e-ISSN: 2582-7464

Computational Intelligence and Machine Learning
Vol-2, Issue-1, April 2021

Scope & Integration of Computational Intelligence in Traditional Power Sector

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Abstract

An electrical power system is an infinite vast complex network of sophisticated equipment and confederate control to ensure a sustainable energy supply. Ever-increasing power demand in the recent decade has made it difficult to maintain its viability. A rapid transformation in the internal architecture of power system infrastructure is the need of the hour to continue the fictitious lifeline. With the passage of time, electricity has become one of the most crucial elements with almost no substitute. Cutting edge energy-efficient technologies and modern generation computational tools can trigger its growth to maximize its potential, which may entirely transform the power sector scenario and make it future-ready. It is predicted that the adoption of artificial intelligence mutually with data science must have a remarkable outcome to incorporate and develop automation and move towards a smart grid by slashing energy consumption, lowering prices, enhance transparency, gear up efficiency and boost clean green renewable sources globally. AI can further improve the planning, operation, and intelligent control of power systems. Data-intensive technologies can be introduced in diverse dimensions of the electricity value chain following an authentic road map which may considerably reduce the conventional challenges and create significant value. In this work, the authors have attempted to study, investigate, and explore the Power System's present outline in context to India and summarize future possibilities, difficulties, and specific outcome in a systematic, logical manner. This novel work shall benefit distinct researchers and dynamic academicians to get a fundamental idea and strengthen their existing knowledge over the subject.

Keywords

AI, automation, cloud computing, data science, Energy, management, power system.

INTRODUCTION

Artificial intelligence (AI) can play an essential role in changing economies and industries, such as the electricity market worldwide. It is still early days in the implementation of AI in the energy and infrastructure sectors, but several possible uses are emerging. It is believed that artificial intelligence (AI) would revolutionize every industry on the planet, including the power market. The whole power market is going through a revolution owing to digitization. The energy market does not seem to be as it was in the '20s. Utilities focus on employing Artificial Intelligence (AI) principles around Big Data, predictive analytics, and machine learning (ML). As of now, it is only in the early stages of general implementation; there are already various ways in which AI has been applied in the electricity and services sectors. Cognitive processing has anticipated to become the nervous centre of the potential smart grid. A centralized national sensor network system hub can constantly accumulate and evaluate vast volumes of data from millions of sensors to identify the health of power infrastructure periodically. Additionally, 'deep learning algorithms can boost both the supply and demand aspects of the energy market. As a consequence, microgrids would overtake regional systems that meet broader electricity requirements. Customers can also benefit from smart meters and transmission sensors which allow for constant demand and supply monitoring. Additionally, 'synchronogists' briefcase-sized instruments are built to monitor flow speeds to eliminate interruptions in the system. This sensor would operate with the grid to modulate the power supply to lower the utility bills' stress for customers. With the growing usage of artificial intelligence, the industry will move to an energy portfolio of sustainable energies, variable supply, and limited intermittency disturbance. Climate change and its subsequent ever-growing need for green power would cause a severe energy industry crisis as its integration in the existing power ecosystem to have several quality and stability issues. AI, robust data science algorithm and analytics prove beneficial by dynamically control the energy produced from numerous power generation resources to meet shifting temporal, geographical, and social needs in real-time.

LITERATURE SURVEY

Renewable energy sources are very significant and beneficial to meet ever-increasing energy requirements sustainably. Though traditional sources might last a little longer, it is not just the availability but also the affordability. Quiet often third world countries with fragile economies suffer from an energy crisis. It is a well-recognized and acknowledged reality that green renewable resources are emerging; more efficient energy sources are bound to be significantly more acceptable in the potential due to their low prices and environmental friendliness. India has tremendous potential to harness diverse non-conventional green energies and other sustainable energy forms, with ample solar resources. The supply of electricity was indeed a crucial factor in national prosperity. The success story of modern India since Independence is remarkable. The power sector also has been similarly hit by the global financial crisis. Over the period from 1947 until now, the per capita intake has risen 12-fold from 16 kWh to 1,181 kWh. The overall amount of infrastructure that caters to this demand falls under the word "Power Scenario." In this area, future electricity generating capacities and distribution channels need to be thoroughly examined. The necessity of the hour is to consider and address the potential issues that arise in this field first, which may prevent its growth and accessibility. Innovative computational tools may act as a game-changer to revolutionize and transform the rudimentary power sector concept and accountability by a systematic, sustainable outcome-based approach. In 2018 L. Wencui et al. has investigated a detailed case study on the Information Security Prevention System of electric grid based on AI tools [1]. S. Kokin et al. has presented a fantastic Optimisation strategy of electrical power system modes by implementing artificial intelligence, which was a remarkable research outcome in 2020 [2]. A. Jalilvand et al., in the year 2010, has studied and explored the design of an energy-efficient PID power system stabiliser in a multi-machine power system using computational intelligence methods [3]. H. Yu and G. Shao [4] in 2019 examined and reviewed the Reactive Power of Electric Drive System of Remote Pump Station utilising Artificial Intelligence Control strategy. In 2019 C. Darab et al. has analysed and reconsidered Fault Location and Detection in Distributed Generation Power Systems using the Machine learning & Data Science approach [5].

