Review of Artificial Intelligence in Electrical Engineering

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Abstract— In this paper, we review the interactions between Artificial Intelligence and Electrical Engineering to understand the new opportunities they have created together. We see that AI is being used for making instruments, measurements, design and manufacturing more accurate, precise and robust. If we combine it with microelectronics, smart electronic devices are currently a high priority. Control systems are becoming smarter, adaptive and can change behaviour with the introduction of AI. Interlinking it with power systems, we see enormous potential to revolutionize the way we can produce, transmit and consume energy. Since fault prediction is being made possible, engineers can be guided with the exact cause, type, location and recommended solution. Leveraging from the success of AI in signal processing and telecommunications for transmission, storage and processing, optimization, utilization, self-healing and automatic decision making, AI is now being extended to array processing from sensors, financial data and markets, optical networks and genomics, to the extent of say, estimating the mental state of the user using raw EEG signals. As human experience and knowledge is being transferred in the form of AI, we can conclude that new opportunities are on the way for electrical engineers to thrive in the AI-driven society.

Keywords: Artificial Intelligence, Electrical Engineering, Machine Learning, Neural Networks, Deep Learning, Electrical Engineers, AI in Electrical Engineering

I. INTRODUCTION

Our everyday life is powered by electricity and electromagnetism. They are everywhere, be it in vehicles, watches, elevators, Power Grids, Mobile Devices, Laptops, Telephone Towers and Traffic Lights. Even inside our bodies. Since Electrical Engineering deals with the property of electricity and electromagnetism, Electrical Engineers make things work. Electronics, which is also a part of Electrical Engineering, made modern-day computers possible. These machines now are leading Electrical Engineers to new heights, due to emerging powerful microprocessors and introduction of Artificial Intelligence (AI). Today, Electrical Engineering and AI work hand in hand, for example, AI techniques help produce optimized results in Electrical Engineering, whereas it leverages AI in many ways to create new opportunities for the society.

AI involves hardware-based and algorithmic-based deep learning and machine learning to bring together researchers and engineers from both academia and industry, to present novel ideas and solid research on the hardware and algorithmic aspects of the industrial applications of deep learning-based AI [3]. In the case of Electrical systems, the models presented by AI are tested and practically used. They have solved many different categories of Electrical system problems. In this article, we will review the interaction between AI and Electrical Engineering by going through the history of AI in Electrical

Engineering, its impact on its different subdisciplines and even across different sectors of the industry. We also discuss how professional roles in Electrical Engineering are changing with the introduction of AI along with the perceived future.

II. HISTORY OF AI IN ELECTRICAL ENGINEERING

Electrical Engineering became an occupation in the late 1800s due to commercialization of the electrical telegraph, the telephone and the electrical power distribution and its use. Electricity from just being coils and magnets became an everyday need. Electricity was transmitted by transmission lines, new ways to store and manipulate electricity were discovered. Soon Electronics came into the picture in mid-1900. Machines were built to process electrical signals to transmit from one place to another. With the introduction of transistors, integrated chips and personal computers it opened commercial avenues [9].

Since the introduction of Intel 4004, which was the world's first microprocessor, computers have changed a lot. They are now faster and smaller. Early Expert systems were used in calculating and estimating the value of parameters used in generation, transmission and distribution of power [13]. The traditional classical controller often needs to design according to the controlled object model, but the model construction will usually have many uncertain factors such as changing of parameters and the numerical type which made design more difficult. Today, we have AI control systems which are easy to handle and the AI function approximator does not need to control the model of the object.

However, the programs so far developed for power system analysis and planning are based on mathematical models and are implemented using languages which are suitable for numerical computation only. Sophisticated approaches for system planning, development of methodologies is needed to incorporate practical knowledge of planning engineers into the programs which also include the numerical analysis programs. The research of AI has developed knowledge representation methods, search strategies, automated reasoning techniques, expert system or knowledge-based system methodologies and languages for symbolic and list processing. Even new tools to augment numeric programs with the experience of engineers and heuristic knowledge.

III. ADOPTION OF AI IN ELECTRICAL ENGINEERING SUBDISCIPLINES

We have broadly identified eight subdisciplines of Electrical Engineering in this section which are leveraging Artificial Intelligence and are evolving.

