Research on Distributed PV Monitoring System Based on Ubiquitous Power IOT Architecture

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Abstract. There are problems of low intelligent management and automatic maintenance of traditional distributed PV power plants. This paper designs a distributed PV monitoring system based on ubiquitous power IoT architecture. LoRa edge computing terminal, Storm data stream processing strategy and Spark in-memory programming model are introduced to meet the needs of distributed PV power plants for fast access and storage, analysis and mining of big data. This system improves the real-time and security of power plant data cloud-edge collaboration, and can efficiently perform status monitoring, maintenance management and data analysis of distributed PV power plants. It is of practical significance to improve the whole life cycle management of distributed photovoltaic power generation equipment and promote the transformation of operation and maintenance mode to automation, intelligence and intensification.

1. Introduction
With the increasing global pollution and the imminent fossil energy crisis, the development of new energy industry has become a breakthrough to solve environmental problems. At present, the more mature domestic new energy utilization methods are mainly photovoltaic and wind power generation, among which distributed photovoltaic power generation has been rapidly promoted since 2014, due to its advantages of small footprint, high power generation efficiency and short approval process, and has become quite large, which is one of the new key industries to help China achieve the double carbon goal. Distributed photovoltaic power generation refers to the small and medium-scale solar power generation equipment built near the load with the main characteristics of self-generation on the user side and online access to the surplus power, and at the same time, in order to facilitate grid scheduling and equipment operation and maintenance, it also needs to be equipped with corresponding monitoring systems and control devices, so the resulting large amount of power generation monitoring data needs to be collected and transmitted [1]. To ensure the safe and stable operation of distributed photovoltaic power plants, a corresponding monitoring and analysis platform must be developed to holographically sense the status of the equipment and timely diagnose system faults to provide a guarantee for safe power generation and grid dispatching.

Ubiquitous IoT refers to the information connection and interaction between any person and any thing at any time, any place, and any thing, and ubiquitous power IoT is the specific expression and application landing of ubiquitous IoT in the power industry [2]. Architecturally, ubiquitous power IoT consists of four parts: holographic sensing layer, edge computing layer, transmission network layer,
and platform application layer. With the development of technology, ubiquitous power IoT and smart grid are coupled with each other, forming a binary complex network with close integration of information communication and power system.

At present, certain achievements have been made at home and abroad about the design of distributed PV monitoring system based on ubiquitous power IoT. The literature [3] is based on VS2012 programming to collect various data in the PV power generation system and upload them to Yeelink cloud server through HTTP communication, and the user's remote device can realize real-time display and historical query of data through webpage or Yeelink client. The literature [4] developed a PV power plant data acquisition and monitoring system using IoT technology, which provides a large-scale field group centralized control side monitoring solution for power grid enterprises. The literature [5] uses wireless LoRa communication technology for monitoring and control networking for the construction characteristics of distributed PV, and demonstrates the advantages of LoRa networking compared with other communication technologies. The literature [6-7] analyzed the construction technology architecture of ubiquitous power IoT and the design principle of distributed PV monitoring platform, but lacked complete engineering practice. The above literature explores the centralized control method of small and medium-sized centralized PV power plants and gives the implementation scheme of traditional PV power plant monitoring based on ubiquitous power IoT, but it lacks in the real-time and accuracy of power plant data processing.

In view of the fact that there is still a lack of research and practice on integrated centralized control and operation and maintenance of distributed photovoltaic power plants and intelligent data processing, this paper introduces edge computing to optimize the overall architecture based on ubiquitous power IoT: for the problems of complicated data types of power plants, large transmission delay and inaccurate correction integrated big data processing framework and machine learning algorithms to build a cloud-edge collaborative data correction strategy to improve the system monitoring and control accuracy.

2. Overall System Design

2.1. Functional Requirements Analysis

With the development of big data, Internet of Things, machine learning and other emerging technologies, intelligent monitoring of distributed photovoltaic power plants has become the key to deploy resources for efficient utilization, improve enterprise economic efficiency and reduce power plant operation and maintenance costs. The system development requirements are analyzed as follows: real-time equipment status monitoring, multi-dimensional energy efficiency analysis display, automated report statistics, classification fault alarm diagnosis, system management and operation and maintenance log.

2.2. Overall Architecture Design

The overall architecture of the system is based on the "Outline of Ubiquitous Power IoT Construction", and the platform layer and edge layer are introduced to reconfigure the system to achieve "edge-end separation and edge management sharing". The overall architecture is divided into four layers, as shown in figure 1.

(1) The holographic sensing layer uses a variety of sensors, cameras, power transmitters, etc. to collect the operating parameters of all the equipment in the distributed PV power plant and the environmental parameters around the plant, and uploads them to the intelligent edge gateway and server through a multi-interface data terminal with a special protocol for IoT to realize multi-dimensional visualization and monitoring of the plant status. The monitored equipment includes: PV panel string, convergence equipment, inverter, protection equipment, and various electric measuring instruments. Environmental monitoring devices include: temperature and humidity sensors, wind speed and direction sensors, vibration sensors, irradiance sensors.
(2) The edge computing layer consists of intelligent data terminals, gateways and servers with edge computing functions and edge node management services. It connects the transmission layer and the perception layer, is compatible with various terminals in the perception layer, meets the requirements of personalized networking and multi-protocol interchange in the transmission layer, can offload the pressure of data calculation and processing in the application layer, and strengthens the security of data transmission in the bottom layer. On the one hand, the system edge computing layer can pre-process and analyze massive information near the data source to meet local online monitoring requirements, and on the other hand, it also has node free cascade networking and network management capabilities to achieve safe data flow within and between layers.

