Application and prospect of artificial intelligence in smart grid

JianJiao

College of Economics and Management, China Three Gorges University, Yichang, Hubei Province, 443002, China
jianjiao@126.com

Abstract. With electricity market reform and the application scenarios of renewable energy and power demand response, the power system presents the characteristics of openness, uncertainty and complexity. The construction and application of smart power grid have become a trend. The application of artificial intelligence (AI) in smart grid provides powerful technical support for digital power network. Scenarios of AI in smart grid include power supply, power system optimization, power user behaviour analysis, fault diagnosis, etc. Although the application of AI in the smart grid faces many problems, such as insufficient data sample accumulation, insufficient reliability, imperfect infrastructure, lack of special algorithm for power industry, etc., on the whole, AI is a powerful tool to push smart grid into the new generation of power systems and energy networks.

1. Introduction

Smart grid is a combination of modern information system and the traditional power grid. Smart grid is the direction of power system development. It can solve the problems of the traditional power system such as low energy efficiency, poor interaction, and difficult security and stability analysis. The increasing scale of the power grid, the access of renewable energy power plants and the reform of the electricity market make the power system increasingly complex, which brings a lot of uncertainty to the operation of the power grid. Furthermore, the power system is closely related to other systems in such as information system, thermal energy system, transportation system, etc. The structure and composition of contemporary power grid are increasingly complex. When the power grid continues to produce a large number of high-dimensional and multi-type data, the traditional modelling, optimization and control technologies have many limitations, which put forward higher requirements on the power grid. AI has become one of the fastest growing areas in technology and is expected to play an important role in energy, transportation, health care, security and other applications. Most of the problems in the power system are optimization and prediction. AI can provide unique solutions for energy production, power grid balance and energy consumption analysis. AI has become an important part of the power industry. AI is an application process of self-learning and calculation. It can integrate human vision, perception, understanding, communication, adaptability and other abilities, and combine with the powerful data processing functions of computers. After summarizing the development of smart grid and AI, this paper will analyze some applications of AI in smart grid, such as the application of AI in the following situations: power load prediction, generation power prediction, power system stability control, power system fault diagnosis, and power network security protection. However, the application of AI to smart grid also faces numerous challenges, which are also analyzed in this paper.
2. Smart grid and its features
Different countries and institutions have different definitions of smart grid, but the connotations of various definitions are basically the same. Smart grid is a highly automated power transmission network that allows information and energy to flow two-way from each node of the grid. Smart grid has more perfect performance and can provide users with a series of value-added services. The ideal smart grid contains the following features.

- Self-repair of the power grid. In smart grid, self-repair control system can automatically diagnose and recover, quickly restore power supply, shorten power failure time, reduce power failure frequency and power failure range.
- Free access to renewable energy. The application of new materials, energy storage technology and information technology, as well as the support of two-way flow of electric energy, makes smart grid have stronger resource allocation capacity and support the access of large-scale renewable energy generation.
- Effective operation. Smart grid can optimize the asset allocation of power grid enterprises. For example, dynamic evaluation and adjustment can make the assets of enterprises play the best performance and improve the use efficiency of assets.
- Two-way interaction with the user. In a traditional grid, the user receives information passively. Smart grid implements two-way real-time communication, so users can not only receive information, but also feedback their own demand information to the system. In two-way communication, users benefit from changes in the way they use and buy power. From the point of view of the power grid manager, effective management of user demand can help balance the power supply and enhance the reliability of the power system.
- Improve the electricity market. The development of electricity market depends on the decent infrastructure and technical support system. With advanced equipment and information systems, the smart grid guarantees the operation of the electricity market, connecting numerous buyers and sellers.

3. AI and its development
AI comes from computer science. This subject tries to analyze the essence of human intelligence, and studies the way that computer or machine simulates human to analyze and recognize information, so as to expand human intelligence. AI architecture is shown in figure 1. In the past decades, AI has made great achievements in research and has been widely applied in various fields.

According to the degree of applicability, AI can be divided into artificial narrow intelligence (ANI) and artificial general intelligence (AGI). ANI refers to AI applied in the situation of clear task, requirement and boundary. At present, ANI has made remarkable achievements, which are better than human in many applications. AGI refers to a system similar to human intelligence that can learn and evolve autonomously just like the human brain. However, for AGI, there are numerous problems to be solved, which cannot be realized for a long time. The wide application of artificial intelligence is a tendency. In the future, all industries will upgrade and change with AI, and more industries and emerging business models will be born. At present, AI in education, medical care, elderly care, environmental protection, urban management, judicial services and other aspects have been outstanding performance, and is gradually infiltrating into all aspects of life.

