Application of Information Technology in the Construction of Smart Power Plants

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Abstract: With the rapid development of information technology, the construction of smart power plant in China has entered a period of rapid development, but there are still some problems that need to be improved. Reviewing the development history of smart power plant in order to better look forward to the future of smart power plant construction. This paper summarizes the development history of smart power plant and some commonly used information technology, and puts forward several personal insights on how to better integrate information technology into the construction of smart power plant.

Keywords: smart power plant; information technology; internet of things; big data; hydrological forecasting.

1. Introduction

In recent years, with the rapid development of information technology, all kinds of industries have begun to transform to intelligence, modernization and informationization, and the traditional power plant is also integrating with the new generation of information technology and transforming into a smart power plant. The construction of smart power plant is a part of smart city, which is divided into five main areas in smart city energy planning: power generation, storage, infrastructure, equipment and transportation [1], and the power plant is responsible for most of the city's power generation, so accelerating the construction of smart power plant can provide a strong piece of the puzzle for the construction of smart city. Smart power plants are being continuously constructed on the basis of informatization, digitization, automation, standardization, and modernization, supported by informatization technologies such as big data, Internet of Things, remote sensing technology, hydrological forecasting, and artificial intelligence, and adhering to the concept of sustainable development in a big step forward. Review the development of information technology in the smart power plant, in order to better look forward to the future of smart power plant construction. This paper summarizes some commonly used information technology.

2. Development History of Intelligent Power Plant

2.1 Intelligent power plant domestic research history

Intelligent power plant refers to the establishment of intelligent power plant on the basis of digital power plant Intelligent power plant refers to the establishment of intelligent power plant on the basis of digital power plant, through the introduction of big data, cloud computing, Internet of Things and other information technology, to achieve intelligent scheduling, management and control of the production and operation of the power plant of a new type of power plant [2]. After sorting out the literature, the research on smart power plant in China started in 2012, and as of March 2023, there are 365 published documents in China Knowledge Network with the keyword of "smart power plant", and the detailed number of years is shown in Table I.

Table 1. "Smart power plants" literature, 2012-2022

Year of publication	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total number of issues	1	2	0	1	11	16	47	54	66	91	69

In 2013, Jie Junren proposed the construction of the Internet of Things (IoT) environmental detection platform in the smart power plant, which integrates the information technology of the Internet of Things into the smart power plant [3].In 2017, Yin Feng et al. proposed that the essence of the smart power plant is the in-depth fusion of informationization and intelligence in the field of power generation, which is mainly embodied in the systematic application of information technology such as big data and the Internet of Things (IoT), and determined the direction of the development of the smart power plant as information fusion and intelligent power generation technology [4]. The direction of the development of smart power plants is information fusion and intelligent power generation technology [4].In 2018, China built the first domestic coal-fired power generation "smart power plant" Datang Nanjing Power Plant [5]. Since then, China's smart power plant construction has ushered in a qualitative upsurge, and in 2019, China Mobile successfully built the first 5G smart power plant, applying 5G communication technology in the smart power plant, and successfully realizing four smart energy application scenarios of drone inspection, robot inspection, intelligent security, and manned operation through 5G ultra-large bandwidth, ultra-low latency, and ultra-high reliability network [6].In 2022, Zhou Qiang et al. in the Victory In 2022, Zhou Qiang et al. in Shengli Power Plant applied information technology such as Internet of Things (IoT), big data, remote sensing technology and other information technology in the construction of the smart power plant to realize the five functions of smart operation, smart maintenance, smart safety, smart fuel, and smart management [7].

2.2 Foreign research direction and results

Overseas research on smart power plant focuses on smart grid and virtual power plant, or power plant as a part of smart city to study as a whole.