A. Power Engineering

Modern power systems are required to generate and supply high-quality electric energy to customers. To achieve this requirement, computers have been applied to power system planning, monitoring and control [1]. Also, with increased competitiveness in power generation industries, more resources are directed towards optimizing plant operations

including fault detection and diagnosis which should be detected early so that correct mitigation measures can be taken whilst false alarms should be refrained to avoid unnecessary interruption and downtime [2].

For the last few decades, there has been a major interest in Intelligent Condition Monitoring System (ICMS) application in power plant, especially with AI development particularly in Artificial Neural Networks (ANN). This is based on simple principles but takes advantage of their mathematical nature, non-linear iteration to demonstrate powerful problem-solving ability. In the process of generating the development and operation plans for a power system, engineers execute system analysis programs repeatedly by adjusting and modifying input data based on their experience and the heuristic knowledge about the system until satisfactory plans are determined. With massive possibility and room for improvement in AI, the inspiration for researching them are apparent, and literally, hundreds of papers have been published discussing the findings of hybrid AI for condition monitoring purposes [7].

As we are moving towards a world where everything is battery powered. The challenges such as making batteries lightweight, energy-efficient, enabling mass production and Generative Adversarial Networks (GANs) to get intuitive solutions is a potential candidate.

B. Control Engineering

Traditionally, classical controller often needs to design according to the controlled object model, but the model construction usually had many uncertain factors which resulted in changing of parameters and the numerical type that made the design more difficult. Use of AI in control engineering is an excellent choice as it is more convenient as well as consistent compared to other methods. The application of AI technology in electrical automation control is focused mainly on Fuzzy Control, Expert System, Neural Network and so on [6].

By properly adjusting related parameters, performance can be improved quickly. For example, the fuzzy logic controller reacts faster than the optimal PID controller and the overshoot method. AI controller is easier to adjust than the classical controller and is more adaptable to new data and information. The traditional control algorithm is designed according to the specific object, so the control effect is very good only for that focused object, but the effect of other control objects is not consistent. AI control algorithm, whether for the specified or unknown input data, can achieve better estimation consistency [14].

Electrical equipment structure is complex. In the actual design process, it not only needs to use the electronics, circuits, electromagnetic fields, motors, automation and knowledge of other disciplines but also needs an understanding of generators, sensors and other components of the role and mechanism along with high requirements of the designer's professional level and work experience. These make the design of electrical equipment's a complex project.

In the operation of electrical automation equipment, the operation of the electrification system is a very complicated problem, for it involves multiple disciplines and fields that require a high degree of knowledge reserves which are of high quality. In order to realize the normal operation of electrical automation equipment, AI technology is a very good path forward. It can improve productivity, reduce production costs and human resources costs.

In general, AI-based fault diagnosis techniques include Rule-based Reasoning (RBR), Case-based reasoning (CBR) and Fault-based Tree diagnosis. Based on basic composition and basic principle of traditional expert systems, a mechanical fault diagnosis expert system based on RBR and CBR reasoning is constructed. Since electrical pieces of equipment are prone to issues, the practical problems of its relevance are very complex. AI techniques such as Fuzzy Logic, Expert Systems and Neural Networks are used to judge the fault system. For example, in the power systems, machine learning techniques are used to analyze the decomposition of gas in the transformer oil for determining the extent of the fault and diagnosing the fault in the transformer. This approach is also used for generator and motor fault diagnosis.

C. Electronic Engineering

Powered by innovation and a knack for adapting quickly to emerging trends, the electronics manufacturing industry has been at the forefront of AI revolution. Extracting semantic insights from infinite pools of data and developing insights require complex modelling processes, often layering algorithms on the top of algorithms. Actions, in particular, occurring at a specific time and place and within a specific context need to be executed within milliseconds which require deep understanding of that context.

In order to exploit the product-based opportunities with AI and to also expand the product scope and create innovative services, electronics companies must select the right hardware platform for their devices. This typically requires the use of high-powered general processing units such as the ones used in smartphones. Silicon technology advances support increased computing power at reduced battery consumption. In addition, special-purpose hardware such as GPUs or Neural Network Processors supports AI functionality in devices with further reduced consumption of electrical power [15].

