Chapter 14
Research and Construction of the Integrated Management System for the Grid-Connected Operation of the System Terminal

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Abstract With the rapid development of the electric power industry, it is particularly important to improve the management efficiency and reliability of the electric power system, and it is urgent to ensure the safe and stable operation of the system. Therefore, this paper studies and builds the integrated management system of system terminal grid connection operation. Using advanced computer technology and modern communication, to realize the comprehensive monitoring and control of all aspects of the power system, the system includes data collection, data analysis and management, information visualization and other functional modules. The experiment proves that the system has a high degree of reliability and security, and can realize adaptive and optimal control under changing environmental conditions. The integrated management system of grid connection operation of the system terminal can provide technical support and guarantee the reliable operation of the power system.

14.1 Introduction

The power system is one of the indispensable infrastructures in modern society, and it is the necessary energy support [1] to ensure the social and economic operation and people's lives. With the continuous development of China's power industry and the continuous opening of the power market, the scale of the power system is expanding, the operating environment is becoming more and more complex and the requirements of power system management are getting higher and higher. How to improve the management efficiency and reliability of the power system to ensure its the safe and stable operation is an urgent problem to be solved [2]. With the continuous

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development of computer technology and communication technology, the technical level of terminal equipment and monitoring system is constantly improved, so that the comprehensive monitoring and control of [3] each link of the power system can be realized. This paper aims to study and construct a system to improve the management efficiency and reliability of power systems. This paper adopts advanced computer technology and modern communication to realize the comprehensive monitoring and control of all aspects of the power system. The system includes data collection, data analysis and management, information visualization and other functional modules. Through the research and construction of the integrated management system, the efficiency and reliability of the power system management are improved, and the technical support and support for the safe and stable operation of the power system [4].

14.2 General Architecture Design of the Integrated Management System for the Grid-Connected Operation of Electric Power System Terminals

Power system terminal grid operation integrated management system is data collection, processing, analysis and management in the integration of the integrated system; it is composed of multiple components, and the function of the whole system covers the power system terminal equipment monitoring, data acquisition and processing, running status evaluation, abnormal early warning and response, etc.; the overall architecture is shown in Fig. 14.1.

The functional requirement of the system terminal grid-connected operation integrated management system is to ensure the normal operation of the photovoltaic power generation system and to provide comprehensive monitoring, management and analysis functions. The following is an expansion of the functional requirements:

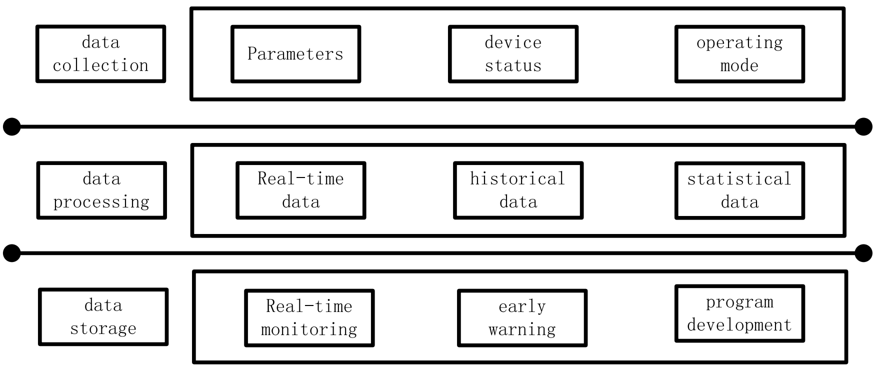

Fig. 14.1 Overall architecture design of the integrated management system

Real-time monitoring of terminal equipment parameters: the system needs to be able to monitor the operating state of the power system terminal equipment in real time, including temperature, voltage, current and other key parameters. Through sensors and monitoring equipment, collect equipment data and ensure the accuracy and timeliness of the data.

Data collection, storage and management: The system shall have the capability of data collection, and shall store and manage the data collected from the terminal equipment. Data storage can be performed using a database or cloud platform for subsequent analysis and queries.

Data processing and analysis: The system needs to clean, normalize and merge the collected data to ensure the quality and consistency of the data. Through data analysis and mining technology, the system can extract the trends and rules of the power system operation, to provide support for the system operation management.

Operating status assessment: Based on the collected data, the system shall be able to evaluate the operating status of the power system terminal equipment. Through the set rules and algorithms, the performance and health status of the equipment are analyzed and determined, and the operation quality evaluation index of the equipment is provided.