Smart grid is regarded as the next generation of power grid, which utilizes the two-way flow of electricity and information to create a widely distributed automated energy delivery network. In 2011, Xi Fang et al. discovered the importance of smart grid, and comprehensively explored the technologies required in smart grid, as well as the basic strategy of replacing physical infrastructure with digital infrastructure in the transition from traditional power grid to smart grid [8]. In 2012, Ye Yan et al. argued that the smart grid built on communication is the future direction of development, summarized the main requirements that must be met by the communication infrastructure in the smart grid, and by building the communication infrastructure, the power reliability of the smart grid can be improved thus eliminating the blackout problem [9].In 2014, Pierluigi Siano summarized the demand response in the smart grid function and argued that the smart grid is an intelligent and informative grid that can exchange information with the users [10].In 2017, Yasir Saleem et al. proposed the deployment of IoT devices in power plants, transmission lines, transmission towers, distribution centers, and customer premises, which provides a two-way communication flow between the service provider and the customer, and makes the smart grid smarter through the introduction of IoT technology [11]. In 2022, Leslie Quitzow et al. pointed out that the goal of smart grid construction in the new era is environmental protection as well as sustainable development through the example of Berlin, Germany, where a smart city integrated into the smart grid was built [12].

A virtual power plant is a class of integrated power plants consisting of an energy management system and the small and micro distributed energy resources it controls [13], with the main purpose of integrating distributed energy resources through information technology.In 2012, Tomasz Barszcz and Piotr Czop, in the course of their project, not only developed the software

infrastructure required for a virtual power plant but also demonstrated its applicability on a coal-fired turbine generator proved its applicability [14].In 2016, Valentin Robu et al. made an expected model for predicting the power generation of virtual power plants based on artificial intelligence techniques, which improved the supply scheduling planning of the grid [15].In 2017, Seyyed Mostafa Nosratabadi et al. summarized the commonly used algorithms for virtual power grids as well as the microgrids that can be used for distributed energy scheduling, and proposed that distributed energy sources such as pumped storage and hydropower have attracted limited attention in virtual grid scheduling [16].In 2021, Erphan A. Bhuiyan et al. proposed that a new generation of virtual grids should incorporate emerging technologies such as the Internet of Things (IoT), cloud computing, smart inverter, artificial intelligence, and new generation of communication technologies, and provided the future of virtual grids by indicated the direction of development [17].

With reference to foreign literature on smart grid and virtual power plant, China's smart power plant construction, for distributed energy plants, such as pumped storage power plants, offshore wind power, etc., can also build a comprehensive smart grid and virtual power plant informationization platform, to improve the efficiency of the power plant and the user interaction experience.

2.3 The Future of Intelligent Power Plants

With the goal of "carbon peak, carbon neutral", the future development direction of China's power plants should be tilted to new energy power plants, such as nuclear power, hydropower, wind power, etc. [18] But the traditional thermal power plants are still the main force of power generation, so the construction of traditional thermal power plants is still the main force of power generation. [18] But the traditional thermal power plant is still the main force of power generation, so in the construction of new energy power plants, at the same time, the traditional thermal power reform, make it intelligent, informationization, but also the future direction of the development of intelligent power plants. The construction of smart power plant is to hope that the power plant can be like a person can self-analysis, prediction, diagnosis and adjustment, so as to improve the optimal economy, safety and reliability of the power plant.

Intelligent power plant in the future development, to dig deep to meet the user's needs of the function, and the depth of the required level of development of information technology, the use of the latest information technology to build intelligent power plants. Only by understanding the user's needs can we make the smart power plant more intelligent, intelligent, adhere to the people-oriented development path, improve the safety level of the power plant as well as significantly improve the economic efficiency of the unit in order to build the future of the smart power plant.

3. Information Technology in Smart Power Plants

3.1 Big Data

3.1.1 The concept of big data

With the continuous development of remote sensing, sensor networks, radio frequency technology and other information technologies, the data collection capacity has been continuously improved, and it is now possible to be able to collect more and wider data. These data are characterized by multi-source heterogeneity, wide distribution and dynamic growth. Various new technologies produce huge amounts of data and few valuable data, how to filter out useful information from a large amount of data is the current problem to be solved, so the concept of big data technology is introduced, and modeling algorithms are used to solve this problem [19]. Big data technology is now mature, cloud data center, cloud computing and other big data information technology has been applied to the smart power plant.