D. Microelectronics

Engineers are not just adding AI capabilities to our devices but are also using this futuristic technology in processors as well. In Microelectronics, the heuristic search techniques are used for the automatic construction of complex circuits and selection of the most promising solutions to the circuit synthesis problems. Take an example of a startup called JITX, which is building an AI system to take the tedious complexity out of designing circuit boards. It is aiming to design optimized circuit boards in a matter of hours instead of weeks, thereby allowing engineers to take on more supervisory roles and creating a need for them to upskill their skillset.

E. Signal Processing

Sensors collect raw data from the environment. It is the job of signal processing to convert that raw signal into a meaningful one. For example, when you get an unprocessed image, the blocks of squares are combined to form an image. But when you apply Fourier transform on it, the sharp edges are smoothed to extract details of the image. Similarly, in

audio signal processing, speech signal is analyzed to determine important parts of the signal. Machine learning is used for extracting features from the given data. It can be any signal such as sound waves, brain waves or radio waves, machine learning can do a similar operation on the data, analyze it, determine key features, and can categorize these important features into different labels.

As signals are everywhere, resulting applications of Machine Learning is extremely vast. Some of the popular applications are for example, Brain-Computer Interface, Voice Assistant in phones and adding a feel of touch to prosthetics. There is still scope for more applications such as aviation, financial markets, radar, medical imaging, radio telescopes, robotics, cellular communications where Machine Learning can be used to understand patterns and predict meaningful information, for example, in climate, VR/AR games, search engines, social applications, traffic control.

F. Telecommunications Engineering

Telecommunication Engineering is one of the main branches of Electrical Engineering. From the electric telegraph to the modern telephones, the idea of signal transmission was simple, to fluctuate current to vary the magnetic field in the coil of the electromagnet. But with the discovery of electromagnetic waves which led to breakthroughs such as mobile phones, satellite broadcasting and wireless communication around the globe. But, communication network became complicated.

Telecommunication engineers design and oversee the installation of equipment and facilities such as complex electronic switching systems, telephonic systems, optical fiber cabling, IP networks, and microwave transmission systems. Networks are an integral part of any mission-critical use case relying on connectivity, be it remote control of heavy machinery, autonomous drones or self-organizing logistics. Zero-touch network operations are the next challenge for these engineers in the coming years. Zero-touch network operations imply that networks can operate without human intervention as predictive operations will detect any potential problems and take measures proactively.

G. Instrumentation Engineering

AI systems give organizations an unparalleled ability to monitor vast amounts of data from different sources, helping them monitor product's progression in real-time. So instead of relying on humans for inspection and quality control, companies, such as Instrumental, utilize cameras powered by computer vision algorithms to spot defects immediately and identify root causes of failure. The overall objective of introducing AI into instrumentation is to free the professional experimenter from unnecessary involvement with minute implementation details of the experiment and provide him or her intelligent assistant for data interpretation, experiment evaluation and ultimately, experimentation and instrumentation control according to embedded knowledge [5].

H. Computer Engineering

Computer Engineers have high domain knowledge, strong programming skills and a good understanding of algorithms. They play a major role in AI application development in Electrical Engineering. They are in demand to build increasingly sophisticated robots for military, companies, consumers and governments. These are popularly known as new AI Engineers.

IV. ADOPTION OF AI IN DIFFERENT SECTORS OF THE INDUSTRY

A. Automation Industry

Software-based control of electronic devices has been in the marketplace for over a decade or so. AI supercharges this trend and expands it to enable smart software-defined device functions, especially embedded AI. For example, security cameras can recognize people and objects and then correlate events to identify potentially dangerous activities. AI offers key opportunity for electronic companies to escape hardware commoditization. It makes it possible to adapt devices to users' needs, rather than requiring users to deal with the idiosyncrasies of the devices [8].

Users can interact with devices through voice, gestures or through no action at all by just being present in the vicinity of the device. By observing them, AI can learn about their preferences and personalize the device functions to individuals. Learning thermostats is a good example of this development. Not only this, webcams and facial recognition systems are improving security in general. Electronic industry is also using this technology to safeguard devices against any infiltration, vulnerability and attack. The ability of AI is to study traffic patterns, baseline performance and user behaviour as well as identify anomalies in real-time is making it beneficial for use in this critical area of business.

