Power Electronics Control Using Machine Learning

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Abstract

Power electronics are critical for a variety of applications in today's fast changing technological landscape. These applications include renewable energy systems, electric vehicles, and consumer electronics. The efficacy and precision of these power electronics systems are the foundational components that allow them to function. When seen in this light, the incorporation of machine learning strategies takes on a very important role. The research is to provide is to detail the methods based on machine learning that are used in the management and optimization of power electronics. By conducting in-depth research, our objective is to shed light on the enormous potential that these techniques provide in terms of influencing the future development of power systems control and optimization.

Keywords: *Power electronics, Control, Optimization, Machine learning, precision*

1.Introduction

By "power electronics," we mean devices that employ solid-state electronic devices to regulate and transform electrical power. These systems may be found in a variety of fields, including as transportation, renewable energy, industrial automation, and other areas. Both the effectiveness and dependability of power technology are very necessary for the proper functioning of these systems [1–8]. Utilizing machine learning techniques has enhanced electrical system management and optimization [9–11]. As a result, power electronics systems are now more efficient overall.

These methods have the potential to lessen the computational burden of illustrating DC-DC converters, a crucial step in designing and improving power electronics systems. For the purpose of precisely predicting the performance of DC-DC converters, machine learning approaches like support vector regression as well as neural networks with artificial intelligence have been used [12–17].

Furthermore, many articles [7–20] have investigated AI's potential applications in power electrical systems. These techniques, which include optimizing, classification, regression, and information structure study, have potential uses throughout the design, management, and maintenance phases of a power electronics system's lifecycle [10]. In the literature, several artificial intelligence approaches have been described [10, 21]. These techniques include expertise systems, fuzzy reasoning, metaheuristic methodologies, and machine learning.

A overview of the present application of machine learning algorithms for the purpose of strengthening power system resilience can be found in [20]. Resilience refers to the capacity to endure and recover from severe events or assaults. A number of facets of power grid resilience, including contextual awareness, contingencies analysis, restoration strategy, and adaptive protection, are discussed in this study. The paper also explores the potential and problems that arise when using machine learning to these processes. The study also discusses the uses of machine learning methods in electrical system resilience and defines the techniques themselves.

In the article [22], the concept of modeling energy consumption via the employment of machine learning was presented. In this study, prediction models for consumption of energy are developed by the employment of machine learning and other methodologies. In this study, a comparison is made between the performance of several machine learning approaches, including but not limited to: multiple linear regression, a Decision Tree, SVMs, K-NN and deep learning. The Random Forest Regressor as well as deep learning has been shown to have the highest level of accuracy among the many strategies that have been evaluated.

It has been given in [23] that a comprehensive study of the defect detection and diagnostic methods for complex technologies and systems has been carried out. There are mechanisms known as fault identification and diagnosis that are responsible for monitoring the health of the system and determining the root cause and location of problems. Methods that are based on artificial intelligence are the primary emphasis of this research, which classifies the techniques into two categories: model-based along with data-driven approaches. In addition, the article provides a description of the common procedures that are executed throughout the process of designing and building autonomous fault detection and diagnostic systems.

Assessment of electrical power flows, quality of power, solar systems, smart transportation, and forecasting load are all topics that have been extensively explored in another research [24]. The survey explores the most current and promising machine learning approaches that have been offered by the literature, stressing the primary properties of these techniques as well as the findings that are important to them. During the course of the review, it was discovered that machine learning algorithms are capable of managing enormous amounts of data, which enables the discovery of concealed aspects of complex systems. It is often the case that hybrid models exhibit superior performance in relation to single machine learning-based models.

The production of solar electricity might be variable depending to the presence of cloud cover and the circumstances of the weather [25]. The creation of a robust model for precise solar power forecast is accomplished via the use of a number of different parameter tuning strategies. These techniques include Random search, Grid search, as well as Tree-based optimization.

When it comes to fuel cell-powered electric cars, traditional electrical systems often include two independent boost converters. This may be a challenge for applications that entail high-density vehicle applications. Methodologies were explored by the authors in [26] specifically with the purpose of developing an ideal system that incorporates fuel cells as well as batteries into electric cars. It presents a method that makes use of reinforcement learning in order to adapt to changing circumstances, which ultimately results in increased efficiency.