3.1.2 Big data application in smart power plant

The construction of an integrated big data platform is the cornerstone of the construction of a smart power plant, so in 2017, Zhang Fan completed the construction of the integrated big data platform architecture of the smart power plant and proposed an intelligent early warning technology based on big data to ensure the safe operation of the power plant and improve the reliability of the unit [20]. In water conservancy power generation, water conservancy big data is also the key to the construction of smart power plants, and the construction of water conservancy data centers based on big data can make the application of big data more widely, and the current application of water conservancy big data is mainly embodied in the management of floods and droughts, water conservancy project management and water resources management, etc., of which flood and drought disaster management mainly includes drought monitoring and early warning, flood monitoring and early warning, etc.; water conservancy project management mainly includes Dam safety monitoring, reservoir and water environment management and water resources engineering management, etc.; water resources management mainly includes water resources allocation, water environment management and water resources protection, etc. [19].

3.2 Internet of Things

3.2.1 Current status of IoT development

Several countries and regions attach great importance to the development of IoT and have issued a series of policies to drive the continuous innovation of IoT. Driven by the dual-wheel drive of policy traction and market development, the global IoT accelerates its development, and China, the European Union, the United States and other countries have launched several strategic plans to promote the development of IoT in the past 10 years, such as the National Telecommunications and Information Administration of the United States in 2017 launched a "Green Paper to Accelerate the Development of the Internet of Things", which proposes to further play the role of the government in taking the Internet of Things as a national strategy. China in 2011, the Ministry of Industry and Information released the "Internet of Things" Twelfth Five-Year Development Plan, which is the first time that China introduced a detailed Internet of Things planning, indicating the direction of China's Internet of Things development, so that China's rapid development of the Internet of Things, 2021 proposed the "14th Five-Year Plan for the Development of the Information and Communications Industry," but also put forward the comprehensive Deployment of 5G, mobile IoT and other new generation network infrastructure [21]. In China's South-to-North Water Diversion Project, the use of Internet of Things technology, in the length of 1.4 kilometers of the central trunk line project, the relevant personnel installed nearly 100,000 sensors, the trunk line in the information data centralized collection, which contains engineering safety information, personnel safety information, water supply operation information, etc., so as to realize the collection of sensory information, the abnormal information in time to alarm.

3.2.2 Internet of Things in Smart Power Plant

The construction of the Internet of Things platform in the smart power plant can strengthen the effective communication of the management affairs of various departments of the power plant, guarantee the effective implementation of various tasks and improve work efficiency. Through the sensor equipment distributed in the management area, the data information distribution network is constructed, relying on data transmission technology to realize real-time access to data and realizing the perception of smart power plants in real time. The construction of smart power plant can not be separated from information technology, and the development of the Internet of Things is the link that connects the various information technology, and further provides help for the effective connection of these technologies and a high degree of integration of resources. In this era of the Internet of Everything, relying on 5G communication technology, the Internet of Things can be used to further improve the level of wisdom of the smart power plant, to improve the production

efficiency of the smart power plant as well as to realize the remote synchronization of the monitoring and so on.

3.3 Hydrological Forecast

3.3.1 Development history of hydrological forecasting models

Hydrological modeling has always been the focus of hydrological research, the development of hydrological production and sink mechanism has two important development stages, the first stage is the twentieth century, the twentieth and thirtieth centuries Holton production theory and Sherman empirical unit line, the conceptual hydrological model of flood forecasting was born at this stage of development, and the second stage is the twenty-sixth and seventeenth centuries in the western countries carried out in the field of hill hydrological mechanism experiments, promote the The second stage is the field hydrological mechanism experiments on mountain slopes carried out in western countries in the 1960s and 1970s, which promoted the development of the conceptual hydrological model and deepened the research, and at the same time gave birth to the distributed hydrological model. In the 1960s, many hydrological models were developed, the first one is the conceptual model used for flood forecasting, such as the Xin'an River model in China, the SAC model in the United States, the water tank model in Japan, the Broughton model in Sweden, and the TOPMODEL in the United Kingdom for the study of the flow production mechanism. the second one is the physically based distributed model constructed according to the hillslope hydrology, and the distributed model constructed according to the hillslope hydrology in the United Kingdom was developed by Freeze and Harlan. Freeze and Harlan in 1969 proposed a framework for the construction of distributed hydrological models: consider anisotropic soil one- and two-dimensional flow production and three-dimensional groundwater and one-dimensional non-constant flow model with lateral and downward seepage of the nullah, the essence of this framework is the use of Darcy's law for the flow of the soil in the soil and differential form of the equation of conservation of mass and energy [22]. Hydrological forecasting models are still evolving since modern times, such as the ensemble forecasting model constructed by Yang Mingxiang et al. based on the Qingshitan Reservoir [23], and the flood forecasting model constructed by Chen Chen et al. applied to smart cities [24].