In his previous work, the authors have studied, investigated, explored, & examined various physical parameter/triggering conditions that affect power system operation, remote health-monitoring, innovative troubleshooting techniques author after exhaustive literature review, has observed much less progress has been reported in the domain of intelligent power system and application of computational tools in solving real-time problems in the recent time. However, numerous scientific research activities are needed to be nurtured and carried out to promote the New Generation power network concept. The author of this work has tried to present an overview of recent research findings and development, possible challenges, and scope for further improvement.

SMART GRID MARKET DYNAMICS

By 2025, the global smart grid market is estimated to be worth USD 94.7 billion. Energy initiatives and activities such as green electricity infrastructure, intelligent metres, energy-efficient resources, and smart appliances are also part of smart grid technologies. Furthermore, the smart grid employs hardware technologies such as security cameras, sensors, and others to detect electricity demand and control the systems. Smart grids may use devices to switch on and off power when the networks are not in use, resulting in lower energy usage. The smart grid offers technologies that increase fault identification and enable the network to self-heal during power outages. Smart Grid enables real-time control and management of the power sector while also assisting in the reduction of AT&C losses. Smart Grid is intended to act as a backbone network to implement emerging market models such as hybrid cars, smart towns and societies. The worldwide market for smart grids is segmented by component, solutions, application, end-user, and geographic region. The industry is split into two components: solutions and facilities. It is categorised into four groups based on application: generation, transmission, distribution, and consumption/end-use. The sector is divided into advanced metering technology (AMI), substation automation, smart grid security, connectivity, network management and other based solutions.

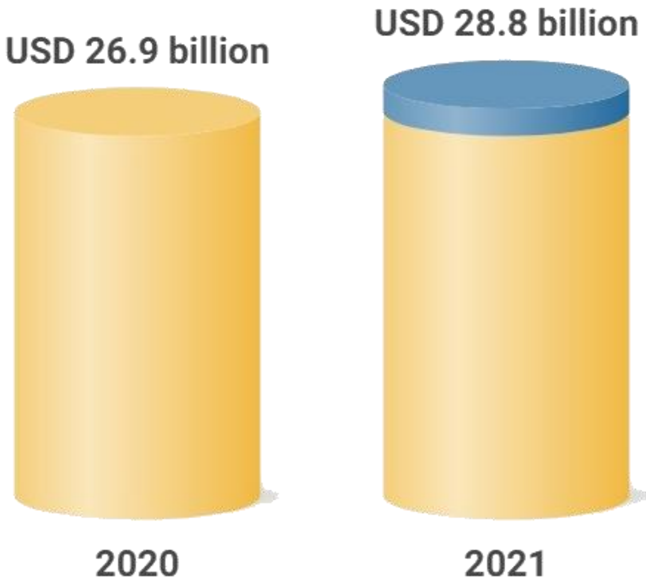

Fig.1: Asia Pacific smart grid market 2020-21 [2]

The existing and prospective potential of smart grid industry dynamics is driving the market's overall attractiveness. During the forecast era, the top influencing factors illustrate the smart grid business opportunities. The increasing concern regarding environmental protection is a primary factor influencing the demand growth for intelligent grid systems. Furthermore, rising favourable government legislation and intelligent metre deployment policies are the main drivers driving demand for innovative grid technologies and services. However, safety and protection issues around smart grid systems are a significant impediment to the smart grid industry's development. Increased smart city projects and government programmes are projected to create substantial growth prospects for the sector in the coming years. Below two charts has been shown with the Asia-pacific smart grid market with an expected steady growth rate of 7.1%, i.e., Fig. 1 and on the other hand, Fig.2 shows existing and future projection of Smart grid infrastructure market of key notable countries in terms of USD.