Data-driven fault categorization for power converter devices is becoming an increasingly important area of study in the fields of power technology, machine drives, along with electric cars more generally. An method to machine learning that is data-driven and supervised, combining PCA along with SVM, has been explored in [27]. This technique is used to categorise various fault topologies in real-time systems of control. In order to demonstrate the practicability of the technique, it is put through rigorous simulations and comparative investigations. Generally speaking, the approaches of machine learning that are shown in Figure 1 provide a potential strategy for enhancing the efficiency of power electronic systems via the use of control and optimization [28].

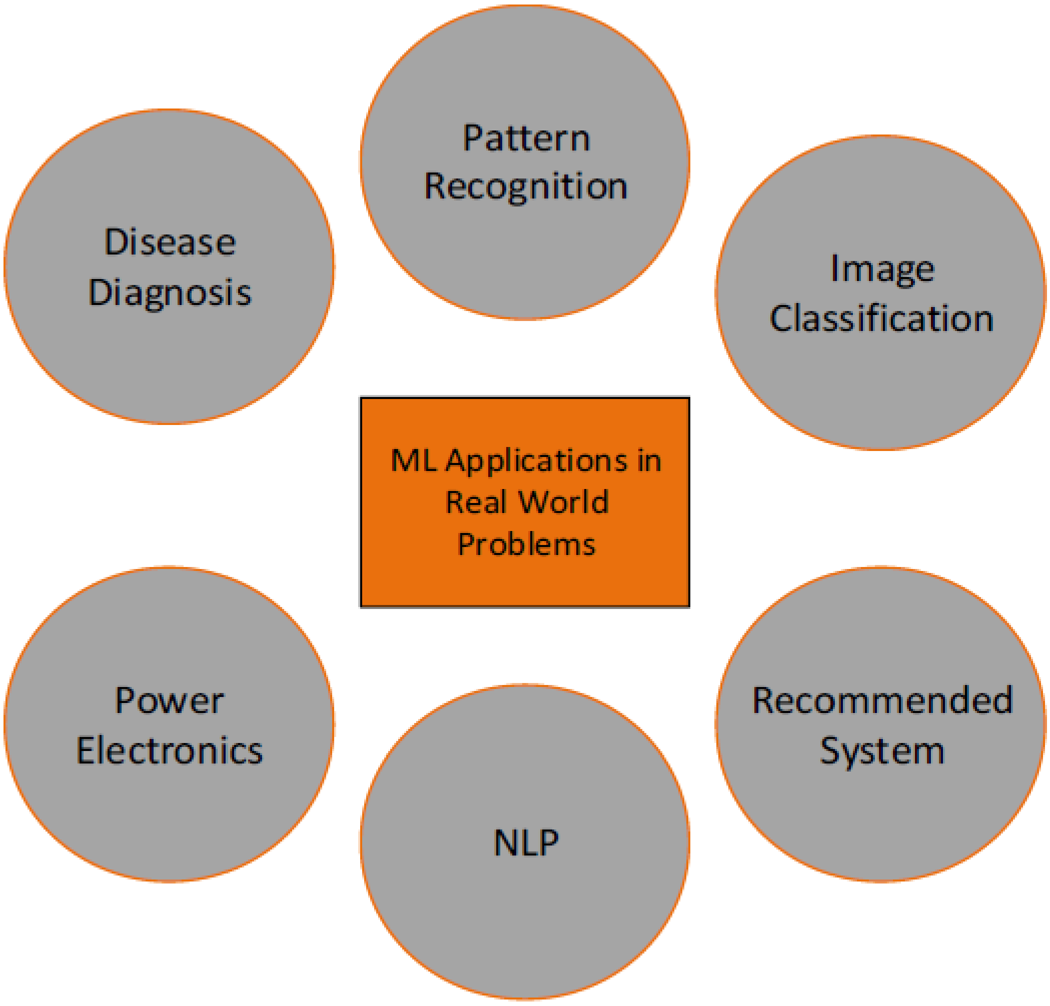

Figure 1: Machine learning Applications

It is necessary to do more study in order to fully use the possible benefits of these methods in this particular subject. Within the scope of this review, we will speak about the function of control and optimization, as well as conventional methods. Within the realm of power electronics, we will also talk about support vector machines (SVM) and neural networks. Application of machine learning algorithms in the actual world is seen in Figure 2.

