Artificial Intelligence Applications for Distributed Energy Resources: A Survey

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Abstract

Distributed Energy Resources (DER) is a concept that is still being worked on in the power grid of today. It makes it possible for electricity and data to move back and forth between adjacent power sources in the networks and clusters of the electricity system. Smart Grid is meant to replace the old grid with a network of Distributed Energy Resources. It combines many new and old technologies, such as information and digital communication technologies, to do a lot of different things. With this, the New System would be ready to identify, respond, and act to changes in utilization and cope with a variety of issues while making sure the power system runs on time. Distributed energy resources are a big part of artificial intelligence (AI). In the past few years, these promising technologies have changed quickly and been used in a growing number of ways. This study focusses on analyzing the applications of AI on DER in the different areas of DER, such as renewable energy, grid control, energy management, and AI in virtual power plants.

Keywords: Distributed Energy Resources, Smart Grid, Artificial Intelligence, Renewable Energy, Energy Management

I. INTRODUCTION

Devices for power generation, transmission, and distribution that are connected to the electric grid are referred to as distributed energy resources. They are typically situated in close proximity to load centres, and they individually or as a collection provide services to the electric grid (Worighi et al., 2019). DERs can be made up of a diverse range of generation, transmission and distribution assets. There are virtual assets that can contribute to the performance of DER electric system.

Physical DERs include things like power plants, battery banks, and solar panels that have a capacity of 10 MW or less. The utility company, a private company, independent power producers operate these facilities. Similarly, to how it supervises the functioning of large central power plants, the utility requests start and stops from these smaller facilities. Like with physical power plants, digital twins can be used to analyze the efficiency of a virtual power plant before it is added to the grid.

The need for energy is going through a significant transformation. Some of the older concepts are becoming obsolete, and it is necessary to develop new ones in order to address the issues posed by climate change and the scarcity of resources. The demand for electricity is skyrocketing at a pace that no one has ever witnessed before. The new cities and their infrastructure need to lessen their impact on the environment caused by carbon emissions. Getting there will be heavily dependent on the proportion of renewable energy sources that are incorporated into DERs (Facchini, 2017).

The emerging model of distributed generation is getting more and more attention, mostly because infrastructures are becoming more and more digitalized. This makes data more accessible and gives users more control over the stability of the network than ever before, even when there are occasional problems and interactions with customers.

Using PV, a wind turbine, fuel cells, and other DERs to make electricity on-site is a faster and less expensive option. Central power plants have larger installed peak capacities, but they also take longer to build than onsite distributed energy resources (DER) power plants. It also takes more time to put up high-voltage transmission lines (Notton et al., 2018).

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Consumers benefit from increased service reliability, increased performance delivery, and energy security when they use an electrical network that is based on distributed energy resources (DER). When distributed energy resources (DER) make use of a renewable technology, they provide a significant contribution to the overall mix of power generation and are a component of the environmentally friendly approach for a cleaner planet.

The paper initially discusses about the AI for power system applications. It discusses the context on renewable energy, grid management, grid control, predictive maintenance and autonomous learning. Further, it is discussed about the use of AI Energy Management, AI for Virtual Distributed Energy Resources. There are edge IoT devices which facilitate the use of AI on the edge. Similar systems are discussed on the paper.