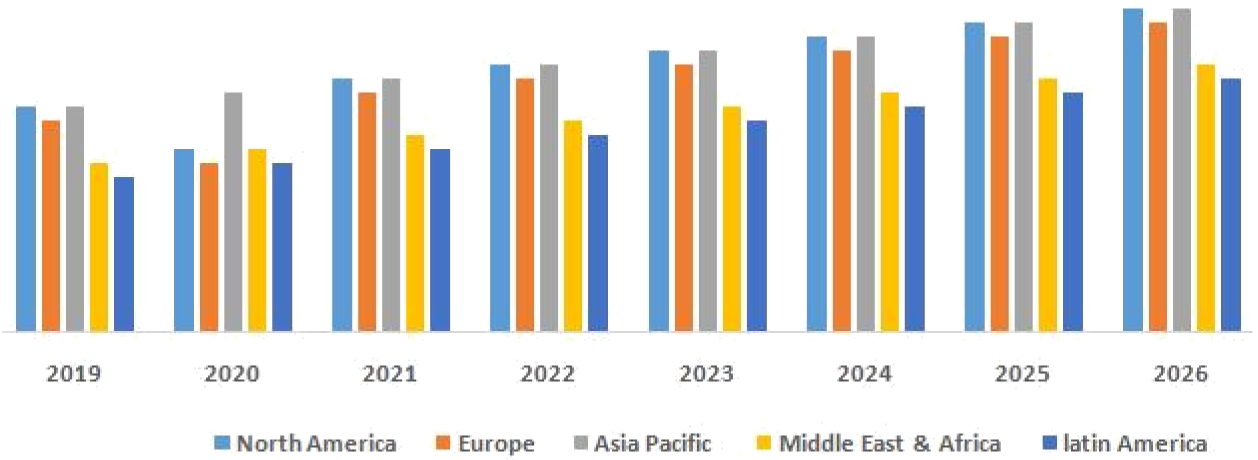

Fig. 2: Smart Grid Energy Market worldwide for 2019 to 2027 [3]

NECESSITY OF AI & DS IN POWER SECTOR

The sophistication of the power system networks has risen significantly as the energy structure has expanded. As a result of this power system research using traditional methods, drawing assumptions from the collected data, the details, remote device control, and utility management processes have become more complex and time-consuming. AI is built with the assistance of advanced programming software and implemented to solve all of the above problems for massive power structures, as the requirement is the mother of innovation. The need for Power Systems architecture with Artificial Intelligence is primarily because of the complexity, flexibility, and extensive knowledge used in the measurement, diagnosis, and learning. Moreover, using traditional techniques becomes more stressful due to the massive device data processing, the computing period, and precision have increased. Understanding the pivotal role data plays in AI's vast complexity helps examine the technology's varied encapsulating and overlapping approaches (Fig. 3). artificial intelligence encapsulates several concepts, including 'natural language processing' (NLP), 'deep learning' (DL), and 'neural networks' (NN).

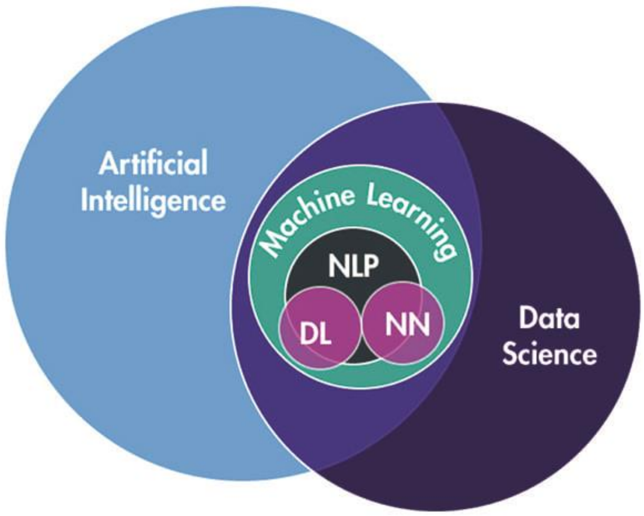

Fig.3: Different sectors of Computational Intelligence

RECOMMENDED AI TECHNIQUES

From the early to mid-1980s, finding solutions to complex issues in numerous power system innovation fields was difficult and time-consuming. Many restrictions can now be efficiently handled using Artificial Intelligence (AI), such as economic load dispatch, load forecasting, generation, and scheduling optimization, transmission ability and optimum power flow, actual and reactive power limits of generators, bus voltages and transformer taps, load demand in interconnected extensive power systems and their protections, and so on. AI methods have successfully eliminated the majority of the efforts of power system research. Modern power infrastructure includes essential families of AI techniques, i.e., Fuzzy Logic systems (FLS); Genetic algorithm (GA); Artificial Neural Networks (ANNs); Expert System Techniques (XPS), and so on.

