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Exploration on the Construction of Intelligent Big Data Platform of Ningxia Solar Photovoltaic Industry based on NB-IoT

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Abstract: As China's first new energy comprehensive demonstration zone, Ningxia's solar photovoltaic (PV) industry has developed rapidly, but it still faces shortcomings in terms of intelligence and digitalization. This study focuses on the application and construction of an intelligent big data platform based on Narrowband Internet of Things (NB-IoT) technology within Ningxia's solar PV industry. It explores the application trends of digital technology in the energy sector, particularly in the PV industry under the backdrop of energy reform, analyzes the technological development status of the smart energy field both domestically and internationally, and details the research methods and design components of the platform (including the photovoltaic base data platform, outdoor mobile application, remote data system, and back-office management system). The study discusses the opportunities and challenges Ningxia's PV industry faces and proposes a construction pathway. It provides a theoretical foundation and technical support for the digital transformation of Ningxia's PV industry, facilitating industrial upgrading and sustainable development. Although the current research is limited to the proposed design scheme, it establishes a basis for future empirical research and platform development.

Keywords: Ningxia; Solar photovoltaic; NB-IoT; Intelligent big data platform; Digital transformation

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1. Research background

In the context of energy transformation influenced by globalization and environmental pollution, integrating new energy sources and digital technologies is profoundly reshaping the global energy ecosystem. Leveraging clean energy resources such as solar and wind power, combined with technologies like NB-IoT, artificial intelligence, and big data to build intelligent systems, has become a key focus for governments in redefining modern energy management and trading. Globally, the digital transformation of the energy industry is emerging as a significant trend [1]. Many countries and regions are actively promoting the application of digital technologies in the energy sector, such as big data analysis, artificial intelligence, blockchain, and Internet of Things (IoT) technology. These technologies are widely used in the production, transmission, consumption, and management of energy, providing energy enterprises with more efficient and flexible operations. In the photovoltaic industry, digital technologies have been shown to optimize energy management, increase power generation efficiency, and reduce energy waste.

Narrowband Internet of Things (NB-IoT), a low-power wide-area network technology suitable for large-scale device connectivity, is increasingly being used in the energy industry due to its characteristics of low power consumption, wide coverage, and low cost. NB-IoT technology can support remote equipment monitoring, intelligent operation, and data management of solar photovoltaic power stations, greatly improving the operational efficiency of the photovoltaic industry chain [2]. Through NB-IoT technology, photovoltaic equipment can transmit operating status data in real-time, and operation and maintenance personnel can remotely diagnose faults and optimize power station operation strategy, to reduce operation and maintenance costs and improve power generation efficiency. In recent years, some areas in China have taken the lead in applying NB-IoT technology, such as the photovoltaic demonstration base in Qinghai and the smart photovoltaic power station in Jiangxi. These successful cases have provided practical experience for Ningxia to explore the construction of a solar photovoltaic intelligent big data platform [3].

As an important window for China to open up to the West, Ningxia is one of the core regions of the "Belt and Road" development strategy. The autonomous region is located at an important node of the Silk Road Economic Belt and has a good foundation for cooperation with countries in Central and West Asia. This unique location advantage provides an international market environment for the development of the solar photovoltaic industry. Ningxia is not only the country's first new energy comprehensive demonstration zone, but also an inland open economy pilot zone, which makes the new energy industry, especially the solar photovoltaic industry, a pillar industry driving regional economic development [4]. The 14th Five-Year Plan and the outline of the 2035 vision goals put forward by Ningxia have clarified the policy orientation of developing the digital economy and promoting the high-quality development of the clean energy industry, providing solid policy support for the intelligent and digital transformation of the solar photovoltaic industry.

Although the photovoltaic industry in Ningxia is developing rapidly, there are still shortcomings in terms of intelligent and digital industrial chains. For example, the current inspection and data management methods mainly rely on manual operations, and the storage, processing, and analysis of data lack a unified platform support. There are also big differences in the depth and granularity of industrial digitalization applications, especially the limitations of small and medium-sized photovoltaic enterprises in terms of technology and resources, resulting in the synergies of the overall industry chain are not obvious. In addition, compared with advanced regions in China, Ningxia is still in its infancy in terms of photovoltaic big data platform construction and NB-IoT technology application. Solving these problems is of great significance for enhancing the core competitiveness of Ningxia's photovoltaic industry and promoting high-quality development of the local economy.

2. Research status at home and abroad

Internationally, technological progress in the field of smart energy has become an important driving force for the global energy transition [5]. For example, the United States leads the world in distributed energy management, cloud storage of energy data, and predictive maintenance of big data, and its advanced technologies have been applied on a large scale in wind energy, photovoltaic, and other fields [6]. Germany, relying on its Industry 4.0 strategy and combined with its energy transformation goals, has successfully built several smart photovoltaic power stations and energy data platforms, which optimize energy management efficiency through real-time data collection and analysis, and significantly improve the utilization rate of renewable energy [6,7].

