Research on Intelligent Operation and Maintenance Technology of Primary Equipment in Substation

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Abstract. In smart substations, how to use multi-interval system information to realize online monitoring of substations, so as to obtain abnormal operation status early through state analysis, is a topic that needs to be solved in smart substations. The paper uses the multi-interval information correlation method to realize the online monitoring of the status of the primary equipment of the substation. By analysing the correlation factors of the electrical sampling of the multi-interval primary equipment, and the online monitoring of the multi-interval start-up information, combined with the traditional substation interval setting, the abnormal inspection of the primary equipment of the substation can be realized. The function of condition monitoring.

1. Introduction

After years of development, in 2014, State Grid Corporation invested in 6 smart substation construction demonstration centers in batches and plans, and made further research and development of smart substations and smart grids during the "13th Five-Year Plan" period. It is planned to build more than 8K smart substations within this period. In recent years, Chinese determination to develop smart grids in the construction and technical investment of smart substations has even more demonstrated Chinese determination to develop smart grids, and we vowed to promote Chinese power generation technology towards the development of new energy sources [1]. Nowadays, intelligent substations are widely promoted, which also exposes various similar technology, management, and equipment problems. The above-mentioned problem occurs because the internal structure of the smart substation is complicated, and the construction process and technical scheme are not unified. Therefore, finding out the problem and analysing the technical means to improve the operation and maintenance is of great significance to reducing the operation and maintenance risk.

In the era of smart grid, the primary equipment condition maintenance has become the main maintenance method, which can realize the online status monitoring and status maintenance of the smart substation [2]. At present is the key stage of the implementation of the smart substation pilot project. It is necessary to fully promote the state maintenance technology of smart substations. On the one hand, it can improve the overall operation level of smart substations, on the other hand, it can reduce operation and maintenance costs, and realize the safety and reliability of the entire substation and the national grid run. The research on the condition maintenance technology of the primary equipment of the substation is an effective way to improve the current smart grid transformation in China, fully implement the pilot project of the smart substation, and realize its comprehensive development.
2. Conditional maintenance principle and analysis of maintenance content
Condition maintenance is based on the current operating status of the equipment as the basis for the maintenance plan, and on this basis, based on the analysis of the monitoring information results, a reasonable project maintenance plan and method can be formulated.

Condition maintenance is generally divided into three meanings: equipment status monitoring, equipment status diagnosis, equipment maintenance plan formulation or equipment maintenance recommendations. Equipment condition monitoring is the foundation and basis of national maintenance. The analysis of monitoring results provides a strong factual and theoretical basis for national maintenance. Equipment diagnosis is based on condition monitoring. By referring to equipment history information, expert systems, analysis hierarchical processes or neural network technology are fully utilized to determine the health status of equipment [3]. The implementation of the condition maintenance method is the maintenance progress of the maintenance method from the original post-inspection and planned maintenance to the present. Its content covers a wide range of technologies including condition monitoring, condition evaluation, and prediction. The content of the overhaul includes online monitoring and diagnosis, equipment operation and maintenance, management, defect records, fault records and equipment maintenance records, and finally an overhaul plan based on operating information, equipment information, and market information.

3. Based on historical data and online monitoring platform
Condition monitoring and diagnosis cannot be judged solely on the basis of the current status. It requires the collection of historical operation and maintenance data to obtain a more objective and reasonable status assessment. Condition monitoring technology research is the key to condition maintenance. For this reason, in this thesis, the author mainly proposes online monitoring content and related regulations based on the corresponding characteristics of the system, combined with a series of relevant regulations and systems related to the management of power grid equipment promulgated by the State Grid. The corresponding troubleshooting plan [4]. The data platform for components such as online monitoring data, equipment history data, and family defect data provides a complete information data basis for the maintenance strategy proposed for the status later.

3.1. Online monitoring data framework
In each logical level of the system, there are distributed online monitoring data fibres. The switch connecting the acquisition unit and the data analysis unit adopts a fibre optic communication interface with a 100M level input, which can realize all the status information of all detection information to be received and store. The information is stored in the process layer with a certain number of acquisition units through the network switch, and the information is effectively converted. According to the type of SCD configuration file obtained, through real-time thermal insulation analysis, the physical and logical connection with the device can be interpreted. The relationship level is transmitted to the client, and advanced real-time processing visualization technology is used to restore the business-related data and display it, complete the status monitoring activities of the business loop, and realize the rapid analysis of the equipment status of the substation.