Abnormal monitoring and early warning: the system shall have the function of abnormal monitoring and early warning, and can timely detect the abnormal condition of the equipment and issue early warning signals. When the equipment has a failure, temperature abnormality or other abnormal conditions, the system can automatically send an alarm to notify the relevant personnel, in order to take timely measures for repair or maintenance.

Fault diagnosis and maintenance support: The system shall provide fault diagnosis and maintenance support functions to help the operation and maintenance personnel accurately locate the equipment faults, and provide corresponding maintenance guidance and suggestions.

Visualization interface and report generation: The system needs to provide an intuitive visual interface to display the monitoring data in the form of charts, graphics or maps, so that users can quickly understand the operating status of the power system. In addition, the system shall have the function of generating reports for recording and summarizing the operation and performance indicators of the system.

Through the realization of the above functional requirements, the system terminal grid operation integrated management system can provide comprehensive, accurate and real-time power system operation status information, help realize the efficient operation and management of photovoltaic power generation system and provide timely early warning and maintenance support, to ensure the stable operation of the power system, improve the efficiency and reliability of the system and provide decision support and troubleshooting information.

14.3 Hardware Design

The hardware design of the integrated management system is an important part of the system, including computer, network equipment, sensors and other hardware equipment. This system chooses the Advantech brand industrial grade computer; the model can choose AdvantechIPC-610H. Network equipment is a bridge connecting the various equipment and sensors of the system, which needs to meet the stability and real-time performance of the system data transmission. The system adopts Huawei S5720-36C-EI-A, with high speed, low delay, multi port, high reliability and other industrial grade switches. The sensor is the sensing equipment of the system, which needs to collect various parameter data on the site, including temperature, humidity, pressure, flow, etc. The model of the sensor is Honeywell PX2AG1XX025PSCHX and the quantity shall be configured according to the actual requirements of the system. In addition to the above hardware equipment, the system will also need to be equipped with the corresponding accessories, such as data cable, power cord and adapter. These need to be characterized by high quality, high reliability and low failure rate to ensure the stable operation of the system. The hardware design of the integrated management system should consider the factors of functional requirements, data processing capacity, communication performance and stability to select and configure appropriate equipment and accessories. At the same time, the corresponding standards and specifications should be followed to ensure that the system can operate stably and reliably.

14.4 Software Design

14.4.1 Data Acquisition Module

The data acquisition module is used to collect the real-time operation data of the power system terminal equipment, including the voltage, current, power, frequency and other parameters, as well as the equipment status, operation mode and other information [5]. Data collection can be uploaded and collected through intelligent terminals through field sensors and monitoring devices, but the collected data generally needs to be processed and cleaned to ensure the accuracy and reliability of the collected data [6]. Data cleaning technology is mainly used to process the original data; in order to remove noise, errors and outliers, we first need to deal with the missing data. The usual method is to fill the missing values with the mean, median, crowd, etc., and to remove repeated data, and the data with missing values can be filled by formula (14.1):

$$x_j = 1/N * sum_{i=1}^{N} x_i \tag{14.1}$$

Shown as formula (14.1), N is the number of data present, and i is the fill value of missing values. Data distribution analysis can include statistical indicators such as the central trend, degree of dispersion and deviation of the observed data. By calculating the indicators of the mean, the median, the standard deviation and the skewness, we have an intuitive understanding of the overall distribution of the data. Moreover, visualization tools such as drawing histograms, boxplots and scatter plots can also help to reveal the distribution patterns and anomalies of the data. After analyzing the data distribution, data points that do not match the data distribution can be excluded. These data points that do not match the data distribution may be outliers or erroneous records, and they may have a negative impact on subsequent data processing and analysis. By identifying and excluding these data points, we can maintain the accuracy and consistency of the data.

Next, to facilitate subsequent data processing, the original data will need to be converted into a target format. This may involve operations such as data type transformation, unit conversion, normalization or standardization to facilitate uniform data processing and comparison: for example, converting date and time data into a unified format, encoding text data or participle processing. In addition, in order to obtain a more comprehensive data perspective, it is necessary to gather different data sources together to form a whole data set and discover the laws and relationships between the data. By integrating data from different data sources, a more comprehensive analysis can uncover potential trends, patterns or correlations. Data pooling may involve operations such as data merging, connection, association and data integration. Ensuring data consistency, accuracy and completeness when integrating data is needed to avoid introducing errors or bias.

To sum up, nalysing data distribution, excluding abnormal data points, transforming data formats and integrating different data sources can provide a more accurate, complete and reliable data basis for subsequent data processing and analysis, help reveal the laws and relationships of data and obtain valuable insight and decision support.