Moreover, Japan has established an integrated energy management platform through the deployment of a distributed energy system based on the Internet of Things (IoT), which greatly improves the flexibility of the electricity demand side [8,9]. Australia has made breakthroughs in PV data analytics and virtual power plants to provide intelligent energy solutions for PV users at the home and community levels [10]. These international practices show that the application of intelligent big data platforms can not only improve energy efficiency but also bring greater resilience and innovation to the energy supply chain.

In China, the photovoltaic industry has developed rapidly in recent years and has initially formed a complete industrial chain integrating research and development, manufacturing, and application [3]. For example, the photovoltaic industry demonstration base established in Qinghai has promoted the continuous optimization of photovoltaic power generation efficiency by integrating design, manufacturing, and empirical data [11]. The country's first "smart photovoltaic power station" built in Jiangxi has achieved several domestic leadership in intelligent forecasting, operation and maintenance management, and data integration [12]. However, on the whole, China's energy digital transformation is still in its initial stage, with unbalanced regional development, inconsistent technical standards, and large differences in the depth, and granularity of digitalization in each link of the industrial chain [13].

Specific to the Ningxia region, the solar photovoltaic industry has not yet formed a comprehensive digital system. The existing business is mainly concentrated in the traditional offline data collection and analysis links, the real-time data, integration, and visualization level is low. This status quo limits the further improvement of industry efficiency and also hinders the optimal allocation of upstream and downstream resources in the industrial chain. In this context, exploring and promoting the construction of an intelligent big data platform based on NB-IoT can not only fill the technical gap in Ningxia's solar photovoltaic industry but also provide important technical support and practical experience for the overall upgrade and sustainable development of the industry.

3. Research methods and contents

3.1. Research methods

This study comprehensively uses a variety of methods to systematically carry out research on the construction of an intelligent big data platform for the Ningxia solar photovoltaic industry based on NB-IoT. The specific methods and implementation process are as follows.

3.1.1. Literature research method

Comprehensively collect and analyze local and international literature related to energy digital transformation, photovoltaic industry intelligence, NB-IoT technology applications, etc. By consulting academic journals, industry reports, technical manuals, and such, we will have an in-depth understanding of the research status quo, technology development trend, and successful case experience in this field, to provide a solid theoretical foundation and practical reference basis for the research, and ensure the accuracy of the research direction and the cutting-edge of the research content.

3.1.2. Case analysis method

Select photovoltaic project cases that have successfully applied NB-IoT technology at home and abroad, such as the photovoltaic demonstration base in Qinghai, the smart photovoltaic power station in Jiangxi, and the relevant intelligent energy projects in Germany, Japan, and other countries. The platform architecture, functional modules, data management strategies, and technical application effects in these cases are analyzed in detail, from which experience and lessons are summarized and lessons can be extracted to provide practical reference examples for the design and construction of Ningxia solar photovoltaic intelligent big data platform, avoid repeated trial and error in the research process, and improve research efficiency and quality of results.

3.1.3. Demand analysis method

Carry out field research in local solar photovoltaic enterprises and power station operating units in Ningxia, and extensively collect the functional requirements, business process requirements, and data management requirements of all relevant parties on the intelligent big data platform through questionnaires and interviews. Systematically combing and analyzing the collected data, clarifying the actual needs to be met in the construction of the platform, ensuring that the designed platform can effectively solve the practical problems faced by Ningxia photovoltaic industry in the process of intelligence and digitalization, and improving the practicability and applicability of the platform.

3.1.4. System design method

Based on fully understanding the needs, the use of system design method to carry out the design of a photovoltaic base data platform and photovoltaic backstage management system. Including the overall structure of the platform planning, determining the logical relationship between the functional modules, and the data interaction process. Technology selection, comprehensive consideration of performance, cost, compatibility, and other factors, choosing the most suitable hardware equipment, operating system, database management system, and development tools. Detailed design of the user interface, to improve the convenience and friendliness of user operation as the goal, optimize the interface layout and interactive functions. At the same time, the data management, security, and other aspects of the comprehensive design ensure the efficiency of the platform operation, stability, and security.

3.1.5. Potential impact discussion method

Although the photovoltaic outdoor data mobile application and photovoltaic remote data system are not included in the core scope of the current research, through theoretical analysis and prospective discussion on their possible roles in the future photovoltaic big data demonstration platform, such as preliminary research on the possibility of functional expansion of mobile application and the optimization direction of remote data system security performance, etc. It provides ideas and directions for further expanding the functions of the platform and improving the system architecture in the future so that the research has certain foresight and scalability.

Through the comprehensive application of the above research methods, this study aims to provide comprehensive, scientific, and feasible design schemes and theoretical support for the construction of an intelligent big data platform for the Ningxia solar photovoltaic industry, and promote the digital transformation and sustainable development of Ningxia photovoltaic industry.

3.2. Research content

The design of the PV base data platform aims to realize efficient integration and automatic processing of data. The platform integrates test data through an automated process, and a remote monitoring computer is responsible for data storage, processing, and display. The process enables automatic identification and recording of device test data, significantly reducing manual intervention and improving the efficiency and accuracy of data management.