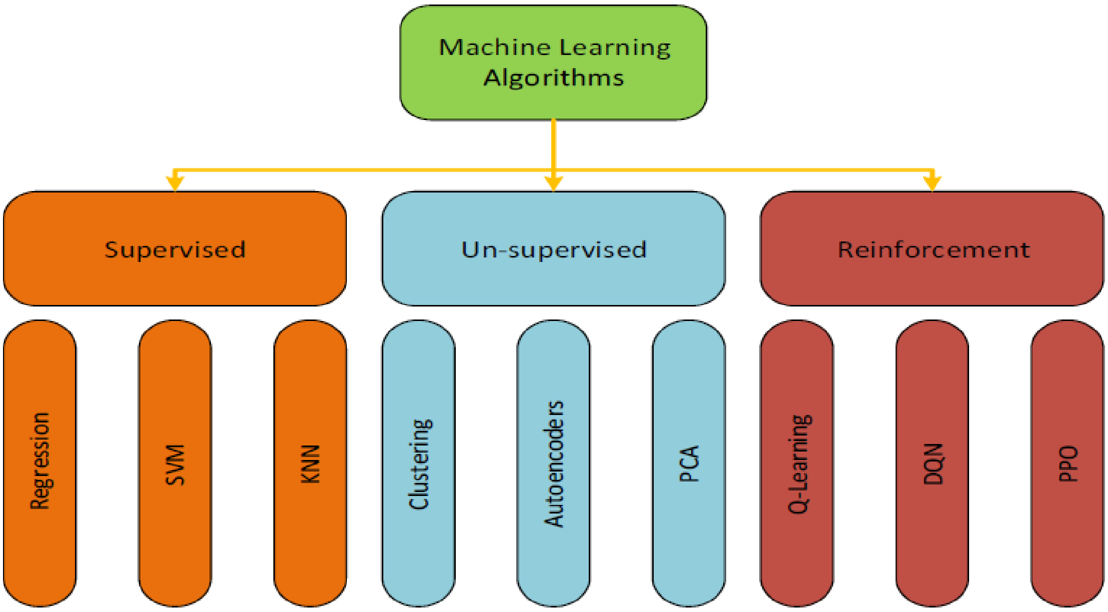

Figure 2: Classification of machine learning

2. Review of Methodology

When it comes to power electronic control and optimisation, the primary objective of this methodical examination is to provide an extensive examination of the methods utilising machine learning that are now available. This study covers the following research problems, which are considered to be the most important:

There have been improvements in efficiency and accuracy, and the use of machine learning. The bulk of the keywords that were targeted throughout the study collecting procedure were aimed at the domains of power electronic control and optimisation. These fields include power electronics converters, control techniques, and power electronics applications.

3.Optimization and Control

When it comes to power electronics systems, control and optimisation are very important components. Power electronics systems main objective is to convert and regulate electrical energy. These systems may be found in a broad variety of applications, ranging from electric cars to renewable energy systems. Control techniques are used in order to keep the outcomes of these devices under control, so guaranteeing that they function in an effective and dependable manner. These approaches [9-11] have been used to control and optimisation of power electronics. It has been shown that machine learning approaches, like random forest as well as gradient boosting, are able to properly forecast the performance of dc-dc converters that are accessible for commercial use. In general, control and optimisation are necessary components that must be included in order to guarantee the effective and dependable functioning of electronic power systems [12–17].

4.Machine Learning Strategies

Mathematical models along with heuristic algorithms have traditionally been used in the field of power electronics for the purposes of control and optimisation. Machine learning, on the other hand, provides a data-driven method that is able to adjust to shifting circumstances and optimise performance in real time. Using analogue control techniques as well as sensor-based approaches to temperature estimates are two of the traditional ways that are used in power electronics regulation and optimisation [13]. This approach has been employed for a considerable amount of time and has been shown to be successful Use of data-driven methodologies for the purpose of power systems control and optimisation [14]. For the purpose for power electronics regulation and optimisation, some machine learning approaches are now being developed [15]. These techniques include fuzzy logic, neural networks with feed forwards, neural networks with recurrent connections, and learning through reinforcement. Power converters may benefit from these approaches because they enable the creation of non-linear control surfaces that are more complex and dynamic, which in turn improves efficiency, dependability forecasts, and health monitoring[16].