Machine learning is a subdivision of AI, is one of the ways to achieve AI. Machine learning research is to create algorithms that enable computers to learn autonomously. Through the machine learning algorithm, the computer analyzes the existing laws of the existing data, and then uses the discovered laws to predict the similar situation.

Machine learning algorithm abstracts real problems into mathematical models and applies mathematical methods to solve the models. By evaluating the mathematical model, researchers can check whether the model really solves the problem raised, or to what extent it solves the problem. According to the classification criteria of learning mode and learning method, machine learning can be classified into distinct categories. For instance, based on the learning model, machine learning can be
divided into supervised learning, unsupervised learning and reinforcement learning. Based on learning methods, machine learning can be divided into traditional machine learning and deep learning.

Figure 1. AI architecture.

- Supervised learning is to establish a mathematical model for the labelled training data set through learning strategies, and then to mark the new data according to the established mathematical model. Typical supervised learning algorithms include regression algorithms and classification algorithms.
- Unsupervised learning is to describe the unmarked data and find out the rules hidden in the data. Typical unsupervised learning algorithms include single-class density estimation, single-class data dimension reduction, clustering, etc.
- Reinforcement learning is when the system maximizes the value of an output function by learning in some situations. Reinforcement learning has been successful in areas such as unmanned driving and robot chess.
- According to the observation of samples, traditional machine learning tries to find some laws existing in them, and then carries out trend analysis of new data based on this law. Algorithms applied to traditional machines include support vector machines (SVM) and bayesian methods. The traditional feature extraction of machine learning mainly depends on human, but the method of feature extraction and expression is not universal.

Deep learning is a subdivision of machine learning, which is a data representation learning algorithm based on artificial neural network. Through feature transformation, deep learning transforms the feature representation of samples in the original space into a new feature representation, making it easier to classify or predict data. Compared with the method of constructing feature rules manually, deep learning method can describe data information more accurately.
4. Application analysis of AI in smart grid

The core of intelligent power grid lies in replacing manual operation with AI to obtain the advantage of high efficiency, reliability and low cost. There are corresponding application scenarios of AI in every link of power system, such as power generation, power transmission, power transformation, power distribution and power consumption. The application of AI in the power grid is shown in figure 2.

4.1. The application of AI in power load forecasting

Forecasting power load makes power production and load match in real-time, which becomes the important work of power grid daily operation. Power load forecasting is the prediction of power demand in the grid. Power load forecasting can be divided into short, medium and long-term forecasting, ranging in time from a few minutes to more than a year. At present, artificial neural network technology has become one of the commonly used methods to predict power load. In the early stages, the back propagation algorithm (BP algorithm) used by the artificial neural network is a model containing only one hidden node. In the case of limited samples and computational elements, the model cannot fully describe complex functions. With the advance of technology, deep learning is widely used in power system load forecasting. The long and short time memory (LSTM) network is a common model in the field of deep learning. This model is an improved one based on recursive neural network (RNN). The characteristic of LSTM network is to use memory modules instead of common hidden nodes to ensure that the gradient will not disappear or expand after passing through many time steps, so as to overcome some difficulties encountered in traditional RNN training. LSTM is suitable for processing and predicting important events with relatively long intervals and delays in time series. The flow chart of LSTM network module to predict the power load is shown in the figure 3.

4.2. Power generation forecast of renewable energy

At present, the application of renewable energy power generation is increasingly popular, but the intermittent and volatility of renewable energy generation will affect the stability of the grid. The accurate prediction of renewable energy generation is of great significance to the stable, efficient and economical operation of the power system. The traditional shallow model prediction method has poor prediction performance when dealing with nonlinear and non-stationary wind or light data. Similar to the load prediction principle, LSTM model can also be effectively applied to the power prediction of wind power and photovoltaic power generation. In addition, other deep learning methods have also been tested in the power prediction of renewable energy generation.

4.3. Fault diagnosis and protection of flexible equipment in power system

Equipment based on power electronics technology can be regarded as flexible power equipment. There are flexible power equipment in alternating current transmission, direct current transmission, renewable energy generation, power storage, power distribution system, micro grid and other fields.