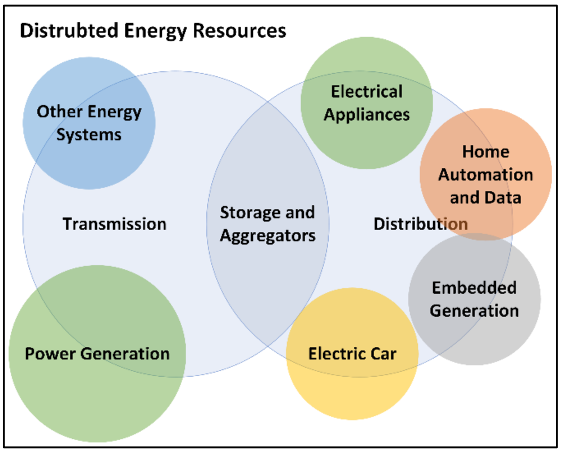

Figure 01: Distributed Energy Resources

II. DISCUSSION

A. *ARTIFICIAL INTELLIGENCE FOR POWER SYSTEM APPLICATIONS*

The growth of analytical models has made it possible to utilize various different tactics from the field of machine learning across a variety of industries, including the field of electricity generation and distribution. (Hossain et al., 2019). At the moment, most researchers are focusing on Machine Learning (ML) and Deep Learning (DL). People have thought of the Deep Learning (DL) as a new area for extracting features and dealing with a lot of data when ML methods fail. AI as a whole includes many subfields, such as machine learning, deep learning, big data, computer vision, neural networks, natural language processing, and many more. (Hossain et al., 2019). DL uses huge computational models like neural network algorithms with many levels of processing units to increase computational power and improve training methods. These networks are used to learn different trends from huge datasets. AI can help make systems in the power industry that are smarter and more reliable.

There are several Deep Learning Algorithms, particularly used in the Distributed Energy Resources. Some of the relevant algorithms are given here in Figure 02(China Electric Power Research Institute et al., 2018; Hafeez et al., 2020; He et al., 2017).

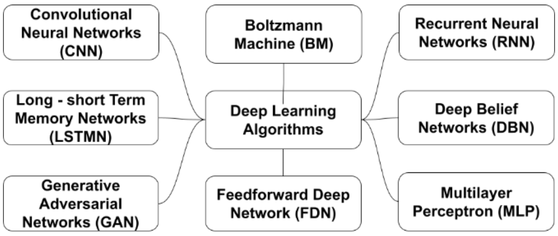

Figure 02: Deep Learning Algorithms

1) *Renewable Energy*

AI has the potential to revolutionize the renewable energy market. Using AI, electricity firms can improve their forecasting, grid management, and maintenance scheduling. Undoubtedly, renewable energy is the future, but its unpredictability poses a significant obstacle. Renewable energy relies on resources such as sunshine, airflow, and water. All of these resources are dependent on the weather, which is uncontrollable by people. Artificial intelligence has helped overcome this obstacle because it is a dependable tool for weather forecasting. It uses machine learning to analyze current and historical meteorological data in order to give reliable forecasts. These forecast data are utilized by the energy corporations to manage the energy systems. If the outlook is favourable, the corporations create and store renewable energy. If the prediction is poor, power firms adjust their load management accordingly. They anticipate the problem and utilize fossil fuels to maintain a continuous power supply.

The good forecast of production can be done by aggregating the forecast that is achieved through traditional method of power curves and the

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forecast using Artificial Neural Networks. The method is explained using the Figure 04.

2) *Grid Management*

Grid management is another essential part of a DER system. Likewise, artificial intelligence and machine learning play a crucial role in this field. These systems utilize data analytics to anticipate residential energy consumption. The forecast is based on a certain portion of the year and data from prior years. This helps power companies predict how much energy will be needed over the next few days. Consequently, they can control their grids without interruption. If consumption is expected to be high, energy production can be increased. Alternately, during periods of the year when energy use is low, production might be reduced to prevent waste.

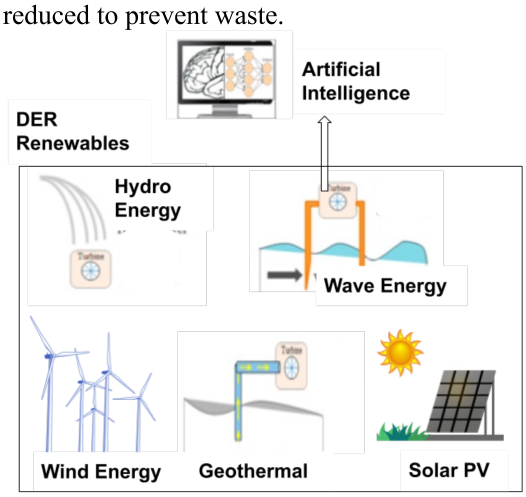

Figure 03: Renewables Associated with AI Forecasting

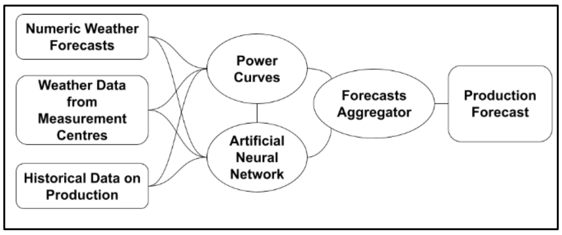

Figure 04: Renewable Forecasting using Artificial Neural Networks and Power Curves.

