature considered. Figure 6 shows a Detection speed comparison of AI techniques used in the literature considered.

6.0 CASE STUDY OF AI APPLICATION IN POWER ELECTRONICS SYSTEMS

6.1. Smart Grid Fault Diagnosis with Graph Neural Networks (GNNs)

Smart grids are cutting-edge power systems that effectively distribute and monitor electricity by combining digital connectivity, automation, and analytics. They are made up of several components, which include distribution nodes, transmission lines, substations, and transformers. Because these components are interrelated, diagnosing faults may be difficult because a problem in one area of the grid might spread to or impact other areas.

6.1.1. AI Technique in a Smart Grid Fault Diagnosis

Deep learning models called Graph Neural Networks (GNNs) are made especially to process data with graph-like structures, in which nodes stand for entities and edges for the connections between them.

Application: To diagnose faults in its smart grid system, a utility firm used GNNs. With nodes standing in for different grid components (such as transformers and substations), GNNs represented the grid as a network graph. Based on past data, the GNN was able to identify fault patterns and effectively diagnose problems throughout the network.

Results:

• Diagnostic Accuracy: GNN was able to diagnose faults throughout the grid with an accuracy range of 92–98%.
• Reduction of Fault Isolation Time: A 50% reduction in fault isolation time allowed for quicker repairs and lessened the effect on service dependability.
• Scalability: Large grid networks can now diagnose faults without incurring extra processing costs because of the GNN model's good scalability.

7. CONCLUSIONS

AI has over time proven to be a transformational tool in many industries and power electronics is one of those areas that indeed could be transformed by AI. The goal of AI in power electronics has been seen in several types of research to improve the efficiency, reliability, and performance of power electronics devices and the power electronics field. In this review, an exploration of different applications of AI to three important aspects of power electronics was discussed which were:

A) AI Application and Challenges in Fault Diagnosis and Condition Monitoring: It was discovered that AI has and could further improve fault diagnosis and condition monitoring in power electronics systems and devices. There were several cases of application during this review that employed several AI, machine learning techniques, and deep learning techniques such as convolutional neural networks, deep learning models, and hybrid methods to significantly improve fault detection in power electronic systems and devices. However, it was discovered that there are still challenges associated with this application such as an imbalanced dataset and unavailability of adequate transfer learning methods which pose a challenge of application across certain operating conditions.

• *Future Direction*: Going forward there will be a need for Future developments in power electronics fault detection and condition monitoring by improving data collection using high-precision sensors and data fusion methods to provide a more thorough picture of system health. Improving defect detection accuracy requires AI-driven predictive models, such as deep learning for feature extraction and machine learning for anomaly detection. To better identify problems before they result in system failures, the creation of digital twin's virtual copies of physical systems will further enable real-time monitoring, fault simulation, and predictive maintenance. Diagnosis will become more flexible with adaptive and self-learning algorithms that can adapt to changing situations and manage a variety of fault scenarios. Particularly useful for capturing intricate, nonlinear processes in power electronics will be hybrid techniques that combine AI and physics-based models.

B) AI Applications and Challenges in Modelling, Control, and Design of Power Electronic Converters: It was also discovered that the integration of AI into the modeling, control, and design of power electronics systems and devices has further improved power electronics systems in terms of performance and efficiency. There were several cases of application during this review which included optimization of control strategy, enhancement of transient response, and improved design methodologies. However, there are challenges regarding model accuracy, especially in managing computational complexity and challenges like varying operational conditions which are a result of immature AI technology and also problems associated with datasets.

• *Future Direction*: Going forward there will be a need for developing advanced and more effective models that represent the intricate, nonlinear dynamics of power electronic systems is one such avenue. More accuracy in simulating real-world behaviors will be required of these models, particularly in the presence of fluctuating variables like shifting loads, voltage swings, and temperature changes. Also, the incorporation of machine learning and artificial intelligence into control systems. By allowing systems to learn from operational data, artificial intelligence (AI) can improve conventional control algorithms and increase their capacity to adjust to changing circumstances. There will be an increase in self-tuning and adaptive control systems, which enable real-time modifications without requiring manual recalibration. These systems provide more flexibility and resilience in power electronics applications by enhancing performance under a range of loads and disturbances.

C) AI Applications and Challenges in Wireless Power Transfers and Emerging Power Electronics Technology: It was discovered that AI has been a key tool in advancing and improving wireless power transfer systems and emerging power technology. There were several cases of applications that included optimizing wireless power transfer designs, enhancing energy trading on microgrids, and ensuring energy security. However, there are still challenges like Complier of wireless power conversion and Implementation of wireless power transfers.

