Research on Key Technologies of Substation Comprehensive Energy Saving in the Background of Smart Grid

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Abstract. In the current process of social and economic development in my country, electric energy as a basic power has become an important foundation for building economic growth. At present, in my country's various substation systems, the application of intelligent substations has become the mainstream form of substation construction engineering with the progress of technology. As an important part of the intelligent substation building, the energy-saving system of intelligent substation building can achieve the purpose of high efficiency and energy saving while ensuring the normal operation of the substation. This article will start with a variety of smart substation building structures, and comprehensively analyse the functions, functions, and effects of smart substation energy-saving systems.

Key words. Smart grid, substation, energy-saving technology, energy-saving evaluation, fuzzy evaluation method.

1. Introduction

At present, with the increase in energy consumption brought about by the development of the national economy, the country has always advocated measures such as building energy conservation to implement sustainable development strategies and reduce building energy consumption. Building energy-saving standards and specifications require the use of high-insulation building envelopes in severe cold and cold areas [1]. Although improving the insulation performance of the enclosure structure for residential and public buildings can indeed achieve the purpose of reducing building energy consumption, it is obviously not feasible to use a high-insulation enclosure structure for the large indoor heat dissipation density such as the main control room of the substation. Therefore, it is very important to scientifically determine the influence of the heat dissipation density of the main control room of the substation on the thermal performance and energy saving requirements of the building envelope.

Building energy saving is the main goal of substation intelligent building. It analyses the energy consumption in the building to control the working status of equipment and improve energy efficiency. The way to achieve building energy saving is to monitor the energy connected to the building, as well as the energy consumption and environment in the station, and then analyse the energy consumption data and power consumption information trends, give advice on equipment energy saving, and control some equipment to operate at the energy saving level. Comprehensive evaluation and reporting of energy consumption levels and energy conservation levels within a certain period of time.
2. The specific framework of the building energy-saving system of the intelligent substation

In the specific framework of the building energy-saving system of the intelligent substation, a series of monitoring, collection and processing of various components in the building system need to be realized through the most basic building energy monitoring system. On the framework of the building energy detection system, the main components are shown in Figure 1:

![Figure 1. General structure diagram of building energy detection system](image)

It can be seen that the monitoring system is driven by the power monitoring subsystem, and the signal is transmitted to the data analysis between the underlying core component and the client via the power monitoring subsystem, and the corresponding data is transferred to the database. Specifically:

2.1. Substation self-use power monitoring module

In the energy-saving system, with the help of the integrated automation system interface in the station, data such as the total voltage and total current on the low-voltage side of the substation and the voltage and current of each branch can be collected and monitored. At the same time, the power monitoring module can also detect the specific working status of various components inside the substation according to the device's own state awareness system and various sensors. For example, when working in substations, the total voltage and total power of camera monitoring equipment, air conditioning, information equipment, lamps, cooling systems, exhaust systems, etc. in the building can be collected and processed in various UI forms with the help of related data. Staff can comprehensively analyse the power usage inside the substation according to the specific influence of different factors such as season, climate, weather, etc. and then optimize and adjust the substation's own energy consumption [2]. The specific system module workflow is shown in Figure 2:
2.2. **Battery status monitoring module**

The energy-saving system can extract the comprehensive battery information such as the total battery voltage and current in the system, the single battery voltage and current in the battery pack, and the internal resistance of each battery through the integrated automation system interface in the station. After extracting the above-mentioned comprehensive information of the battery, the system manages and controls various signals through various subsystems under the power detection system and present thresholds in the subsystem. For battery packs that exceed the threshold range, the subsystem is processing. Relevant signals can be transmitted to the cameras around the battery monitoring point to extract images of the target area; the relevant lights issue warning instructions. The battery state monitoring module records and stores a series of commands and signals at this stage. The staff can then combine various factors to analyse the relevant battery state and faults, and then adjust the relevant threshold settings in the sub-module [3].

2.3. **UPS monitoring module**

UP means uninterrupted power supply system. The working mode of the UPS detection module in the energy-saving system is the same, and the interface of the integrated automation system in the station can collect and extract various UPS information such as the status of the host, inverter alarm, device alarm, and pass it to the power detection subsystem. The power detection subsystem can judge, process and record the signal according to the set threshold, and the staff can set and adjust the relevant threshold based on multiple data to deal with the relevant fault and error signals [4].

3. **Energy consumption analysis and management**

The system accesses the electricity information of various equipment in the station from the integrated automation system to realize the energy consumption is classified and measured according to the electricity equipment, mainly including IT equipment energy consumption, lighting equipment energy consumption, refrigeration equipment energy consumption, other energy consumption (ground plug, Access control, etc.) power consumption information of equipment. The data is transmitted to the power monitoring subsystem through the integrated automation interface or sensor collection, and the power monitoring subsystem calculates the energy consumption according to the calculation formula related to energy consumption analysis. Collect various information on the voltage, current and energy consumption of the station's electricity (such as total battery voltage, total battery current, single cell
voltage, single cell current, battery internal resistance, etc.), and pass it into the power monitoring subsystem through the integrated automation interface. The power monitoring subsystem performs corresponding signal processing according to a present threshold, and issues a linkage command to the cameras and lights around the battery detection point. The entire process will write the alarm records and linkage actions into the database, and display them in the three-dimensional scene. The user can configure the specific camera, lighting and battery alarm detection threshold information of the battery alarm linkage as needed [5]. The energy consumption analysis process is shown in Figure 3.