Fault diagnosis and protection of flexible equipment in power system is the defence line to ensure the safety of equipment, which plays an important role in quickly isolating faults, avoiding equipment damage and fault expansion. The fault characteristics of flexible equipment in power system are affected by its own variable structure, strong coupling, uncertain control variables and other factors, so it is difficult to carry out fault diagnosis. Deep learning can acquire deep features of fault samples of flexible equipment, and introduce new knowledge to expand the sample space through migration learning, so as to clearly express fault characteristics of flexible equipment in different levels.

4.4. Analysis of consumer electricity consumption behaviour

The clustering and identification ability of machine learning in AI can be utilized to analyze the power consumption behaviour of users, detect abnormal power consumption and non-invasive load monitoring. These analyses and tests provide theoretical support for the reasonable pricing of comprehensive energy system and the improvement of energy structure, and support two-way flexible
interaction between energy supply and users. For example, based on the data of power, voltage and current measured by smart meters, AI clustering and data mining can be used to identify the characteristics of electricity consumption behaviour of different user groups, realize scientific segmentation of customers, and then provide personalized marketing and services. Non-malicious factors (such as changes in electrical equipment, seasonal changes, changes in behavioural activities, etc.) can change power consumption patterns at short or long time scales and affect the accuracy of abnormal behaviour detection results. Therefore, it is necessary to identify and exclude the influence of these non-malicious factors. Power consumption analysis and abnormal behaviour detection can be summarized as the description of user characteristics, which can be solved mathematically by feature extraction or classification. The establishment of multi-hidden layer deep learning network can build a classifier with better performance.

4.5. Power network security protection
Smart grid is a complicated system with real-time perception, information service and dynamic control. The deep information flow interaction will make the power system face more potential threats. The network attack of the power system has the characteristics of strong concealment and long incubation period. Although the primary equipment is not directly damaged, the secondary system can be destroyed to attack the physical power grid. Deep learning can automatically identify network attack features, detect malware and intrusion, and provide network security protection for the power systems. The probability of power system being attacked is far less than that of normal operation, so the abnormal sample data of power network being attacked is far less than that of normal sample data. The training process of deep learning does not require sample labels, which can mitigate the impact of insufficient sample size.

5. The challenges of applying AI to smart grids
Based on the current development of AI technology, it is expected that AI technology application in smart grid will face the following key challenges:
- Insufficient data sample accumulation. Application of mass data analysis in smart grid is still in the initial stage, and the data accumulation in various application scenarios is different. Data samples that meet the requirements of diverse AI technology applications are not rich enough, so the realization of AI applications based on small samples is a problem that needs to be studied continuously.
Reliability needs to be further improved. Although AI technology applied to power system has reached a high level of identification rate for problems and faults, it still cannot meet the requirements of practical application. At present, AI method can only be used as an auxiliary way of work.

Infrastructure needs to be improved. The application of AI is based on abundant data samples, advanced computing power and distributed communication collaboration. However, the supporting capacity and level of relevant infrastructure resources such as big data, cloud computing and distributed collaboration platform need to be improved.

Lack of power industry specific algorithms. Algorithm is the basis of AI. Compared with perception, prediction and security maintenance, algorithm adaptability of AI in a power system is still weak. It is one of the key points of the follow-up research to improve the basic algorithm and propose the special intelligent algorithm for power system that conforms to the characteristics of the industry.

References
[1] Tuballa M L and Abundo M L 2016 Renewable and Sustainable Energy Reviews 59 710
[2] Colak I, Sagirolgu S, Fulli G, Yesilbudak M and Covrig C F 2016 Renewable and Sustainable Energy Reviews 54 396
[3] Gahramani Z 2015 Nature 521 452
[4] Feng C, Cui M, Hodge B M and Zhang J 2017 Applied Energy 190 1245
[5] Yiyian L, Dong H and Zheng Y 2018 Journal of Modern Power Systems and Clean Energy 6 306
[6] Rahman A, Srikumar V and Smith A D 2018 Applied energy 212 372
[7] Khodayar M, Kaynak O and Khodayar M E 2017 IEEE Transactions on Industrial Informatics 13 2770
[8] Bose B K 2017 Proceedings of the IEEE 105 2262
[9] Diamantoulakis P D, Kapinas V M and Karagiannidis G K 2015 Big Data Research 2 94
[10] Faia R, Pinto T and Vale Z 2016 Advances in Distributed Computing and Artificial Intelligence Journal 5 23
[11] Mahela O P, Shaik A G and Gupta N 2015 Renewable and Sustainable Energy Reviews 41 495