• *Future Direction*: Going forward there will be a need for the development of robust AI solutions that can assist in complier wireless power conversion and implementation of wireless power transfer. Finally, if these challenges are addressed quickly and appropriately, the optimal application of AI in real-world power systems will occur soonest thereby improving fault detection, automation, and efficiency in power systems.

7.1. Potential of AI in Future Power Electronics Research and Application

The studies in the literature have provided a solid basis for the use of AI in power electronics and power electronics systems future research should concentrate on areas where AI approaches are integrated with developing control systems, real-time monitoring, and decentralized architectures. The focused research should be in the following areas.

7.2. Integrating AI and Adaptive Control Systems

Adaptive control systems that can self-tune and change depending on real-time data. Because they are critical for the effective functioning of renewable energy systems like wind farms and solar power inverters. AI can play a critical role in the creation of self-optimizing, data-driven controllers.

AI-Driven Predictive Control: research in the area of AI-Driven predictive control will involve the use of AI techniques such as the combination of deep reinforcement learning (DRL) and recurrent neural networks (RNNs) to forecast system behavior and dynamically alter control settings for optimal efficiency, particularly under changing conditions, especially for the special case of varying solar irradiance.

7.3. Decentralized Adaptive Control

Research to investigate how AI can support networked control techniques in microgrids or distributed renewable energy sources. To optimize energy production and consumption autonomously among network nodes, rather than depending on a central controller.

7.4. Deep Learning for Real-Time Fault Detection

Real-time defect detection and diagnosis in power electronics systems is critical for ensuring system dependability and avoiding unplanned outages, especially in renewable energy installations that operate in demanding and unpredictable conditions.

AI-Based Real-Time Monitoring: Consider the use of AI techniques in conjunction with Internet of Things (IoT) sensors to create a real-time monitoring network capable of continuous system health assessment and defect identification. Deep autoencoders and generative adversarial networks (GANs) can be used to discover irregularities in distorted sensor data.

7.5. AI for Hybrid Energy Systems

As hybrid energy systems (e.g., wind, solar, and battery storage) grow increasingly popular, AI can enhance their functioning by tackling the difficulties of many power sources and storage systems that interact dynamically.

Specific Research Directions:

7.6. Hybrid Energy Optimization Algorithms

Create AI algorithms that optimize the integration of numerous renewable sources (wind, solar, and hydro) with energy storage. Deep learning or genetic algorithms can be used to determine the optimal combination of energy sources and storage options depending on weather forecasts, demand, and system limits.

7.7. Explainable AI for Power Systems

One issue with AI models, particularly deep learning, is their lack of interpretability. In essential applications such as power electronics and renewable energy systems, system operators must understand how AI makes Decisions.

Interpretability in Fault Diagnosis: Investigate ways to make AI models more interpretable, particularly in the context of fault diagnosis in power electronics. This involves creating tools to illustrate how AI models find flaws and why certain decisions are made, which will increase engineers' faith in AI-driven diagnostics.

REFERENCES

[1] I. Markovsky, L. Huang, Florian Dorfler, "Data-Driven Control Based on The Behavioral Approach: From Theory to Applications in Power Systems", IEEE Control Systems Magazine, Vol. 43, No. 5, pp. 28-68, October 2023.

[2] S. Zhao, F. Blaabjerg, H. Wang, "An Overview of Artificial Intelligence Applications for Power Electronics", IEEE Transactions on Power Electronics, Vol. 36, No. 4, pp. 4633-4658, April 2021.

[3] E. Mohammadi, M. Alizadeh, M. Asgari Moghaddam, X. Wang, M.G. Simoes, "A Review on Application of Artificial Intelligence Techniques in Microgrids", IEEE Journal of Emerging and Selected Topics in Industrial Electronics, Vol. 3, No. 4, pp. 878-890, October 2022.

[4] U. Pandey, A. Pathak, A. Kumar, S. Mondal, "Applications of Artificial Intelligence in Power System Operation, Control and Planning: A Review", Clean Energy, Vol. 7, No. 6, pp. 1199-1218, 2023.

[5] A. Beskardes, Y. Hames, K. Kaya, "A comprehensive Review on Fuzzy Logic Control Systems for all, Hybrid, and Fuel Cell Electric Vehicles", Soft Comput., Vol. 28, No. 13, pp. 8183-8221, 2024.