![Figure 3. Energy consumption analysis process](image)

Using the Internet of Things and three-dimensional visualization technology to collect and analyse the environmental parameters and power system data of the substation, the real-time monitoring of the operation status of the information equipment room and the related equipment of the substation is realized and displayed in three dimensions. According to the collected data analysis results, linkage, optimization of refrigeration systems, fresh air, fans, power supply, electricity consumption and other equipment can monitor and manage the energy efficiency of the substation to achieve the purpose of energy saving and emission reduction. The intelligent auxiliary control system mainly includes the monitoring and adjustment of the environment of the whole station, the monitoring of the operation status of the equipment, and the modelling of energy efficiency assessment and so on [6].

4. Comprehensive energy-saving evaluation of substations

4.1. Index selection
With reference to the "Interim Measures for Energy Conservation Assessment and Review of Fixed Asset Investment Projects" issued by the National Development and Reform Commission Order No. 6, and combining the aspects and links of substation construction projects that involve energy consumption and sustainable use, substation construction projects can be selected from substation energy conservation The energy efficiency of the substation equipment and the energy-saving design (renovation) of the substation are discussed in three major aspects [7]. The evaluation index system of the substation energy-saving project is shown in Figure 4.
4.2. Evaluation method

The fuzzy gradual comprehensive evaluation method combines the advantages of the fuzzy comprehensive evaluation method in dealing with incomplete information and the analytic hierarchy process in calculating the index weight. The specific model is established by using the analytic hierarchy process to determine the index weight, and the fuzzy comprehensive evaluation obtains the final evaluation level. When constructing the judgment matrix using the index scale method, the construction of the judgment matrix in the index scale changes with the value of the importance ratio of "slightly important" and "equally important", and its value is between the time and experts feel that the judgment is in line with reality, and the resulting judgment matrix will be consistent with the relative "weight" of the actual physical quantity [8]. In order to obtain a specific importance ratio value that is in line with the actual judgment and judgment of experts, an importance ratio questionnaire is prepared. The method of calculating the importance ratio in this paper is as follows:

\[
\lambda^2 = \begin{cases} 
1.1, & \sum_{i=1}^{n} Y_i / n \leq 1.1 \\
1.5, & \sum_{i=1}^{n} Y_i / n > 1.5 
\end{cases}
\]

(1)

Among them, \(n\) is the number of experts, and \(Y_i\) is the ratio of the average temperature rise given by the \(i\) expert to the weight of the importance level of the load level. The judgment matrix \(R\) obtained by this method satisfies the consistency test and can be directly used in the calculation of weights. The calculation formula of the subjective weight of the evaluation index is:
\[ a_i = \left( \prod_{j=1}^{n} r_{ij} \right)^{1/n} / \sum_{i=1}^{n} \left( \prod_{j=1}^{m} r_{ij} \right)^{1/n} \]  

4.3. Calculation evaluation result

For the single-factor evaluation of the influencing factors of substation energy saving, 10 experts in this area are invited to score the energy saving level of each indicator in the implementation of the project with reference to the energy saving standards of the indicators specified by the state. The results of the investigation are shown in Table 1.

| Evaluation index                          | Evaluation set (energy saving level) | Index Weight |
|-------------------------------------------|--------------------------------------|--------------|
| Distance from load centre                 | high: 2, Higher: 3, General: 2, Lower: 2, Low: 1 | 0.0352       |
| Grid structure                            | 1: 1, 5: 5, 2: 2, 1: 2                | 0.0551       |
| Geographical location and geological conditions | 0: 0, 6: 6, 2: 2, 2: 2             | 0.0451       |
| Investment Analysis                       | 1: 1, 4: 4, 3: 3, 0: 0               | 0.0708       |
| Civil engineering                         | 5: 5, 2: 2, 0: 0                    | 0.0648       |
| Plumbing                                  | 4: 4, 3: 3, 1: 1                    | 0.0792       |
| Transformer energy efficiency             | 5: 5, 3: 3, 0: 0                    | 0.1055       |
| Conductor energy efficiency               | 7: 7, 2: 2, 1: 1                    | 0.0863       |
| Lighting energy efficiency                | 4: 4, 3: 3, 1: 1                    | 0.0707       |
| Air Conditioning System                   | 3: 3, 5: 5, 0: 0                    | 0.0648       |
| DC system                                 | 4: 4, 3: 3, 0: 0                    | 0.0531       |
| Internal rate of return FIRR              | 1: 1, 2: 2, 4: 4, 2: 2             | 0.0187       |
| Investment recovery period Pt             | 0: 0, 1: 1, 3: 3, 4: 4, 2: 2         | 0.0119       |
| Financial Net Present Value NPV           | 0: 0, 2: 2, 4: 4, 2: 2              | 0.0145       |
| Investment profit margin                  | 1: 1, 2: 2, 4: 4, 2: 2              | 0.0169       |
| Loss                                      | 2: 2, 3: 3, 2: 2, 1: 1              | 0.0545       |
| Network loss                              | 2: 2, 2: 2, 3: 3, 1: 1              | 0.0342       |
| Line Loss                                 | 1: 1, 3: 3, 3: 2, 1: 1              | 0.032        |
| Exhaust emissions                         | 3: 3, 2: 2, 4: 4, 1: 0              | 0.0233       |
| waste water disposal                      | 2: 2, 3: 3, 3: 2, 0: 0              | 0.0348       |

5. Conclusion

The construction of energy-saving substations is an inevitable choice for implementing the scientific development concept and taking the path of sustainable development. It is an important measure to promote energy conservation, an important measure for building a first-class power grid, and an important means to enhance the competitiveness of enterprises. On the basis of gaining experience and results, it can be promoted in the construction of substations in various regions of the country. The construction of energy-saving substations can achieve economical investment savings and lower operating costs. It has huge social and economic benefits.

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