Advanced Metering Infrastructure (AMI), Distributed Automation (DA), Distributed Generation (DG), Distributed Storage, Home Energy Management Systems (HEMS), and Demand Response are examples of SG applications for monitoring and grid management (DR)(China Electric Power Research Institute et al., 2018). Smart Grids are one of the greatest possible IoT network deployments, with smart meters, wireless smart sensors, and smart appliances communicating to ensure reliable and effective power generation and distribution. Utility companies have to submit AMI end-user sensor, monitoring system, and smart meter data for billing, grid management, and forecasting. Sensor network data and SG interactions(Kimani et al., 2019).

3) *Predictive Maintenance*

There are times when electrical networks require repair, regardless of how effectively they are managed. It is essential that the entire system operates efficiently. By utilizing the power of AI and machine learning, it is simple to predict which system component will require repair(Shin et al., 2021). When power companies are made aware of imminent grid repair, they are able to inform customers. Scheduled maintenance allows users to anticipate upcoming power outages. Currently, we are experiencing power outages with no prior notification.

Predictive maintenance can be done via signaling systems through mobile alerts. They also can be alerted with Dashboard warnings. Here the previous historic data in Distributed Energy Resources are stored in the cloud. The data is then fed to an AI system which works as a decision-making system. These decisions are then given to the user in order to achieve predictive maintenance. This is shown in Figure 05.

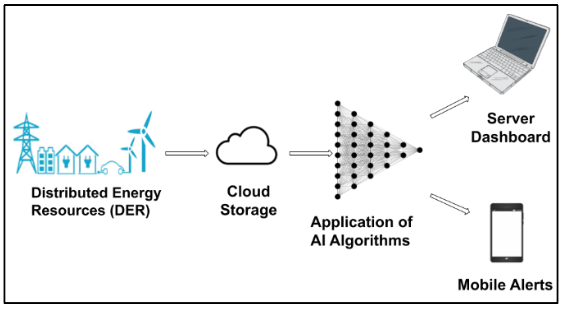

Figure 05: Usage of Artificial Intelligence for Predictive Maintenance

4) *Grid Control*

In power systems, new AI models in power systems are constructed using recursive neural networks. Transient stability of the electrical grid has been identified and its defining properties retrieved using data mining technologies(Rafik et

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al., 2020). This has resulted in answers for problems like assessing the current state of the system's operations, optimizing its controls, and coordinating their actions. The findings were used in load forecasting and standby dispatching systems, allowing for more informed choices in power grid monitoring, network analysis, index management, and index control(Ali and Choi, 2020).

5) Autonomous machine learning drives smart grid autonomy.

Using machine learning, DER - smart grid autonomous management can improve the intelligence of its planning, decision-making, and system comprehension(Jiao, 2020). In the field of smart grid applications, researchers frequently run into issues including adaptability in relay protection, assessing grid equipment defects, assessing grid parameters, and identifying stealthy faults. The smart grid's ability to learn on its own will be bolstered by the cumulative effects of autonomous machine learning, which will also raise the smart grid's level of learning in terms of perception, cognition, and behaviour(Azad et al., 2019).

6) Knowledge Information System

The expert system was the first and most important use of artificial intelligence. It was closely related to knowledge engineering. At the moment, experts' experience and knowledge are also needed to solve many issues in smart grid DERs. With an insight knowledge information system (KIS), specialists can learn more about a certain field and gain more knowledge and experience in it. The KIS's inference engine can be used to simulate how experts make decisions on the job. Setting up power grid knowledge data about fault diagnosis, intelligent control, fault localization and analysis, energy router self-determination, and other things will be a big step in the right direction for smart grid knowledge engineering (Kabalci and Kabalci, 2019; Li et al., 2018).