4.1.Supervised Learning Strategy

In the field of machine learning, supervised learning is a subfield that involves the training of an algorithm with the use of labelled data in order to get an understanding of the connection among variables that serve as inputs and outputs [17]. In the area of power electronics management and optimisation, supervised learning is a technique that assists in predicting how a system will operate based on input variables such as voltage, current, and temperatures [18-20]. Regression analysis, support vector machines (SVMs), along with neural networks are not the only supervised learning approaches that may be used in the field of power electronics [9,21–23].

A.Support Vector Machines

SVMs are yet another popular supervised learning technique that may be used for solving classification as well as regression issues. SVMs are able to perform their duty by locating a hyperplane that successfully divides data into various categories while simultaneously increasing the gap between these categories. When it comes to the control and optimisation of power electronics, SVMs have the ability to categorise the system into several operating modes or to anticipate output variables (such as voltage or current) depending on the input parameters [15,24].

B.Linear Regression

Linear regression is a basic and commonly used supervised learning approach that can handle both regression (the process of forecasting numerical values) as well as classification (the process of allocating data points to groups) problems. The fundamental idea behind it is to find the line that provides the greatest fit by minimising the sum of squared discrepancies between the values that were predicted and those that were actually observed. ccording to the factors that are input into the system, linear regression may be used in the field of power electronics to make predictions about the current or voltage that is output of the system.

C.Neural Networks

Neural networks are more complex supervised learning models that are meant to perform a wide variety of tasks. Some examples of these tasks include picture recognition, audio processing, natural language comprehension, and power electronics management and optimisation.It is composed of layers of linked nodes (neurons) that are responsible for processing and transmitting data, and it functions in a manner that is analogous to that of the human brain. In the field of power electronics, neural networks have the ability to make predictions about output variables (such as voltage or current) according to input parameters, or these networks may optimise system parameters for particular applications.It should come as no surprise that supervised learning methods, such as linear regression, support vector machine learning, as well as neural networks, are very useful tools for the control and optimisation of power electronics. They make it possible to make predictions about the behaviour of the system based on the data that is input and to fine-tune the parameters of the system in order to accomplish certain objectives in power electronics usages [5,7,24].

4.2.Unsupervised Learning Strategy

The paradigm of machine learning known as unsupervised learning is one in which the algorithm operates without the use of labelled data and seeks to identify patterns or structures that are already present within the data. Within the realm of power electronics, the use of unsupervised learning approaches is of great importance in the optimisation procedures [11,17,26]. Three of the most important methods of unsupervised learning are clustering and the analysis of principal components (PCA), which will be addressed in the following paragraphs [10-15].

4.2.1.Clustering

The term "clustering" refers to a technique that is used to group data points that are comparable together on the basis of their qualities or properties [13,14,26]. There are a few different applications for clustering that may be used within the realm of power electronics.

a. Recognise Power Consumption Patterns

The use of clustering algorithms allows for the grouping of consumers or devices that display similar patterns of power consumption. According to [25,27], this information may be useful for load balancing since it assists utilities in more effectively allocating resources at their disposal.

b. Detection of Anomalies

In addition, clustering may be used to detect patterns in power usage that are exceptional or out of the ordinary. For instance, problems or anomalies in the electric power system may be indicated by unexpected spikes or reductions in the amount of energy that is being used. When it comes to defect detection and preventative maintenance, the identification of these abnormalities is very necessary [26].

4.2.2. Principal Component Analysis (PCA)

In the process of simplifying complicated datasets by translating them into a space with less dimensions. PCA is a technique for decreasing dimensionality approach [7]. PCA may be useful in power electronics in a number of different ways, including the following:

a. Reducing Data Complexity

There is an enormous quantity of data produced by power systems. PCA is helpful because it identifies the most important components of the data, which are known as primary components, and this helps to simplify the data [5].

b. More Efficient Optimization

Data that has been simplified as a consequence of PCA may lead to optimisation techniques that are more effective. Tasks like as load allocation of resources, power flow evaluation, and system parameter tweaking are all areas in which these algorithms may be beneficially employed. In the field of power electronics, unsupervised learning methods, such as grouping and principal components analysis, are very useful tools. This was made abundantly evident in the previous paragraph. The identification of trends and abnormalities in power usage is facilitated by clustering, which also helps with load balancing as well as fault detection. On the other hand, PCA decreases the dimensionality of complicated power system data, which makes it easier to handle for optimisation procedures, which eventually leads to more effective power electronics systems.

