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Significance of Artificial Intelligence in the Production of Effective Output in Power Electronics

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Abstract

The power electronics (PE) industry is expected to play a significant role in the development of energy conservation and global industrialization trends of the 21st century. Due to the technological advancements that have occurred in the field, such as transportation and communication, the need for efficient and quality products is becoming more prevalent. The importance of power electronics is acknowledged in the automated industries that are constantly striving to improve their efficiency and effectiveness. Due to the increasing global energy consumption, the need for more energy-efficient technologies is also becoming more prevalent. Around 87% of our energy is derived from fossil fuels, while 6% is generated from nuclear power plants and 7% from renewable sources. Due to the increasing concerns about the environment and safety issues associated with nuclear plants and fossil fuels, the need for energy conservation is becoming more prevalent. This is also expected to be achieved through the development of power electronics. In the coming decades, the development of artificial intelligence (AI) tools, such as neural network, expert system, and fuzzy logic, is expected to bring a new era to the field of motion control and power electronics. Despite the technological advancements that have occurred in the field, these tools have not yet reached the power electronics sectors. In this paper, the AI tools and their applications in the field of power electronics and motion control are discussed.

Keyword: Power Electronics, AI, Smart Grid, Fuzzy logic.

I. Introduction:

The development of mercury-arc valves during the 1900s was regarded as a revolutionary innovation in the power electronics industry. Due to its numerous applications, the market for power electronics grew significantly. The introduction of bipolar junction transistor devices led to improved performance and reduced costs. Due to the technological advancements that have occurred in the field of semiconductor-based power devices, artificial intelligence has been integrated into the system. Almost every automation application has a power electronics component. The various applications of power electronics include renewable energy generation, high-speed direct-current transmission, and flexible AC systems.

As the power electronics industry continues to evolve, the need for more efficient production, maintenance, and control of these components has increased. One of the most common factors that affects the performance of semiconductor-based power devices is the high switching frequencies. Through the use of AI, power electronics can be designed and controlled efficiently. It has the ability to maintain and improve their efficiency.

Machine learning and artificial intelligence are becoming the foundation of Industry 4.0, as the need for intelligent systems and automation has become more severe due to Industry 3.0. The goal of AI is to enable machines to think and act like humans, without getting tired. It can be used in various fields such as speech recognition and facial recognition. AI has advantages over other technologies when it comes to implementing power electronics due to its high sensitivity and tuning speed. This is especially true in condition monitoring. AI can also be used in various life cycle phases of power electronics.

Big data analytics and the Internet of Things (IoT) are providing a huge amount of data that can be fed into AI algorithms to monitor the various life cycle of power

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electronics. This data can be used to improve product competitiveness and provide more accurate and timely reports. Through the use of data-driven methods, researchers can conduct studies in power electronics more effectively. This is especially beneficial in complex use cases. The most impactful phase of AI in power electronics is the control phase. It is also most commonly used during the maintenance phase. There are various functions that are performed by AI in this area, such as data structure exploration, classification, and optimization.

There are various AI methods used in power electronics, such as expert systems, metaheuristic systems, and machine learning as shown in fig.1. Machine learning is commonly used in this area. It is also classified as supervised learning, reinforced learning, and unsupervised learning. Due to the increasing number of powerful computing devices and the development of more sophisticated AI tools, the application of fuzzy logic and expert systems has become more moderate. This is why the use of metaheuristic methods in power electronics is continuously evolving. They are commonly used in combination with other ML techniques to perform a complete task. Reinforcement learning is a new frontier in the field of power electronics.