14.4.2 Data Analysis and Management Module

The data analysis management module is used to store and manage the collected data, including real-time data, historical data, statistical data, etc. Data storage adopts Apache Cassandra distributed database, which has the characteristics of high scalability, high-speed reading and writing ability, and large capacity storage capacity, and can meet the data management requirements of the integrated management system of grid-connected operation of power system terminals. In addition, the collected data also needs to be analyzed and processed to extract useful information and indicators, such as power grid load prediction, power quality analysis, fault diagnosis and others [7]. Data analysis can use the traditional statistical analysis method; for the data with outliers, formula (14.2) can be used to process:

$$z = (\mathrm{x} - \mathrm{mean})/\mathrm{std} \tag{14.2}$$

where x is the raw data, mean is the mean of the data, std is the standard deviation of the data and z is the normalized data. If the z-value is greater than a certain threshold, the data point can be treated as an outlier. The data analysis and management module detects and handles the outlier values of the collected data by applying various outlier value detection methods. Among them, the standardized method (z-score) is a common method of outlier detection. This method transforms the data into a standard normal distribution by standardizing the raw data, where each data point is subtracted from the mean of the data and divided by the standard deviation of the data. Then, a threshold can be set to treat the normalized data point as an outlier when they exceed it. In addition to the standardized methods, the data analysis management module can also use cluster analysis-based and box-plot-based methods for outlier detection. Through effective outlier detection and processing, the credibility of data and the accuracy of analysis can be improved, so as to provide a more accurate basis for subsequent data analysis and decision-making.

14.4.3 Visualization Module

The visualization module is used to provide decision support for the power system operation and management personnel, including real-time monitoring, early warning, scheme formulation, instruction issuing, etc. Decision support can adopt a rule-based method, combined with artificial intelligence technology, to realize automatic decision-making, and collect, store and analyze decision data and information in the form of charts, curves, maps and other visualization, so as to facilitate users to intuitively understand the operating status and change trend of the power system [8]. Visual display can adopt modern interactive data visualization technology, such as large-screen displays, mobile terminal applications, virtual reality and other forms, to improve the efficiency of information communication and sharing [9, 10]. Artificial intelligence technology can automatically analyze and judge the operation state and change the trend of the power system through data mining, machine learning and other means, so as to provide more accurate decision support for the power system operation management personnel [11]. Commonly used visualization methods in the visualization module include histogram, line map, scatter map, heat map, map, etc. Among them, the heat map is a visualization method that can intuitively display the data density, and its mathematical model can be expressed as Eq. (14.3):

$$f(x, y) = \frac{1}{2\pi\sigma^2}\mathrm{e} - \frac{(x - x_0)^2 + (y - y_0)^2}{2\sigma^2} \tag{14.3}$$

where x_0 is the expected early warning value along the X-axis in the visual heat map, and y_0 is the expected early warning value along the Y-axis in the visual heat map. In the integrated management system of the power system, the heat map can be used to show the operation status of each equipment in the power system, so as to provide timely monitoring and early warning information for the operation management personnel of the power system and help them take timely measures [12, 13]. In addition, virtual reality technology can also be used in the integrated management system of the power system [14]. By establishing a three-dimensional model of the power system, data display and interactive operation in the virtual environment can improve the efficiency of information communication and sharing.

14.5 Test the Experiment

14.5.1 Experimental Preparation

In order to test the performance of the integrated management system of grid-connected terminal operation, the experiment used two photovoltaic power generation systems using different models of terminal equipment. This can evaluate the performance difference of the different terminal devices when operating the integrated management system. The first photovoltaic system uses model A1 terminals, while the second photovoltaic system uses model A2 terminals. In order to ensure the normal operation of the system. To carry out the test, the ThinkPad X1 Carbon Intel Core i5 flagship version was selected as our computer model. The laptop is equipped with a powerful processor and memory to provide enough computing power to support the operation of the integrated management system. In addition, the corresponding monitoring equipment and terminal equipment are also needed to realize the monitoring and control of the photovoltaic power generation system. To meet this need, JZ-KQ 1 monitoring equipment and NPort 6400/6600 series terminal equipment were selected for the experiment. The JZ-KQ 1 monitoring device is able to collect various data on the photovoltaic system, such as power, voltage, current and temperature information. The Nport 6400/6600 series terminal equipment provides a stable and reliable connection between the computer and the terminal equipment of the photovoltaic power generation system.