[6] M. Al-Saadi, M. Al-Greer, M. Short, "Reinforcement Learning-Based Intelligent Control Strategies for Optimal Power Management in Advanced Power Distribution Systems: A Survey", Energies, Vol. 16, No. 4, p. 1608, 2023.

[7] S. Gawde, S. Patil, S. Kumar, P. Kamat, K. Kotecha, and A. Abraham, "Multi-Fault Diagnosis of Industrial Rotating Machines Using Data-Driven Approach: A Review of Two Decades of Research," Eng. Appl. Artif. Intell., Vol. 123, p. 106139, 2023.

[8] M.A.S. Al Tobi, K.P. Ramachandran, S. Al-Araimi, R. Pacturan, A. Rajakannu, C. Achuthan, "Machinery Faults Diagnosis Using Support Vector Machine (SVM) and Naive Bayes Classifiers", International Journal of Engineering Trends and Technology, Vol. 70, No. 12, pp. 26-34, 2022.

[9] B.A. Tama, M. Vania, S. Lee, S. Lim, "Recent Advances in the Application of Deep Learning for Fault Diagnosis of Rotating Machinery Using Vibration Signals", Artificial Intelligence Review, Vol. 56, No. 5, pp. 4667-4709, 2023.

[10] F. Cipollini, L. Oneto, A. Coraddu, S. Savio, "Unsupervised Deep Learning for Induction Motor Bearings Monitoring", Data-Enabled Discovery Appl., Vol. 3, No. 1, p. 1, 2019.

[11] M.J. Hasan, M.M.M. Islam, J.M. Kim, "Acoustic Spectral Imaging and Transfer Learning for Reliable Bearing Fault Diagnosis under Variable Speed Conditions", Measurement, Vol. 138, pp. 620-631, 2019.

[12] S. Haidong, C. Junsheng, J. Hongkai, Y. Yu, W. Zhantao, "Enhanced Deep Gated Recurrent Unit and Complex Wavelet Packet Energy Moment Entropy for Early Fault Prognosis of Bearing", Know. Based Syst., Vol. 188, pp. 10-50, No. 22, 2020.

[13] W. Mao, Y. Liu, L. Ding, Y. Li, "Imbalanced Fault Diagnosis of Rolling Bearing Based on Generative Adversarial Network: A Comparative Study", IEEE Access, Vol. 7, pp. 9515-9530, 2019.

[14] H. Qiao, T. Wang, P. Wang, L. Zhang, M. Xu, "An Adaptive Weighted Multiscale Convolutional Neural Network for Rotating Machinery Fault Diagnosis Under Variable Operating Conditions", IEEE Access, Vol. 7, pp. 118954-118964, 2019.

[15] D.C.P. Barbosa, et al., "Machine Learning Approach to Detect Faults in Anchor Rods of Power Transmission Lines", IEEE Antennas Wireless Propag. Lett., Vol. 18, No. 11, pp. 2335-2339, 2019.

[16] Y. Gao, T. Yang, S. Bozhko, P. Wheeler, T. Dragicevic, "Filter Design and Optimization of Electromechanical Actuation Systems Using Search and Surrogate Algorithms for More-Electric Aircraft Applications", IEEE Trans. Transport. Electrific., Vol. 6, No. 4, pp. 1434-1447, December 2020.

[17] H. Taneja, V. Jain, A. Jain, A.K. Dubey, M.C. Taplamacioglu, M. Demirci, "Weather Prediction Using Regression Algorithm and Neural Network Technique", International Journal on Technical and Physical Problems of Engineering (IJTPE), Vol. 16, No. 2, pp. 303-312, June 2024.

[18] S. Zhao, F. Blaabjerg, and H. Wang, "An overview of artificial intelligence applications for power electronics," IEEE Transactions on Power Electronics, Vol. 36, No. 4, pp. 4633-4658, 2020.

[19] H. Hussaini, T. Yang, Y. Gao, C. Wang, T. Dragicevic, S. Bozhko, "Droop Coefficient Design in Droop Control of Power Converters for Improved Load Sharing: An Artificial Neural Network Approach", Proc. IEEE 30th Int. Symp. Ind. Electron., pp. 1-6, 2021.

[20] R. Anugula, S.P.K. Karri, "Deep Reinforcement Learning Based Adaptive Controller of DC Electric Drive for Reduced Torque and Current Ripples", Proc. IEEE Int. Conf. Technol. Res. Innov. Betterment Soc., pp. 1-6, 2021.