AAN: Artificial Neural Networks

ANN are biologically motivated structures. Each neuron generates one output as a function of inputs in ANN mathematical models, which simulate the human biological neural network for information processing. After being learned, each form of the neural network is capable of completing a feature based on insights encountered in real life, such as function approximation, recognition, data processing. Its main advantages are the ability to learn algorithms, online dynamic machine adaptation, fast parallel computation, and intelligent data interpolation. Their architecture, number of layers, topology, communication pattern, feedforward, backpropagation, and radial base function or recurrent, among other factors, are used to classify them. ANNs are dissolute and efficient, and they do not need any previous knowledge of the device model. They can tolerate missing or corrupt data and details because they are fault-tolerant. They have understanding and data adaptation potential. ANNs, on the other side, can only execute the purpose for which they were programmed. They must be retrained for some other mission. ANNs often produce a verdict, even though the input data is illogical. ANNs are particularly useful for problems requiring quick performance, such as those in real-time operations. Power device security may benefit from ANN techniques. Real-world challenges in power production, storage, and delivery may be fed into ANNs for a solution.

FLS: Fuzzy Logic systems

Fuzzy structures were invented in 1965 and quickly gained popularity in scientific problem-solving. Instead of an exact mathematical interpretation, they are regarded as mathematical means of explaining complexity in linguistic words. Since it works and can make decisions like a human brain, approximate logic can be standardized and systematized. As a result, it provides precise solutions with limited or even approximate knowledge and details. As a result, this technology is used in computers to mimic human performance. Fuzzification allows for oversimplification, superior expressive capacity, and a better opportunity to model a complicated problem at a low expense. It requires a certain degree of ambiguity in analysis, and as a result of the permitted uncertainty, it reduces problem complexity and defines facts. Fuzzy logic can be used in power system applications such as reactive power & voltage management, system stability analysis and control, fault analysis, security evaluation, load forecasting, power system safety, and so on. It may be used to improve performance as well as to build physical components of power systems ranging from small circuits to massive mainframes. Since most of the utmost power system research is done with approximation or assumption-based results, fuzzy logic can help obtain a consistent and exact output free of uncertainty.

XPS: Expert System Techniques

Expert technologies were built in the 1960s and 1970s and commercialized in the 1980s. It is often referred to as a knowledge-based method or a rule-based system. Computer software uses information derived from experts on a particular topic to provide users with problem analysis. This information is usually saved in one of many formats, such as rules, decision trees, templates, and frames. It implements this knowledge and interface mechanism to solve problems that are either hard or challenging to solve using human ability and intelligence. A computer program providing rules for interpretation and advice for users is the most famous example of an expert framework. Since expert systems are essentially computer programs, they are built on the method of writing codes, which is more accessible than simply measuring and estimating parameter values. As a result, specific changes can be made quickly, often after the concept has been completed. These programs are incapable of accepting non-programmed issues or conditions. Expert networks are beneficial where a vast volume of data and knowledge must be handled in a limited period. Many power systems applications relating to power system architecture and study are compatible with expert systems' capabilities.

GA: Genetic algorithm

The Genetic algorithm has a global strategy focused on biological metaphors. It is an optimization method focused on the study of "Natural Selection and Natural Genetics." Several approaches for improving performance and power system analysis to improve power production may be suggested, but Genetic Algorithms outperform all chosen constraints. It is the most effective approach for dealing with dynamic and nonlinear problems. It is used for power supply, storage, and delivery preparation. It modifies the excitation parameters to address the voltage regulation and reactive power compensation problems.

KEY CHALLENGES NEED TO BE ADDRESSED

Advanced technology is permeating every sector of the global economy, including the electricity sector. Computational intelligence has the ability to overhaul this industry around the world entirely. AI is supposed to progress from a valuable technology to the most effective decision-maker the electricity market has ever seen. It is expected to minimise manual labour, reduce costs, and enhance data and asset protection. However, before the promising future can arrive and AI can revolutionise the energy market, several obstacles must be needed to overcome, below few are addressed for better understading.

Inadequate theoretical framework

One explanation for the sluggish implementation of AI in the energy sector is a lack of decision-makers awareness of AI technologies. Many businesses actually lack the technological knowledge required to realise how AI will support their operations. Conservative stakeholders would rather stay with tried-and-true approaches and tools than take a chance with the fresh. If more markets, such as schooling, banking, healthcare, and transportation, recognise AI's potential, decision-makers in the energy sector shall follow it.