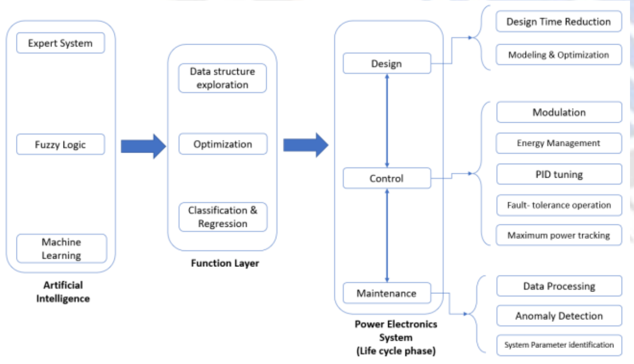

Fig. 1 AI + Power Electronics

Through the use of AI, power electronics can now benefit from various features, such as fault-tolerance, simulation, and control. This is especially beneficial in the design and implementation of smart grids and renewable energy systems. The development of advanced electric power grids using the latest technologies, such as computers, power systems, communications, and AI, is expected to improve their reliability, availability, and security. It will also help them meet their customers' energy efficiency and supply more reliable and economical electricity. AI has been extensively used in this field over the past few decades. Fig.2 shows the corporation of AI and power electronics using Sankey diagram

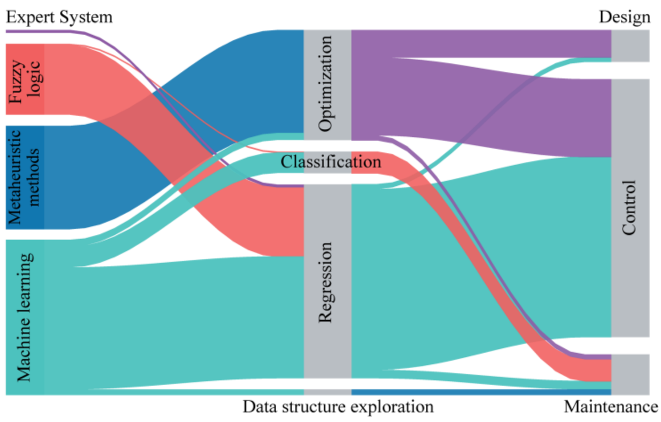

Fig. 2 Sankey Diagram for AI + PE

The complexity of power electronic systems, such as their high tuning speed and sensitivity to aging detection, make implementing AI in these areas very challenging. Compared to other engineering fields, such as image classification, this area has its own unique set of features. There is a need for an overview of Artificial Intelligence in power electronics to accelerate interdisciplinary studies and improve synergy research. The main contribution of this paper is

- An analysis of the relationships between the various AI algorithms in power electronics is carried out from a life-cycle perspective.
- An extensive analysis of the limitations and advantages of AI algorithms is carried out.

Power Electronics

The complexity of power electronics has grown significantly over the past century. An engineer with a broad knowledge of this field should be able to handle various disciplines. Various kinds of electronic devices, such as power semiconductors, digital and analog control electronics, and microchips, are involved. These include complex control theories, computer-aided design techniques, and application specific integrated circuits (ASIC). The knowledge of components such as capacitors, inductors, and transformers are very important in order to develop effective design and test procedures[1], [2].

The rapid emergence and evolution of AI techniques, such as fuzzy logic, expert system, and genetic algorithms, have advanced the field of power electronics. As the smart grid era continues to evolve, this sector is expected to merge with other high-tech areas in the power engineering industry.The various discipline technologies that are involved in power electronics are undergoing rapid evolution as shown in fig.3. This is creating challenges for engineers[3], [4].

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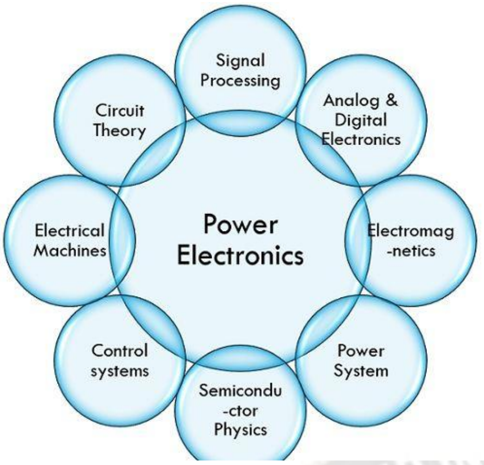