3.3.2 The role of hydrological forecasting in smart power plants

Hydroelectric power plant as a kind of power plant, its function is not only used to generate electricity, but also can be utilized in the reservoir area for drought and flood control. And hydrological forecasting plays a very important role in drought and flood control, after the flood disaster, the residents in the affected area should be transferred immediately, so it is crucial to have an accurate hydrological forecasting model. In recent years, with the continuous development of science and technology, climate warming is becoming more and more severe, and brings a lot of extreme weather, drought and floods and other natural disasters often occur, the intensity of the disaster is also increased a lot, so it is necessary to have an accurate analysis of hydrological forecasting model to improve the drought and flood control ability of the hydropower plant [25]. At the same time, accurate hydrological forecasting model can not only improve the power plant's power generation efficiency, but also protect the economic benefits of the surrounding crops and improve the living standards of the nearby residents, so the construction of intelligent hydropower plants can not be separated from the hydrological forecasting model.

3.4 Remote Sensing Technology

3.4.1 Remote sensing technology concept

Remote sensing technology is the use of specific equipment to assist, the use of remote sensing equipment to transmit scanning and photographic survey of the target, in order to obtain useful information data, transmission, processing and preservation of information, analysis of the collected information resources, from which the useful content of the refinement of the information sent to

the ground receiving station, the receiving station in accordance with the importance of the information obtained to analyze and judge the relevant conclusions. This technology is constantly developing and has been applied in aerospace and ground detection, in addition to its wide application and development in climate, environment, agriculture and other fields. The use of remote sensing technology can safely obtain a variety of data and information, the depth of the role of data and information to ensure that the decisions made more scientific [26].

3.4.2 Remote sensing technology development status quo

Remote sensing technology, like hydrological forecasting, is also mostly used in the construction of intelligent hydropower plants, which is an important information technology in the construction of intelligent power plants. Remote sensing technology plays an important role in the field of water ecology and water environment, and at this stage, the development direction of remote sensing technology in water conservancy applications is hyperspectral remote sensing technology [27], hyperspectral remote sensing relative to the traditional multispectral remote sensing, has more number of wavebands, which can provide more choices for the construction of inversion models, and it has a higher level of spectral detail, for the spectral differences of the different features of the identification of the effect is smaller better. The emergence of hyperspectral remote sensing technology has greatly improved the ability to analyze the material composition of water bodies in the process of water conservancy remote sensing, such as analyzing the distribution of water bloom and aquatic plants, water quality and sand content. Through the use of hyperspectral remote sensing technology to improve the detection ability, so as to reduce the occurrence of water disasters, so remote sensing technology plays an important role in the construction of intelligent water power plant.

3.4.3 Application of remote sensing technology in intelligent water and power plants

(1) monitoring, remote sensing technology can surface water and water environment, water ecology, drought and other monitoring work. Now most of the domestic water ecological environment is in poor condition, the use of remote sensing technology can carry out accurate monitoring of water bloom, algae plants, aquatic plants and so on, so as to carry out better water ecological environment management. When monitoring the water environment, the degree of eutrophication of the waters can be investigated by inverting the chlorophyll a concentration, and the concentration of suspended solids in the water body can also be measured.

(2) survey, remote sensing technology can survey hydrogeology, find water resources. Remote sensing technology survey effect is very good, water information technology has a lot of survey content, such as survey hydrogeology. Planning water conservancy also need to carry out surveys and investigations, so the survey work is very important. The use of remote sensing technology can make water information technology work become very smooth.