Incompetent pragmatic knowledge

AI is still a newer concept, and experts who have mastered it are few. There are numerous experts with comprehensive theoretical knowledge of the topic. However, it is exceedingly difficult to find experts capable of developing robust AI-powered applications of real-world utility. Furthermore, the oil market is notoriously traditional. Even though energy firms gather and maintain info, digitising it using cutting-edge technology is problematic. Data loss, bad customisation, server malfunction, and unauthorised access are both threats. Since the risk of error is considerable in the energy sector, many businesses are afraid to pursue innovative methods for which they are inexperienced.

Antiquated Infrastructure

The most crucial impediment to energy sector transformation is the ageing infrastructure. Currently, energy providers are trapped under a mountain of data that they have collected and have little idea how to do with it. While the business has more data than anyone, that data is often dispersed, disorganised, dispersed through several platforms, and often processed locally. Although the industry makes a lot of money, it still loses much money because of old structures' flaws.

Financial stress

Implementing advanced smart technologies in the energy sector might be the safest alternative, but it is far from the cheapest. It requires a lot of time and money to locate an experienced software services supplier, build and configure software, modify, maintain, and track it. Until companies in the energy industry enjoy the advantages by integrating AI, artificial learning, and deep learning into their plans, they must be prepared to devote a sizable budget and recognise the uncertainties involved with updating obsolete technologies.

EXPOSURE OF AI & DATA SCIENCE IN POWER SYSTEM

A reliable and adequate electricity supply has been a necessity of the planet to prevent environmental effects. This is accomplished by careful control of power system facilities and consumption. It necessitates AI-based strategies that are highly secure, precise, and automatic systems such as EMS, Intelligent sub-stations adorned with high-speed security, tracking, and communication systems. Savings in the fields of remote control of facilities, operation, repair, and manufacturing may be realized by promoting these advances with AI techniques. Much research has been done, and a lot more research is needed to reap the maximum benefits of AI technology for cost reduction by enhancing the performance of the power grid, distributed control and monitoring system, renewable energy resources system, and electricity market and investment system.

Several challenges with power networks cannot be addressed using traditional approaches. As a consequence, AI strategies in power device implementations are attracting much interest. Outage detection and prediction begin with the selection of the appropriate metrics and their threshold values. Any outage case should be thoroughly investigated to determine the root cause. Only then can statistical algorithms be used to forecast the probability of an outage in the future. The usage of intelligent electricity failure ecosystems facilitates reliable real-time outage statuses to enhance overall consumer service and retention. Some of the areas of the power scheme applications are highlighted here.

- Economic load dispatch, generation, organizational preparation dependent on load forecasts, hydrothermal generation scheduling optimization, power transmission capability, optimum power transfer, generator actual reactive control restrictions, and device efficiency
- Dynamic energy management, real-time customer billing, improving operational efficiency, optimizing asset performance, analysis of energy prices and auction tactics, enhancing customer experience, Smart Grid security and theft detection, preventive equipment maintenance, demand response management
- Distribution planning and service, network reconfiguration, demand-side reaction and management, innovative grid operation and control, power restoration, fault detection, and protection margins may all be automated
- Voltage and frequency management for machine reliability, sizing, and control of FACTS systems

SPECIFIC OUTCOME & DISCUSSION

This paper reviews the latest artificial intelligence applications in power systems, such as artificial neural networks, expert systems, and fuzzy theory. These applications have the enormous potential to vastly improve power system performance, minimize human and material resource input, and play a critical role in power system defense. It is projected that the power system's scale will continue to increase in the coming years, as will its complexity, which will bring some more difficult factors to deal with. Some artificial intelligence already has its range of remarkable opportunities, restraints, limitations, and a lack of a sustainable roadmap, applied to the compelling hybrid intelligent. It is believed that in the future, as research advances, computational intelligence may become more advanced and simpler to use, allowing it to help solve real-time difficulties in power systems. Integrating a range of innovations with computational intelligence would be a big trend in growth prospects in a nutshell. Injection of more eco-friendly EVs near future market needs next-generation charging infrastructure with 24x7 power availability which is needed to be ensured by the application of computational intelligence and sophisticated, cutting-edge technologies which have a unique role in transforming centralized power system into numerous smart microgrid, in turn promotes the adoption of more renewable captive energy power sources and thus moves towards a greener, sustainable future.

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