Before conducting the experiment, ensure that the computer and monitoring equipment are correctly connected to the terminals of the two photovoltaic systems. In this way, the remote monitoring and control of the two photovoltaic power generation systems can be realized through the system terminal grid connection operation of the integrated management system. Once the system equipment is connected, the integrated management system can begin to remotely monitor and control the photovoltaic system. Through the integrated management system, it can communicate with the terminal equipment of the photovoltaic power generation system, obtain real-time data and send control commands. In the experiment, the output power, voltage, current and other parameters of the photovoltaic power generation system can be monitored, and the corresponding control operation can be carried out according to the need. The collected data should be fully documented during testing. These data are very important for the subsequent performance analysis. Experiments can record the performance of photovoltaic power generation systems in different time periods, and compare the differences between the A1 model and the A2 model terminal equipment. In addition, the experiment should record the operation and control commands for the system in order to associate them with the changes in the performance.

14.5.2 Experimental Result

The experimental test results include the data of the total power generation, average power generation, maximum power generation and minimum power generation of the photovoltaic power generation system. Table 14.1 shows the data obtained from the remote monitoring and control of the two photovoltaic power generation systems through the system terminals when using different types of terminal equipment.

Data analysis for terminal device type A1: Values of generating capacity 1 (kW/h) are between 56, 58 and 57. The generating capacity of 2 (kW/h) is between 54, 57 and 55. The total generating capacity (kW/h) is the sum of capacity 1 and capacity 2, 110, 115 and 112, respectively. The average power generation (kW/h) is the average of the total power generation and is calculated as 55, 57.5 and 56. The maximum power generation (kW/h) is the maximum of generating capacity 1 and generating capacity 2, at 56 and 58, respectively. Minimum power generation (kW/h) is the smaller value of generating capacity 1 and generating capacity 2, at 54 and 57, respectively.

Data analysis for terminal device type A2: The value of generating capacity 1 (kW/h) is between 52, 53 and 51. The generating capacity of 2 (kW/h) is between 53, 51 and 50. The total generating capacity (kW/h) is the sum of capacity 1 and capacity 2, 105, 104 and 101, respectively. The average power generation (kW/h) is the average of the total power generation, and the calculated results are 52.5, 52 and 50.5. The maximum power generation (kW/h) is the maximum of generating capacity 1 and generating capacity 2, at 53 and 51, respectively. Minimum power generation (kW/h) is the smaller value of generating capacity 1 and generating capacity 2, at 52 and 50, respectively.

Table 14.1 Experimental result

Serial number	Terminal equipment type	Generating capacity1 (kW/h)	Generating capacity2 (kW/h)	Gross generation(kW/h)	Average power generation (kW/h)	Maximum power generation (kW/h)	Minimum power generation (kW/h)
1	A1	56	54	110	55	56	54
2	A1	58	57	115	57.5	58	57
3	A1	57	55	112	56	57	55
4	A2	52	53	105	52.5	53	52
5	A2	53	51	104	52	53	51
6	A2	51	50	101	50.5	51	50

By nalysing these data, the average power generation of terminal device type A1 is slightly higher than terminal device type A2, 56 and 52.33 kW/h, respectively. The maximum generating capacity of the terminal equipment type A1 is 58 kW/h, and the minimum generating capacity is 54 kW/h. The maximum capacity of terminal equipment type A2 is 53 kW/h and the minimum capacity is 50 kW/h.

It can be seen from the experimental results of the system that the use of the system terminal grid-connected operation of the integrated management system can improve the average and total generating capacity of the photovoltaic power generation system, effectively monitor and control the operation status of the photovoltaic power generation system and improve the efficiency of the system. Through the remote monitoring and control system, the faults in the photovoltaic power generation system can be found and solved in time, so as to improve the reliability and stability of the system [15]. The system can realize the real-time monitoring and remote control of the photovoltaic power generation system, and improve the flexibility and operability of the system, so that the system can better adapt to various environments and operating states.

14.6 Conclusion

The integrated management system plays a very important role in the operation of the power system, and the system terminal grid connection operation integrated management system is an important means to apply the integrated management system to the terminal equipment and realize remote monitoring and control. This paper adopts advanced computer technology and modern communication to realize the comprehensive monitoring and control of all aspects of the power system. The system includes data collection, data analysis and management, information visualization and other functional modules. The integrated management system can improve the efficiency and reliability of the power system management, reduce the operation cost and provide an important guarantee and support for the safe and stable operation of the power system. In the future research and practice, we can improve and optimize the shortcomings of the integrated management system of system terminal grid operation, strengthen the compatibility of equipment and user interface design, and enhance the scalability and maintainability of the system.

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