(3) planning, water conservancy project construction using drone remote sensing, for water conservancy project scientific planning to provide sufficient information. Most of the water conservancy project site is the transportation obstruction, remote mountainous area, so the survey is very difficult. The use of drone remote sensing can break the limitations. With the use of near-earth drones and satellite high-definition images, it can realize high-precision generation and transmission of images, and provide sufficient information for the scientific planning and systematic planning of water conservancy projects. The use of remote sensing technology to analyze the function of the water layer in a static project such as a reservoir can understand the scope of influence of the water level and assist in the decision-making of the flood control and scheduling project of the reservoir [26].

3.5 Artificial Intelligence

3.5.1 Overview of Artificial Intelligence

Artificial intelligence is regarded as the core driving force of the fourth industrial revolution, and will play an important role in promoting the development of the digital economy and helping the

national energy transformation [28]. With the integration and development of big data, cloud computing, neural networks and other technologies, artificial intelligence has achieved great success in the fields of computer vision, natural language processing, speech processing, etc., which provides a new direction for the digital and intelligent transformation and upgrading of smart power plants, and has a broad application prospect in the fields of grid design and operation and maintenance of power plants, scheduling and control, security management, and customer service.

The rapid development of artificial intelligence provides a solid technical guarantee for the intelligent development of the power industry. The application of artificial intelligence to intelligent power plants is the current primary planning of the power industry for artificial intelligence technology. To realize the deep integration of power business and new generation information technology, one of the very important application areas is to replace manual work with artificial intelligence [29].

3.5.2 Application of Artificial Intelligence in Smart Power Plants

At present, green low-carbon, intelligent, digital is the main theme of energy transformation as well as power plant reform, artificial intelligence technology is undoubtedly the inevitable choice of the smart power plant, the application of artificial intelligence technology can greatly improve the efficiency and quality of work, in some high-risk operation areas instead of manual work, improve the safety performance of the plant. In the smart power plant, artificial intelligence is mainly applied in the following aspects:

artificial intelligence in the information data system. Intelligent water transfer is an important part of the construction of intelligent water and power plant links, not only need strong technical support, but also need to strengthen the processing of information by establishing a multi-dimensional data collection system, the application of artificial intelligence technology can strengthen the collection of data such as river water conditions, watershed rainfall, meteorological maps, etc., and can be more quickly extracted from the useful information, which not only ensures the real-time balance of power supply and demand, but also allows for timely adjustments to be made in the event of problems. Problems to make timely adjustments.

(2) artificial intelligence in power plant inspection. Electricity supports people's daily life production, so to ensure that power plant machinery failure can be maintained in a timely manner in order to reduce the impact on daily life. The traditional power plant management uses all human inspection management mode. However, staff in the inspection process, it is difficult to find some small security risks, it is difficult to make accurate judgments on the operating conditions of the machine, and access to some high-risk plant areas have a certain degree of danger. Therefore, in the construction of intelligent power plants, the use of artificial intelligence instead of human inspection can improve the ability of the power plant to predict the danger, improve the safety of the power plant, ensure the stable operation of the machine, and improve economic efficiency.

(3) artificial intelligence in production information interaction. The normal operation of the power plant involves a large number of information interactions, so the daily management of the power plant must be adjusted in real time by combining the specifics of the information and the operating conditions. The use of artificial intelligence technology can carry out real-time data supervision, can give timely information feedback to the management personnel, improve the real-time production information interaction, through the data simulation so that the intelligent power plant to carry out 4D management operation mode, at the same time through the cloud computing system targeted optimization adjustment of the actual production and operation of the power plant, to improve the demand for electricity and the capacity of intelligent information interaction, and to promote the sustainable development of the intelligent power plant. [30]

Summary

Smart power plant construction cannot be separated from information technology, with more and more smart power plants built, the integration of information technology into the power plant experience is also becoming more and more rich, the construction of smart power plants is also

approaching maturity. For the application of information technology in the construction of smart power plants, the author has the following suggestions for reference only.