Fig. 3 various discipline in power electronics

The operation of modern power electronics has been completely transformed as a result of the development of power semiconductor devices. The efficiency of power electronic converters has nearly reached 100% as a direct result of the technological advancements that have been made in the field of power semiconductors. Fig.4 represent the various types of semiconductor devices

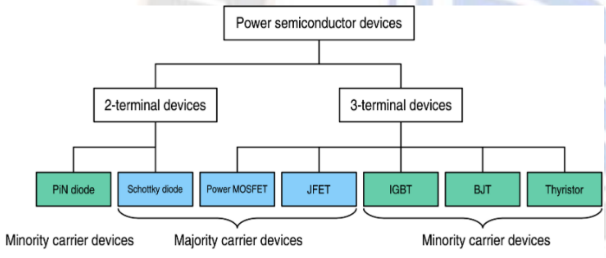

Fig. 4 Various types of semiconductor devices

The devices that are used in solid state power electronics are based on silicon. The BJT and the old generation of the GTOs are no longer available. The era of phase-control devices started with the triacs and thyristors. Problems with power quality are caused by these devices because they produce electromagnetic interference (EMI), a lagging power factor, and harmonics. In spite of the fact that thyristors are frequently utilised in high power HVDC systems and large load-commutated inverter drives, phase-control devices such as the IGCT are gradually falling out of use. In a variety of applications requiring low voltage and high frequency, power MOSFETs are the device of choice. In the realm of power semiconductor technology, the development of the IGBT has been regarded as a significant step forward in the advancement of technology[5]–[7].

II. Applications of Power Electronics

- **Smart Grid –** One of the most significant advancements in technology over the course of the past ten years has been the lightning-fast development and proliferation of smart grids. It is a highly integrated and automated system that is designed to improve the efficiency and reliability of the electrical networks. The goal of this system is to improve the efficiency and reliability of the electrical networks. Within the next few years, it will be an extremely important factor in the process of modernizing the power grid and expanding the available supply of electricity.. The increasing importance of electric supply to consumers has become the main concern of policymakers and the public in developing and developed countries. Through the implementation of smart grid technology, the transmission and generation of electrical energy can be monitored and controlled. This can help reduce the carbon footprint of the electric system. Besides renewable energy sources, smart grid can also integrate plug-in hybrid electric vehicles and energy storage. Various power electronic devices such as the metal oxide silicon field effect transistor (MOSFET), insulated gate bipolar junction (IGBT), and integrated gate compensated thyristors (IGCT) are commonly used in smart grid applications. These devices have high current carrying capacity and are ideal for handling high voltage. These devices, which are known as power electronics, are used in various applications such as power conversion and frequency control. They can be used in converters, which are used to convert electrical energy. Due to their high switching frequencies, these devices can also control the flow of electricity[6], [8], [9].
- **Energy saving -** The reduction of energy consumption can help lower the electricity cost and lessen the environmental impact of fossil fuel-based power plants. In addition, power electronics equipment can perform well in various energy processing applications. An air conditioner or heat pump that uses power electronics to control the variable speed of its fan can improve the efficiency of its individual components by as much as 20%. Additionally, solid-state LED lamps and compact fluorescent lamps are able to cut their energy consumption and increase their lifespan. It is estimated that if we were to improve the efficiency of the power grid, we could save a certain amount of energy. Several different types of technology, such as power electronics, can be utilised to accomplish this goal. It has been estimated that by putting into practise the technologies that are currently available, up to 20% of the world's total energy demand can be

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saved. Another 20% in savings can be realised by reducing unnecessary energy use[10].

Incorporation of AI in power electronics

- **Fuzzy Logic**
  A typical fuzzy-control system consists of a plant and a fuzzy controller. The four components of this system are: fuzzy inference, knowledge database, defuzzification, and fuzzification. This type of system can reflect human reasoning. Unlike a traditional control method, a fuzzy controller is not dependent on the mathematical model of the object it is controlling. It can be implemented effectively if the object is linear or non-linear. Due to the popularity of fuzzy logic, it has become one of the most successful control methods in today's market. The most important factors that a control system designer should consider when it comes to developing its complex control system is the design of its membership functions. This type of system can reduce the time it takes to learn and improve its performance[11], [12].