AI, in the development of automation, not only can promote the overall progress in the field of electrical automation control but it can also promote the development of automatic control of progress. So, in the field of electrical automation control, innovation needs AI support to improve human consciousness of mechanical ability and strengthen the electrical automatic control. In addition, the failure of the power system will be ruled out, promoting the development of the AI technology in constant forward, carving out a new direction in electrical automation control through the theory of all aspects of applications of intelligent technology. Thus, contributing in improving the living standards of people [10].

B. Broadcasting and Telecommunication

Market Research Future (MRFR) Report identified that the global AI in telecommunication market is predicted to touch USD 1 billion at 32% CAGR over the forecast period (2018-2023). A Self Organizing Network (SON) fueled by AI can help networks continually adapt and reconfigure based on current needs. It is also beneficial when designing new networks. Through algorithms, which look for patterns, Artificial Intelligence is helping to detect and predict network anomalies, allowing operators to fix problems proactively before they impact customers. By using such intelligent and autonomous network solutions, telecommunication companies are achieving automation and value creation by enhancing their service speed and quality. In addition, improving the overall customer experience through a reduction in operating cost, as well as, developing new unique features in 5G networks.

C. Instrument Manufacturing

AI-enabled electronics manufacturing helps companies to create agile workflows for the rapid development of the next line of products. They combine and collect anonymized data from various sources like sensors attached to the products, customer usage patterns, current market scenario, audio and video files, technician comments, device manuals and more. This helps to generate key insights through which electronic companies can improve product quality, reduce costs and answer to market demands in a more efficient manner.

D. Power Generation

Deepmind, for example, is working with National Grid to better forecast the demand of their system, with the stated goal of reducing the entire country's energy usage by 10%. The power sector has long held a well-developed culture of sharing anonymized data sets which enables innovators and contractors to develop new AI robotics solutions for managing the power supply. Currently, these are mainly fault detection intelligent systems like Spark Cognition to reduce energy consumption, optimize field performance and raise efficiency [12].

V. CHANGE IN PROFESSIONAL ROLES AND SKILL SET

Electrical Engineers shape the world we live in today. Industries are converging industries and so is rapidly changing demand of different skillsets. Upcoming markets require a broader skill set that can be widely applied over many physical sciences areas, from anatomical intelligence through to autonomous vehicles. In other words, this skill set is what turns electronic engineers into invention developers. AI robotics is changing the role of energy workers from one focused on finding problems to the one solving them; moving away from low to high skill work as well as a suite of new tech jobs.

A. Electrical Engineers

Electrical Engineers design, develop, test and supervise the manufacturing of electrical equipment such as electric motors, radar and navigation systems, communications systems, power generation equipment. They also design electrical systems of automobiles and aircraft. AI can help engineers design and develop communications equipment, medical monitoring devices, navigational equipment and other electrical and electronic equipment. It can also help in product evaluation and testing, using measuring and diagnostic devices to adjust, test and repair equipment's [12].

B. Electronics Engineers

Electronics Engineers design and develop electronic equipment, including broadcast and communication systems, such as portable music players and Global Positioning System (GPS) devices. Many also work in areas closely related to computer hardware. AI will help them to design new ways to use electrical power to develop or improve products, perform detailed calculations for aiding manufacturing, construction and installation standards and direct the manufacture, installation and testing of electrical equipment to ensure that products meet specifications and codes. It can also investigate complaints from customers or the public, evaluate problems and recommend solutions or can work with project managers on production efforts to ensure that projects are completed satisfactorily on time and within given budgets. AI can help in design of electronic components, software, products or systems for commercial, industrial, medical, military or scientific applications. Also, it can analyze customer needs and determine the requirements, capacity and cost for developing an electrical system plan.

Deep learning techniques can augment maintenance and testing procedures for electronic components and equipment, evaluate systems and recommend design modifications or equipment repair, inspect electronic equipment, instruments and systems to make sure they meet safety standards and applicable regulations. They can help optimize electronic properties used in parts and systems in order to improve technical performance. Electronic engineers who work for the federal government, research, develop and evaluate electronic devices used in a variety of areas such as aviation, computing, transportation and even manufacturing. Nowadays, national institutes are pushing their edges to collaborate AI with federal electronic devices and systems including satellites, flight systems, radar and sonar systems and communications systems.