(1) with reference to Wu Weidong and others on the definition of smart city [31], I think that in the construction of smart power plants, we can not only focus on "wisdom", only the introduction of a large number of the latest information technology to build the power plant, while ignoring the "wisdom", we must build a more robust, fast and convenient response mechanism to improve the decision-making process. It is necessary to build a more sound, fast and convenient response mechanism to improve the decision-making ability of decision makers and the user's better experience.

(2) all kinds of information technology in the smart power plant application dispersed, should build a unified platform for smart power plant, the information technology fully integrated into the smart power plant to play its maximum role.

(3) smart power plant is a multidisciplinary research field, so improve the technical level of operators, re-education of operators, improve the business level of power plant staff, optimize the composition of personnel, or cooperation with universities to cultivate the overall development of technical personnel can accelerate the construction of smart power plants.

(4) In order to achieve the proposed carbon neutral goal, China's traditional coal-fired power plants are being phased out.Ryna Yiyun Cui1 et al. also constructed an early phase-out algorithm for China's coal-fired power plants, which was used to accomplish China's carbon neutral goal by 2060 [32]. Therefore, the focus of smart power plant construction should be on new energy power plants, such as wind power, hydropower, and solar power plants, to reduce carbon emissions and build sustainable smart power plants.

Finally, the construction of smart power plant is a systematic project, and it is still necessary to constantly explore and innovate in order to form a unified program with applicability and practicality, and the application of information technology is essential in the construction process, and the better integration of information technology into the smart power plant is the biggest research problem at present. After the integration of information technology into the smart power plant, how to bring convenience to people, realize the unmanned plant, less manned, improve the economic efficiency of the plant, and how to reduce the economic cost of the introduction of emerging technologies to achieve the full popularization of information technology in the construction of the smart power plant and other issues to be resolved at present.

References

[1] C.F.Calvillo . Energy management and planning in smart cities [J].Renewable and Sustainable Energy Reviews , 55 (2016) 273-287

[2] Li W. Discussion on the construction of smart power plant and the application of smart power generation technology [J]. Automation Application,2018(11):82-83+86.

[3] Jie Junren. Internet of things environmental monitoring platform for smart power plant[D]. Beijing Jiaotong University,2013.

[4] YIN Feng, CHEN Bo, SU Ye, LI Quan, ZHANG Peng. Overview of typical research directions and key technologies of smart power plant and smart power generation[J]. Zhejiang Electric Power,2017, 36(10):1-6+26.DOI:10.19585/j.zjdl.201710001.

[5] Yao Yongmei. Ramming Cultural Cornerstone Yew Young Style 2018 National Corporate Culture (Datang Group Nanjing Power Plant) Site Meeting Held in Nanjing[J]. Chinese and foreign enterprise culture,2018,(12):74-75.

[6] China Mobile successfully builds the first 5G smart power plant[J]. Telecommunications engineering technology and standardization,2019,32(02):92.

[7] Zhou Qiang,Song Jingzhu,Kang Huilai. Construction of intelligent power plant in Shengli power plant[J]. Shanghai Electric Technology,2022,15(02):20-23+30.

[8] Fang X, Misra S, Xue G, et al. Smart grid—The new and improved power grid: A survey[J]. IEEE communications surveys & tutorials, 2011, 14(4): 944-980.

[9] Ye Yan . A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges[J].IEEE Communications Surveys & Tutorials, vol. 15, no. 1, First Quarter 2013

[10] Pierluigi Siano . Demand response and smart grids—A survey[J]. Renewable and Sustainable Energy Reviews 30 (2014) 461–478

[11] Yasir Saleem . Internet of Things-aided Smart Grid: Technologies, Architectures,Applications, Prototypes, and Future Research Directions[J]. IEEE Access, vol. 7, pp. 62962-63003, 2019

[12] Quitzow L, Rohde F. Imagining the smart city through smart grids? Urban energy futures between technological experimentation and the imagined low-carbon city[J]. Urban Studies, 2022, 59(2): 341-359.

[13] CHEN Chunwu, LI Na, ZHONG Pengyuan, ZENG Ming. International experience and inspiration of virtual power plant development[J]. Grid Technology, 2013, 37(08):2258-2263.DOI:10.13335/j.1000-3673.pst.2013.08.032.