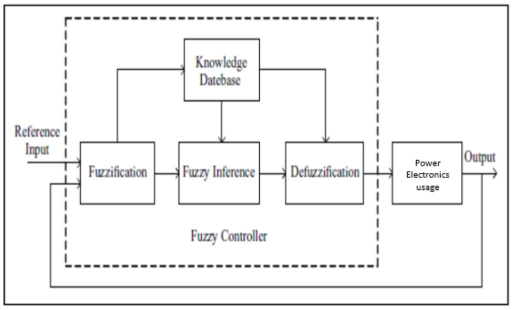

Fig. 5 Fuzzy logic in PE

A residential energy management system that can operate in two different operating horizons is proposed. The system uses a combination of fuel cells, a battery bank, and a photovoltaic to provide local loads. It can operate in various operation modes. The system's long-term data prediction unit is composed of a short-term fuzzy controller and a two-D dynamic programing system. It can be used to determine the optimal battery state for the system. Besides the efficiency of the components, other factors such as the demand and supply cost of energy are taken into account to evaluate its performance. The data collected by the system is then sent to a short-term fuzzy controller, which can then determine the operation mode of the microgrid. The development of the MPPT function using the Fuzzy Logic Controller is mainly focused on increasing the output power of the solar photovoltaic system. Its fast response and solid performance were demonstrated. Based on the predicted consumption and generation of energy over time, an EMU is then created to select the optimal operation mode[13], [14].

- **Expert System**
  It is generally agreed that the expert system was the first system developed in the field of artificial intelligence that was applicable to business settings. It is a database that stores the knowledge of specialists in a context-aware manner, making use of the IF-THEN rules that are prevalent in human reasoning. It is a highly intelligent system that has the ability to provide responses to questions regarding the reasoning process. The database incorporates both the results of simulations and the knowledge and experience of field experts. It is possible to update it on an ongoing basis. Additionally, presented here are the technical particulars of the expert system. In addition, a number of applications have been discovered that are superior in a variety of ways[15].
  The construction of the system is predicated on a set of rules and principles that are specific to the system. It does not have universality and can only be applied to fields where there are well-established expert rules. The functions of the expert system are susceptible to being replaced by other advanced AI methods because the number of computational platforms is continually growing. Some examples of these are machine learning and fuzzy logic[16], [17].

- **Machine Learning and Big Data**
  The mathematical technique used to forecast the power generation output from photovoltaics has been widely used. There are two main types of methods used to forecast this output: the statistical method and the Persistence model. Unfortunately, the latter is prone to producing low accuracy and fails to work properly with non-linear data. Some of the recent techniques that are commonly used in this field include machine learning, artificial neural network, and metaheuristics. Through machine learning, we can solve problems that are not possible with an explicit algorithm. This allows us to develop a relationship between outputs and inputs, which makes these models ideal for classification, forecasting solar energy efficiency, and pattern recognition[3], [4], [18].

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Big data and machine learning are being used in the electrical power grid to improve the efficiency and effectiveness of its operations as shown in fig.6. The rise of the Internet of Things (IoT) has created a vast amount of data that is required to be analyzed and made available to the public. This data, which is collected and analyzed through the various connectivity features of the system, requires highly specialized techniques to perform properly. The ability to integrate the Internet of Things (IoT) into a system can provide various benefits, such as cost-effectiveness and load forecasting[8]. However, it is also important to keep in mind that the security of the data collected and stored in the system is a critical issue.