4.3.Strategy of Reinforcement Learning

The paradigm of machine learning known as reinforcement learning, or RL, is one in which an agent acquires knowledge by its interactions with its surroundings [2,5,7]. It does this by following a series of choices in order to achieve the goal of maximising the cumulative incentive signal over time. There are a number of uses and benefits that are exclusive to RL in the field of power electronics.

4.3.1. Adaptive Control

It is common for power electronics devices to function in situations that are both dynamic and unpredictable. The fact that RL enables systems to develop themselves and adapt to different circumstances makes it an excellent choice for these kinds of situations. The performance of the system may be optimised by the use of RL algorithms, which are able to continually alter control parameters like voltage or current setpoints. When it comes to systems that have fluctuating loads or energy from environmentally friendly sources, this flexibility is especially important [25,28].

A. Energy Management

In the field of power electronics, energy management refers to the process of controlling and optimizing the distribution and use of electrical energy. The use of RL allows for the making of choices in real time about the allocation of energy. RL algorithms have the ability to continuously operate microgrids by determining when it is appropriate to take electricity directly from the grid, conserve energy, or utilize renewable sources depending on real-time information along with demand [5,25].

B. Fault Detection and Diagnosis

Power electronics systems may benefit from the early identification and diagnosis of defects that can be accomplished with the help of RL. By gaining an understanding of the typical behaviour of the system, RL agents are able to identify variations that may be indicative of faults or abnormalities. RL algorithms are able to provide suggestions for remedial measures or control modifications after a defect has been identified. This helps to limit the effect of the malfunction, which in turn ensures the dependability and safety of the system.

C. Energy Optimization

The variability of renewable energy sources, such as sun and wind, is intrinsic to these sources. Through the use of real-time decision-making about energy production and distribution, RL is able to maximize the efficiency with which various sources are integrated into the power grid. Managing the output of energy from renewable sources, like as wind turbines, in order to preserve grid stability in the face of oscillations is one way that RL may contribute to the balancing of the grid. In the field of power electronics, reinforcement learning is shown to be an effective instrument for adaptive control along with optimisation, as was previously stated. Managing complex and dynamic power systems, optimising energy use, identifying defects, and effectively incorporating renewable energy sources are all tasks that are well-suited to this system because of its capacity to learn through environmental interactions. With the progression of scientific knowledge, it is quite probable that RL will play an increasingly significant function in enhancing the dependability, efficiency, and sustainability of power electronics systems [18, 26].

5. Challenges in Implementing Machine Learning

While the use of machine learning techniques for power electronics systems has the potential to bring about major advantages, it also comes with a number of problems that are associated with the quality of the data, the interpretability of the model, and the fulfillment of real-time requirements. The successful completion of these difficulties is very necessary in order to fully use the endless possibilities of machine learning in order to enhance the effectiveness, dependability, and performance of applications that include power electronics.

5.1.Data Collection and Preprocessing

If you want your machine learning application to be successful, the cornerstone of such application is high-quality data collecting [16]. When applied to the field of power electronic devices, this entails the collection of precise and exhaustive data about the temperature, voltage, current, and any other characteristics that are pertinent. There are many other sources from which data might originate, including sensors and monitoring equipment that are installed inside the power system. It is of the utmost importance to guarantee the reliability and uniformity of this data.

The process of cleaning, converting, and organizing the data prior to its incorporation into predictive models for machine learning is referred to as an example of data preprocessing. As a result of the possibility that the raw data may include noise, anomalies, or missing values, which might result in erroneous model predictions [14], this phase is very important.

Additionally, feature selection is a part of data preparation. This is the procedure by which the variables that are most relevant to the training of the model are selected. The performance of a model might be severely impacted by characteristics that are inaccurate or irrelevant.