[21] S. Zhao, Y. Peng, Y. Zhang, H. Wang, "Parameter Estimation of Power Electronic Converters with Physics-Informed Machine Learning", IEEE Trans. Power Electron., Vol. 37, No. 10, pp. 11567-11578, 2022.

[22] D.R. Nair, M.G. Nair, T. Thakur, "A Smart Microgrid System with Artificial Intelligence for Power-Sharing and Power Quality Improvement", Energies, Vol. 15, No. 15, p. 5409, 2022.

[23] A.S. Soliman, M.M. Amin, F.F. El-Sousy, O.A. Mohammad, "Experimental Validation for Artificial Data-Driven Tracking Control for Enhanced Three-Phase Grid-Connected Boost Rectifier in DC Microgrids", IEEE Transactions on Industry Applications, Vol. 59, No. 2, pp. 2563-2580, 2022.

[24] S. Zhao, F. Blaabjerg, H. Wang, "An Overview of Artificial Intelligence Applications for Power Electronics", IEEE Transactions on Power Electronics, Vol. 36, No. 4, pp. 4633-4658, 2020.

[25] T. Ahmad, D. Zhang, C. Huang, H. Zhang, N. Dai, Y. Song, H. Chen, "Artificial Intelligence in Sustainable Energy Industry: Status Quo, Challenges and

Opportunities", Journal of Cleaner Production, Vol. 289, p. 125834, 2021.
[26] B. Clerckx, K. Huang, L. R. Varshney, S. Ulukus, and M. S. Alouini, "Wireless Power Transfer for Future Networks: Signal Processing, Machine Learning, Computing, and Sensing", IEEE Journal of Selected Topics in Signal Processing, Vol. 15, No. 5, pp. 1060-1094, 2021.
[27] A. Al-Othman, M. Tawalbeh, R. Martis, S. Dhou, M. Orhan, M. Qasim, A.G. Olabi, "Artificial Intelligence and Numerical Models in Hybrid Renewable Energy Systems with Fuel Cells: Advances and Prospects", Energy Conversion and Management, Vol. 253, p. 115154, 2022.
[28] L.A. Romero-Ramirez, et al., "Spectral Kurtosis-Based Methodology for the Identification of Stationary Load Signatures in Electrical Signals from a Sustainable Building", Energies, Vol. 15, No. 7, p. 2373, 2022.
[29] P. Liu, et al., "Joint Route Selection and Charging-Discharging Scheduling of EVs in V2G Energy Network", IEEE Trans. Veh. Technol., Vol. 69, pp. 10630-10641, 2020.
[30] M. Zile, "Improved Control of Transformer Centers Using Artificial Neural Networks," International Journal on Technical and Physical Problems of Engineering (IJTPE), Iss. 40, Vol. 11, No. 3 pp. 28-33, September 2019.

BIOGRAPHIES

Name: **William**
Middle Name: **Olurotimi**
Surname: **Falana**
Birthday: 04.07.1996
Birthplace: Kogi State, Nigeria
Bachelor: Electrical Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, 2019
Master: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, 2022
Research Interests: Artificial Intelligence, Power Electronics
Scientific Publications: 6 Papers

Name: **Samuel**
Middle Name: **Nii**
Surname: **Tackie**
Birthday: 27.03.1988
Birthplace: Accra, Ghana
Bachelor: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Faculty of Engineering, Ho Technical University, Ho, Ghana, 2007
Master: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, 2015
Doctorate: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, 2021
The Last Scientific Position: Assist. Prof., Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, Since 2022
Research Interests: Power Electronics, Renewable Energy Sources, Power Quality
Scientific Publications: 20 Papers
Scientific Memberships: IEEE

Name: **Bulent**
Surname: **Bilgehan**
Birthday: 15.10.1958
Birthplace: Balalan, Cyprus
Bachelor: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Faculty of Engineering, Southbank University, London, UK, 1984
Master: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Eastern Mediterranean University, Famagusta, Northern Cyprus, 1991
Doctorate: Electrical and Electronic Engineering, Department of Electrical and Electronic Engineering, Engineering Faculty, Eastern Mediterranean University, Famagusta, Northern Cyprus, 2006
The Last Scientific Position: Prof., Department of Electrical and Electronic Engineering, Engineering Faculty, Near East University, Nicosia, Northern Cyprus, Since 2017
Research Interests: Signals and Sytems, communication Systems, Renewable Energy, Electrical Circuits.
Scientific Publications: 56 Papers
Scientific Memberships: EMO, IEEE