(3) The design of network transmission layer is guided by local conditions, and the designed system adopts the redundant combination of LoRa wireless transmission and RS485 wired transmission according to the location of distributed photovoltaic equipment, surrounding environmental conditions, user needs and engineering requirements. The local data and application servers are set up with one main and one standby machine each, and the server cluster adopts multi-network access to prevent data loss due to network failure.

(4) The platform application layer is designed to develop multi-service integrated management and intelligent automatic operation and maintenance applications with business management and data analysis and calculation of ubiquitous power IOT as the core. The distributed PV intelligent monitoring platform application designed in this paper consists of two systems: station side and cloud side. The station side equipment sends information to the cloud after data collection and edge processing, and the cloud side system transmits data to the station side system after parsing, calculating, analyzing and storing, realizing dynamic monitoring, power prediction, fault alarm, automatic operation and maintenance, and report statistics of distributed PV power plants.

Figure 1. Overall system architecture diagram.
3. Distributed Photovoltaic Monitoring System Design and Implementation

3.1. Station-side System Design
In order to collect data from distributed PV plants and perform preliminary processing, a distributed PV station-side data acquisition and processing system is designed. The station-side system mainly includes the data acquisition module and the calculation and forwarding module.

The data acquisition module terminal MCU adopts STM32F103RCT6, which has high-speed computing capability, and its and sensor sub-MC through single bus, AD conversion, UART serial port, I2C bus mode, communication module adopts YOUREN cloud IOT WH-L102-L-C digital transmission module, using Lora one master multi-slave star network, TTL serial communication, master sub-nodes use embedded USR private protocol, to achieve multi-node data orderly transmission, non-interference.

The calculation and forwarding module reads the data from the sub-nodes through the Lora wireless gateway USR-LG220-L, and adopts the Edge X Foundry edge computing platform framework to gather, compress, pre-process, encrypt and then transmit the data to the cloud system through public network or VPN network. In order to ensure the security of data transmission, a forward isolation device is designed and installed between the data acquisition and data forwarding procedures, and a firewall is installed at the beginning and end of the data stream.

3.2. Cloud-based System Design
The architecture of distributed PV power plant monitoring cloud platform is shown in figure 2, with three layers of package expansion: data access layer, analysis and processing layer, and application layer. The overall distributed architecture is used to deploy processing units and build a data analysis system based on Hadoop to realize data cloud processing and mining.

The data access layer collects all kinds of data such as station-side equipment operation and environmental monitoring, converts them into JSON data format required by the analysis and processing layer, and sends them to the upper message queue Kafka.
The analysis processing layer uses SparkSQL and JDBC to interact with the access layer database, and writes the deserialization results to the relational database so that it can be used as the underlying layer for other applications, while importing the information in the relational database to the NoSQL database Hbase through the Sqoop connection component to serve the upper layer programming model. For strongly time-sensitive data, we improve the efficiency of periodic computation by configuring the real-time computing system Storm, building a data flow processor, selecting data storage nodes nearby, arranging computation tasks in a distributed manner, and writing the latest data to the cache Redis. For massive historical data, the processing is performed by programming modeling on Spark and using machine learning algorithms. Meanwhile, after deserializing the message queue generated by the Storm program, the results are stored using a non-relational database, Hbase, for time-based results and a relational database for alarm-based results.

The application layer is developed using Java EE technology. The J2EE platform provides a unified and secure model, the ability to reuse components and flexible processing control. It also utilizes ECharts, HTML5 and other technologies to achieve real-time status monitoring and comprehensive report display, and keeps the client page data refreshed in real time by subscribing to the messages of the data push message queue via WebSocket.

4. Results and Analysis
Based on the above research, the experimental monitoring platform is built for sensory data collection and transmission, and visualization and analysis in the cloud. The experimental platform conditions are Windows 10 X64 operating system and Intel i7-9750H.

Enter the remote web access ip address to access the monitoring system as shown in figure 3, with clear data display and friendly human-machine interaction design, which is convenient to view equipment process parameters and energy efficiency performance indicators.

The visualization and reporting module provides tables, documents and graphics related to the environment, equipment and power plant benefits to assist power plant decision making and O&M personnel, as shown in figure 4. It also supports backup storage of O&M logs and abnormal data for uploading to the cloud, which facilitates notification of on-site O&M personnel for maintenance and cloud-based diagnostic model training.

![Figure 3. Distributed PV monitoring system web side.](image)

![Figure 4. Visualization and Reporting Module.](image)

5. Conclusion
This paper designs a distributed PV monitoring platform based on ubiquitous power IoT architecture, introducing LoRa edge computing terminal, Storm data stream processing strategy and Spark in-memory programming model to meet the needs of accessing and storing massive data of distributed PV clusters, analyzing and mining, overcoming the inconvenience of long-distance data transmission, improving the performance of distributed PV power plant data cloud-side collaborative data processing, and having high application value.
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