5.2. Interpretability of the System

In certain instances of power electronics, especially those that have consequences for safety or regulation, it is absolutely necessary to have machine learning models that can be interpreted. Models that are interpretable are ones in which the judgments they make can be comprehended and communicated in a way that is user-friendly. This is very necessary in order to guarantee accountability and openness. In the event that a model developed using machine learning is used to manage the voltage levels on a power grid, for example, engineers and regulators are required to have an understanding of the reasoning behind the model's choice in the event that it produces unexpected results or mistakes [24]. In order to achieve interpretability of the model, it may be necessary to use more straightforward algorithms or methods that provide transparent insights into the decision-making process of the model. Complex deep learning models, despite the fact that they may often provide superior performance, are sometimes more difficult to analyse than more straightforward models such as decision tree models or linear regression.

5.3. Real-time Constraints

Real-time settings are often encountered in the operation of power electronics systems, which need the prompt making of choices in order to preserve stability and safety. Since many machine learning methods need a significant amount of computer power, it is possible that they are not optimally suited for decision-making in real time [26]. In order to meet real-time limitations, it is necessary to optimise the responsiveness and efficiency of the machine learning model. Implementing strategies such as model simplifying, parallel processing, or the use of specialised hardware accelerators are all viable options for accomplishing this goal. In addition, in order to guarantee that models continue to be accurate and adaptable to changing circumstances, it may be necessary to continually retrain them or update them in real time as additional information becomes available [27].

6. Discussion

We carried out a comprehensive literature analysis for the purpose of this investigation, with the objective of determining the extent to which different machine learning strategies are used in the field of power electronics control along with optimisation. Following that, we rigorously selected and analysed the papers that were retrieved, concentrating on how relevant they were for power electronics control, optimisation, and the machine learning approaches that were described. Through the use of the data that we gathered, we were able to determine the proportion of research projects that utilised each methodology.

Figure 3. Percentage utilization of machine learning algorithms for Power Electronics and Control

The percentages that were obtained as a consequence, which are displayed in Figure 3, provide helpful information into the relative uptake and utilisation of certain machine learning methodologies within the area of power electronics monitoring and optimisation. It is stated below that the percentages for each model are as follows: eight percent for linear regression, thirty-six percent for support vector machines, twenty-two percent for neural networks, twenty-eight percent for clustering, and six percent for principal component analysis. A presentation of the comparative findings, as well as the metrics and parameters that were used, may be seen in Table 1.

Table 1: Comparison of various machine learning models

References	Algorithms Used	Metrics	Values	Important parameters
[5]	SVM	$Irms$	0.84	Input voltage and switching frequency
[7]	SVM	RMSE	2254.66	Random Search
[11]	Random forest	RMSE	3.3714	Correlation coefficient
[13]	Neural network	Overshoot (%)	29	A and λ
[17]	1-NN	F1-score	>95%	TS COM
[19]	NN	Overshoot (%)	0.976	K_p
[21]	FF-NN	Voltage	80	$Vref$
[22]	NN	MAE	0.85	H, S, L, N, I
[23]	Auto-ML	Voltage	0.4	DC link voltage
[25]	KNN	$R2$	0.79	S_i

In addition, we have investigated a great number of machine learning-based models that are utilised in the administration and optimisation of power electronics in order to enhance our capacity to foresee outcomes.

CONCLUSION

This article provides a complete description of the mutually beneficial link that exists between machine learning methods and the management and optimisation of power electronics circuits. As we make our way through the ever-changing terrain of contemporary technology, it is becoming more and more obvious that power electronics play an important role in a broad variety of applications. The incorporation of machine learning techniques is significant because the precision and effectiveness of electrical systems are non-negotiable aspects of their operation. This is where the relevance of the incorporation of these methodologies resides. As a result of our investigation, we have discovered the enormous potential that machine learning approaches offer in terms of improving the control and optimisation of power electronics devices. The use of these techniques enables us to make choices based on accurate information, adjust to shifting circumstances, and reach better levels of energy conservation. When we look into the future, it is clear that the combination of machine learning with power electronics is going to be a driving force behind additional innovation, which will completely transform the way in which we harness and make use of electrical power within the contemporary networked world. In the direction of the next generation in power electronics control as well as optimisation, the trip has started, and the strong beacon of machine learning is guiding the way.

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