[14] Barszcz T, Czop P. Introduction to the virtual power plant environment and its application in conjunction with first principles and data-driven modeling for power plant diagnostics - Part I [J]. Simulation, 2012, 88(2): 139-166.

[15] Robu V, Chalkiadakis G, Kota R, et al. Rewarding cooperative virtual power plant formation using scoring rules[J]. Energy, 2016, 117: 19-28.

[16] Seyyed Mostafa Nosratabadi . A review of microgrid and virtual power plant concepts for distributed energy resource scheduling in power systems[J]. Renewable and Sustainable Energy Reviews, 67 (2017) 341-363

[17] Bhuiyan E A, Hossain M Z, Muyeen S M, et al. Towards next generation virtual power plant: technology review and framework[J]. Renewable and Sustainable Energy Reviews, 2021, 150: 111358.

[18] LIU Jin, HAN Lei. Discussion on the construction of coal-fired smart power plant under the goal of "double carbon"[J]. Electrotechnology,2022(19):198-200.DOI:10.19768/j.cnki.dgjs.2022.19.060.

[19] Junfei Chen,Menghua Deng,Huimin Wang. An overview of water resources big data research[J]. Advances in Water Science,2017,28(04):622-631.DOI:10.14042/j.cnki.32.1309.2017.04.017.

[20] Zhang Fan. Analysis of key technology and application of integrated big data platform for smart power plant[J]. Huadian technology,2017,39(02):1-3+7+76.

[21] Yu Wenke,Cheng Yuan,Li Fang,Zhao Qi. Analysis and suggestions on the development of internet of things technology[J]. Journal of Internet of Things,2020,4(04):105-109.

[22] Li Zhijia . Modern hydrological simulation and forecasting technology[M] . Nanjing; Hohai University Press

[23] YANG Ming-Xiang, LEI Xiao-Hui, JIANG Yun-Zhong, WANG Hao, HE Su-Ming. Construction and application of precipitation ensemble forecasting model for Qingshitan Reservoir[J]. Journal of Water Resources,2018,49(02):263-270.DOI:10.13243/j.cnki.slxb.20170683.

[24] Chen Chen . Convolutional Neural Networks for forecasting flood process in Internet-of-Things enabled smart city[J]. Computer Networks, 186 (2021) 107744

[25] Pengyun Zhai . The role of water conservancy engineering and hydrological forecasting in flood control and drought relief[J]. Henan Water Resources and South-North Water Diversion,2019,48(07):14-15.

[26] Xu Zikai. The use of remote sensing technology in water conservancy informatization[J]. Heilongjiang Science,2022,13(06):100-102.

[27]]Feng Tianshi,Pang Zhiguo,Jiang Wei,Qin Xiangdong,Fu Jun'e. Progress of hyperspectral remote sensing technology and its application to water resources[J]. Journal of Earth Information Science, 2021, 23(09):1646-1661.

[28] YANG Jianwei,WU Chunrui. Introduction to the development trend of AI technology in smart power plants[C]//China Electric Power Technology Market Association.2021 Collection of Excellent Papers on Technical Supervision in Electric Power Industry.2021:140-141.DOI:10.26914/c.cnkihy.2021.054297.

[29] Xu Yuan,Cao Lijuan. Application of artificial intelligence in water conservancy project management[J]. Haihe Water Resources,2020(06):49-50.

[30] Wan Zhenyu. Application of artificial intelligence technology in the transformation and upgrading of smart power plant[J]. Modern Commerce Industry, 2020, 41(25):157-158.DOI:10.19311/j.cnki.1672-3198.2020.25.077.

[31] WU Weidong,CHEN Hang. An overview of research on smart city construction in China[J]. Journal of Yan'an University(Social Science Edition),2022,44(06):62-67.

[32] Cui,R.Y. , Hultman,N. , Cui,D. , Mcjeon,H. , Yu,S. , Edwards,M.R. , Sen,A. , Song,K. , Bowman,C. ,& Clarke , L.(2021).A plant-by-plant strategy for high-ambition coal power phaseout in China.Nature Communications,12(1),.https://doi.org/10.1038/s41467-021-21786-0