In terms of data management, the platform provides an integrated management function that can store, query, print, and analyze test information of measuring equipment for outdoor projects. This not only improves the accessibility and operability of the data but also provides a centralized management solution for the equipment detection information.

The design of the user interface focuses on intuitiveness and ease of use, making it easy for operators to access and manipulate the data. Whether it is real-time monitoring or backtracking of historical data, the user interface provides clear, intuitive views and tools to support complex data analysis efforts.

In terms of data content, the platform includes two parts: general data and project data. The general data integrates the meteorological data acquisition module, including key parameters such as irradiance, temperature, and ultraviolet irradiance, which provides the basis for the analysis of all projects. These common data can be accessed on every project page to ensure the comprehensiveness of the analysis. Simultaneously, project data provides an independent test business data store for each project, supporting both real-time and cumulative storage methods to meet the flexibility of different analysis needs.

The design of the photovoltaic outdoor data mobile application aims to provide a convenient mobile monitoring function for field workers so that they can view the operation status of the photovoltaic base in real-time through mobile devices. This function is essential for quick response and site management. The application's data query and analysis function allows users to query historical data for specific projects and perform basic data analysis, providing on-site decision support for users. The report generation function allows users to generate and view project reports directly on the mobile application, further simplifying the workflow. Additionally, the integrated notification and alarm system can immediately notify relevant personnel when equipment is abnormal or performance deteriorates, improving the response speed and reliability of the system.

The photovoltaic remote data system is characterized by its remote access capability, allowing authorized users to remotely access the photovoltaic base data platform for data monitoring and analysis. This system ensures the real-time synchronization of data and maintains the data consistency between the remote data system and the PV base data platform. To protect the security of data transmission and storage, the system has implemented strict security measures, including data encryption and user authentication. These measures provide a solid guarantee for the security of the data.

The photovoltaic background management system realizes the persistent storage of data through the docking with the database. This system provides the necessary basic data support for the photovoltaic data platform, including user data, event data, project data, etc., to ensure the accuracy and integrity of the data. The integration of the logic judgment module enables the system to make intelligent decision support according to the basic data, such as fault diagnosis, performance prediction, etc., which improves the intelligence level of the system. In terms of data interface, the photovoltaic background management system ensures that the data source of the basic data interface is reliable, including the user (manufacturer) data, event data, and project data obtained from the photovoltaic background management system. Concurrently, the data update mechanism is designed to ensure the timely update and accuracy of the basic data, which provides a solid foundation for the stable operation of the whole photovoltaic big data demonstration platform.

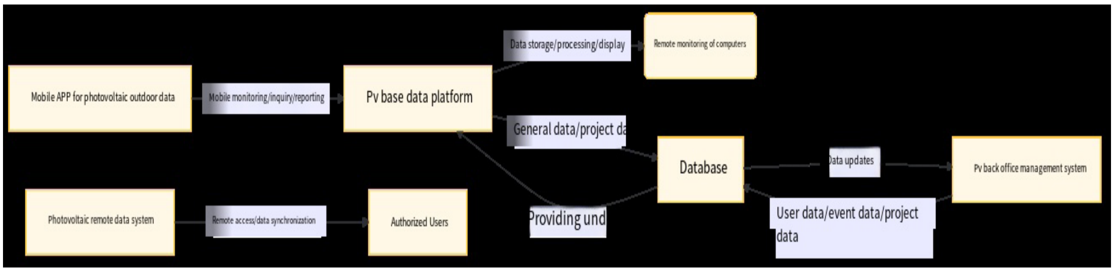

Figure 1. PV big data demonstration platform architecture design diagram

4. Conclusion and prospect

This study proposes a preliminary design scheme of a PV base data platform and PV back-office management system, aiming to provide support for the digital transformation of the solar PV industry in Ningxia. Through the in-depth discussion of the data integration, automatic processing, data management, and user interface design of the PV base data platform, this study presents an efficient, reliable, and user-friendly data management solution. At the same time, the design of the PV background management system emphasizes the importance of data persistence and intelligent decision support, which provides a solid foundation for the stable operation and data analysis of the PV data platform.

The research results show that the proposed design scheme can effectively integrate and process a large amount of data from photovoltaic power stations, and provide a powerful tool for the monitoring, maintenance, and performance optimization of photovoltaic power stations. Moreover, by introducing the concepts of photovoltaic outdoor data mobile applications and photovoltaic remote data systems, this study further expands the potential function and application range of photovoltaic big data demonstration platforms.

Although the current study is limited to the proposal of a design scheme, it lays the foundation for future empirical research and platform development. Future work will focus on the implementation, testing, and optimization of the scheme, as well as further exploration of practical applications of mobile and remote data systems in the PV industry. Overall, this study provides valuable insights into the digital transformation of the photovoltaic industry and provides directions for subsequent technological development and research.

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Disclosure statement

The authors declare no conflict of interest.

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