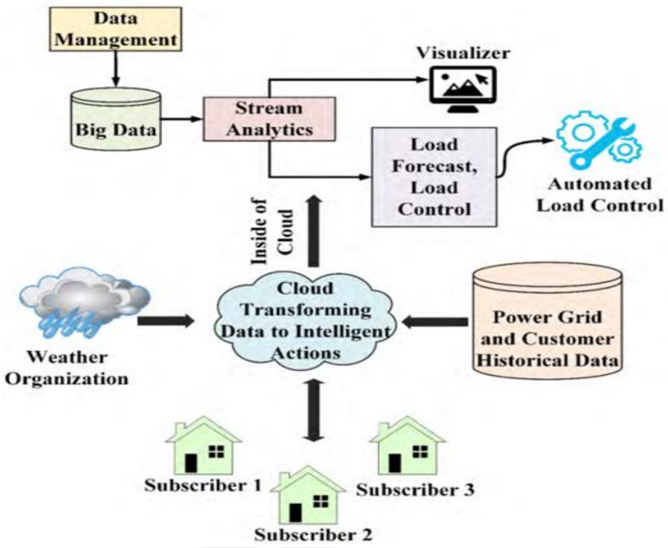

Fig. 6 Usage of ML & Big data in PE (Smart Grid)

When it comes to the implementation of induction motors in industrial processes, one of the most important factors that industrial process managers need to take into consideration is the accurate diagnosis of a variety of mechanical and electrical faults. Through the use of machine learning, a fault diagnosis method can be easily implemented to minimize the loss and downtime of the motors[19], [20].

III. Challenges and opportunity

The continued development of AI/ML in power control applications will depend on the availability of improved performance and scalability of these algorithms. Like other digital power implementations, the computational burden associated with these technologies will be a significant challenge. Due to the increasing complexity of digital signal processing systems, the need for faster and more accurate AI/ML implementations in power converters has become a major issue. Some of the applications that are being developed for AI/ML in power electronics include fuzzy logic, reinforcement learning, feed-forward neural network, and recurrent neural network. There are various limitations and advantages of these implementations.

- Light weight algorithm - Most AI/ML systems require large datasets to perform well. Unfortunately, the availability of such datasets can be limited by the varying operating environments and power converter designs. This is why the development of data-light algorithms in safety and life applications will be required. The development of AI/ML in power control applications is expected to lead to the creation of spin-off innovations that can reduce the processing requirements of these algorithms.
- Low-cost setup - Unfortunately, the development of AI/ML in power control applications is not yet feasible due to the lack of high-performance hardware and the cost of implementing it. Currently, the only solution that is available for implementing this technology is the use of low-cost and specialized integrated circuits. When it comes to the development of artificial intelligence and machine learning in applications for power control, the availability of learning techniques in the cloud is one of the most important factors that can be taken into consideration.. This can help enhance the performance of these algorithms by reducing the computational requirements.
- Information Fusion - When it comes to the advancement of AI and ML, one of the most important considerations that can be made is the availability of data in power control. This can help improve the performance of these algorithms by combining them with the power converter operation's differential equations. For instance, by implementing AI/ML in a hybrid solution, it can be used to improve the performance of the power inverter's condition monitoring. A proposed system that combines the capabilities of AI/ML and a differential equations model can be used for improving the accuracy and robustness of these algorithms.

IV. Conclusion

Over the past decade, the development of AI and machine learning for power electronics systems has been significantly accelerated. However, the computational requirements of these algorithms are much more demanding than those of current implementations. As a result, the adoption of AI in power electrics is mainly concentrated in large-value-added applications. These include the ARCP control algorithm. The power electronics industry is expected to adopt the use of AI/ML in various applications such as classification and maintenance. However, the development of more efficient techniques such as multilevel information fusion and data-light AI will be required to ensure its success. The design, control, and maintenance of power electronic systems are typically the domains in which artificial intelligence is utilised. The characteristics of this technology, including the percentage of its application and the requirements during each phase of its life cycle, are investigated. On the other hand, the approaches that are utilised in this industry can be broken down into the following three categories: expert system, machine learning, and fuzzy logic. The primary purpose of this investigation is to investigate and compare the various benefits and drawbacks of AI algorithms across a variety of application areas. In addition to this, it examines the functions of the relevant applications as well as their milestones. When viewed from the point of view of their functions, the applications are primarily concerned with classification, the exploration of data structure, and prediction.

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