B. AI IN ENERGY MANAGEMENT

The world of energy has always faced problems with sustainability. By using energy at its best level, any industry can help save energy and use it efficiently without wasting it. As we've already talked about, AI is giving different services and industries new ways to use unmapped data and link it to decentralized energy resources(Lee et al., 2022). So, industries can use AI to optimize how energy is used in different sectors. This gives us real chances to solve the problems facing the environment. When AI, machine learning, and deep learning algorithms are used with an organization's core energy system, it's easy to get insights into how the energy operations work. Then, it breaks down the data and suggests an actionable way to manage energy while helping you save money on energy you don't need. It is a real-time way to cut down on energy waste and find new ways to save energy by using untapped data to optimize how much energy each industry uses.

A successful AI Energy Management system can be taken into action by considering the following factors.

- Always keeping an eye on the Al control system to make sure it doesn't go against safety rules (Khargonekar and Dahleh, 2018).
- If the Al control system does break the safety rules, the system will automatically switch to a neutral state (Khargonekar and Dahleh, 2018).
- Maintain a smooth transfer during failovers to prevent the system from going through any abrupt changes (Urlini et al., n.d.).
- Verification of the acts taken by Al on two different levels before implementation (Schneier, 2005).
- Communication that takes place continuously between the cloud-based AI and the physical Infrastructure (Kumari et al., 2020).
- Estimation of the degree of uncertainty in order to guarantee that we will only carry out actions with a high level of confidence (Kläs and Vollmer, 2018).
- Human override is always an option and will take precedence over any actions taken by the AI algorithm (Hendrycks et al., 2021).

C. AI FOR VIRTUAL DER

To begin, a digital twin model is produced that is a reflection of the real environment. This model includes each item and the location at which it is located. Utility companies are gaining more insight into their power grids and DERs with the use of digital twin models, which is increasing their level of safety and productivity while simultaneously cutting down on equipment downtime (Steindl et al., 2020). After the data has been incorporated with digital twin, the AI equipped simulations, analyze performance, and identify potential areas for improvement in order to maximise the intended level of performance (Novais et al., 2021). To achieve strategic and compliance objectives, different rules can be implemented, and the insights acquired can then be dynamically transferred back onto the original power system by means of AI-based asset controllers. A virtual environment is developed when more assets are added, and inside this environment, numerous different simulations may be run, problems can be investigated, and feedback can be sent to the DERs and smart grid. The AI models will continue to learn with the real-time data as they learn continuously through continuous learning in order to maximize long-term performance (Nikam and Kalkhambkar, 2021). This continuous influx of data and knowledge in real-time enables the models to become more intelligent over time and benefit from the decisions they have made in the past. An all-encompassing AI strategy may also actively synchronise and optimize traditional and newer DER with one another and with the electricity network. This opens the door for machine-to-machine interaction and decision-making. Because all of the assets are being controlled by AI, this active synchronisation capability ensures that they are all working together to achieve both individual & combined goals of the devices and systems in the grid.

D. EDGE AI FOR DER

The use of machine learning and deep learning algorithms make the edge IoT smart system intelligent and powerful (Loven et al., n.d.). Therefore, the following systems can be made smarter with the use of AI.

1) Advanced Measurement and Sensors

Smart metering, which customers and utilities can use to find out how much and when they use electricity, is part of the AI powered smart grid. This checks the safety of the system, the integrity of the grid, and helps with highly developed protective relays (Kabalci et al., 2019). This gives customers more options and lets them meet demand. It also makes the grid less crowded. Evaluation and monitoring carried out in advance make the grid more stable by finding problems early and isolating them so that power outages don't happen. The sensors collect data which is very helpful for forecast, analysis and predictive maintenance works.

2) Automatic Monitoring and Control

Smart Grid DER offers direct tracking and presentation of the statuses and efficiency of energy system devices over vast geographies, allowing device controllers and users to recognize this information and optimize electric grid components, activities, and output (Hancke et al., 2012; Meral and Çelík, 2019).Monitor and control technology from SG assist inform decisions, minimize wide-area problems, and enhance distribution reliability and capacity.

III. CONCLUSION

The use of the most recent AI technology is anticipated to be inevitable for the high performance of the newer DER system. Integrating Artificial Intelligence with Distributed Energy Resources (DERs) is a critical component for the successful operation of smart grid. Throughout the course of our study, we investigated the potential applications of AI in areas such as renewable energy, grid control, energy management, virtual power plants, and Edge AI devices. The DERs powered with AI will be able to provide many smart features thereby giving us reliable, less energy consuming electrical systems.

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