C. Biomedical Engineers

Since our nervous system is in fundamental electric, we can record our brain signals to know what it's doing or can control prosthetics or can even restore movements to people who are paralyzed. Biomedical engineers can combine engineering principles with medical sciences to design and create equipment, devices, computer systems and software used in healthcare. Applications cochlear implants including BCI through EEG data, monitoring heartbeats through ECG data, controlling prosthetics through our muscle EKG data and Deep Brain simulations to treat Parkinson's are some of the examples.

Other thriving approaches like controlling and understanding consciousness, memory and attention are coming up. Both, Biomedical Engineers and AI Engineers, can really help in advancing neuroscience research and could possibly control robots through human mind as our algorithms will get better in decoding signals from the brain. The better we train our machines to understand our brains, the better we will know ourselves.

D. Computer Hardware Engineers

Computer hardware engineers research, design, develop and test computer systems and its components such as processors, circuit boards, memory devices, networks and routers. With the rise in cloud adoption, electronics companies are broadening from an operational mindset to an innovation orientation. Hybrid cloud is the driving force behind this transition, providing new use cases that empower business reinvention.

As electronics CIOs and business executives negotiate their company's unique position in the cloud continuum, they are using key criteria to identify compelling use cases for hybrid cloud adoption that can generate business innovation and value. Moreover, computer hardware companies are trying to change the traditional computational circuit, specially designed to perform deep learning operations. Faster hardware augmented by specialized arrays

of GPU processors, Neural Network Processing Units (NNPUs), Field-Programmable Gate Arrays (FPGAs) and Application-Specific Integrated Circuits (ASICs) supported by frameworks, to distribute workloads and perform faster computations in real-time.

E. Electrical and Electronics Installers and Repairers

Electrical and Electronic installers and repairers install or repair a variety of electrical equipment in telecommunications, transportation, utilities and other industries. To install, maintain and repair electrical power, communications, lighting and control systems in homes, businesses and factories, electricians need sophisticated approaches like system planning, development of methodologies and techniques to incorporate their practical knowledge into programs which also include the numerical analysis programs.

Advanced analytics with insights to support the decision-making process, autonomous business processes, eliminating manual process to achieve faster time to market and AI-powered immersive, conversational and continuous interfaces will help deliver a 'wow' customer experience and achieve greater involvement from the user.

F. Network and Computer Systems Administrators

Computer networks are critical parts of almost every organization. Network and computer systems administrators are responsible for the day-to-day operation of these networks. In IT industry, research has been performed to try to automate system administration tasks. The infrastructure of networks and servers deployed in order to manage the data produced by research institutions like LHCb to control the experiment are critical for its success. For example, in 2001, IBM defined the so-called self-objectives which lead to autonomic computing to help IT infrastructure.

G. Sales Engineers

Sales engineers sell complex scientific and technological products or services to businesses. They must have extensive knowledge of the products' parts and functions and must understand the scientific processes that make these products work. Start-ups like people.ai are worth noticing as they are trying to build a platform for all business activity across every organization to help in sales, marketing and customer success teams for uncovering every revenue opportunity from every customer.

VI. Conclusion

Human ability to review information is intrinsically limited in terms of breadth and speed. Thus, we need subtle Machine Learning and Deep Learning techniques to augment the human ability to invent new products and services, accelerating the invention process and producing truly novel solutions. Devices may well be smart or intelligent but that doesn't mean they are AI. The intelligence could be algorithms or logic to improve performance or data processing and analytics to detect trends and provide information back to the user, but it's still not AI. The main challenge is to use that data effectively to create the next generation of electronic devices which will be controlled by AI at the backend [4]. As algorithms automate away routine decision-making, people will see both an increase in the time they have for tasks related to critical thinking and creativity, allowing them to focus on activities that the value more and eventually, will allow humans to be more human.

AI is among the newest signal processing technologies in the engineer's toolbox. It is the new electricity which is recommended to be used wisely by Electrical Engineers, for their benefit and of the society. According to a Professor Penfield of Electrical Engineering Department at MIT, "Technicians use existing technology and they do interesting things with it and they make inventions and scientists advance science. But the link between those two is engineers, who not only use existing technology but develop new technology using known science. Engineers generally don't wait around for the science to be fully developed before they want to make use of it. Engineers should remain tinkerers and inventors at heart. And if the science isn't there, they'll go ahead anyway." AI-powered Electrical Engineering is not just smart lighting, smart devices, it's much more than that with AI, intended to behave like humans as new innovations emerge.

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