The merging unit is used as a key point for the primary voltage and current transformers and test unit. The accuracy of the data greatly affects the reliability of the monitoring information. For this reason, it is necessary to collect the operating status of the merging unit online. Using a flexible distributed deployment method, it is arranged in the multi-bay hierarchical structure of the smart substation, and the smart electronic device messages from different bay layers are simply filtered and processed, and the merging unit will uniformly sort the pre-processed messages. Figure 1 shows the integrated data processing platform for smart substations.
3.2. Defect data framework of smart substation family

The service life and operating status of the monitoring system are mostly determined by the design and production level of the complete machine, the cutting process and the software version update status, and the quality of the components in the integrated circuit. The above indicators are determined by the manufacturer. For the same production batch, even the same model, the same factory hardware and software version have similar series of defects. For example, the defect of the DC plug-in of a single monitoring device may cause common failures or defects in other devices of the same batch number. For this reason, when building an offline database of a smart substation, it is necessary to comprehensively summarize and summarize the family defect information of all batches of monitoring devices from the same manufacturer, so as to provide a more scientific and objective maintenance strategy for the later monitoring equipment operation and maintenance [5]. After completing a single batch of family defect information statistics, it is necessary to establish a family defect information database of national manufacturers, equipment models and batches, and implement a family defect file database based on all monitoring devices of the smart substation to help maintenance personnel to determine the type of failure and make it Good overhaul plan. Generally, the determination of family defects needs to pass through three stages, namely project evaluation, status analysis and plug-in defect evaluation.

4. Primary equipment condition maintenance algorithm

Establishing a reasonable system health evaluation model is the basis for developing a state maintenance plan. According to the data, the general methods for evaluating the health of electrical equipment include fuzzy fault tree evaluation method, neural network evaluation method, and state evaluation method based on fault entropy [6]. In the paper, the equipment state evaluation method based on fuzzy comprehensive evaluation is selected, which can realize the comprehensive analysis and analysis of

![Integrated data processing platform for smart substation](image)
online monitoring information and offline data on the comprehensive platform of the equipment, and calculate the current state of the equipment through the state evaluation model. Generally speaking, the evaluation of electrical equipment in the fuzzy comprehensive evaluation consists of a historical score and a current state score.

4.1. Scoring of detection data of smart substation equipment
In order to obtain the status data of the equipment and carry out the status scoring, the status monitoring information of the equipment parts is analysed and processed on the basis of the fuzzy comprehensive evaluation model, and the qualitative analysis is transformed into the quantitative evaluation using the subordination theory of fuzzy mathematics, so that the overall evaluation thinking is clearer and more comprehensive. The process is more transparent, and it has a good application effect for problems that cannot be quantified or have complex relationships. The steps of the fuzzy comprehensive evaluation model constructed for the equipment status are as follows:

First, aggregate the detection data volume of the auxiliary equipment status, and establish a measurement set $U$ for judging the equipment status, so that various status parameters are fed back. The expression is as follows:

$$U_i = \{u_{i1}, u_{i2}, u_{i3}, A, u_{in}\}$$

In the above formula, $U_i$ represents the state quantity corresponding to equipment $u_{i1}, u_{i2}, u_{i3}, A, u_{in}$. The current state of the equipment in the system is comprehensively fed back, and the system evaluation of the equipment can be obtained through the analysis of the state quantity. Represents the various status quantities of the online monitoring of this type of equipment.

Second, for each type of equipment $U_j$, determine the set $V_{in}$ of each state monitoring quantity $u_{in}$ to produce each result quantity.

$$V_i = \{v_{i1}, v_{i2}, v_{i3}, A, v_{inn}\}$$

In the formula, $v_{inn}$ represents the quantitative expression of the result evaluation of each condition monitoring quantity $u_{in}$, and the evaluation corresponds to the three categories of "good (100 points), normal (50 points), and failure (0 points)".

Third, for any type of equipment $U_j$, corresponding to the index weight coefficient $W_j$ of each state monitoring quantity, and then obtain the comprehensive equipment evaluation $C_j$ based on the detection quantity.

$$W_j = \{w_{j1}, w_{j2}, w_{j3}, A, w_{jn}\}$$

$$C_j = \sum_{j=1}^{n} w_{ij} v_{ij}$$

In the above formula, $w_{j1}, w_{j2}, w_{j3}, A, w_{jn}$ represents the index weight relationship of the online monitoring status of the electrical equipment of the system.

4.2. Scoring of historical data
Historical scores include factory test scores, handover test scores, fault diagnosis record scores, maintenance record scores, maintenance test scores, and family defect information scores. It is a
comprehensive evaluation of the equipment. The basic state of equipment after commissioning, handover, and overhaul often becomes the historical data basis for the next stage of state evaluation. As shown in Table 1 is the equipment history scoring table.

**Table 1. Equipment history scoring method table**

| Project                                      | In accordance with                                                                 | Full marks |
|----------------------------------------------|----------------------------------------------------------------------------------|------------|
| Family equipment operating data, 20         | Reliability statistics of similar equipment that has been put into use            | 20         |
|                                              | Factory test data and technology meet technical standards                          | 5          |
|                                              | The manufacturing process of the equipment caused no major abnormalities or was repaired. | 5          |
| Factory test, 15                            | The test value of the equipment state is different from the dangerous value.       | 5          |
| Handover test, 10                           | The equipment fully complies with the manufacturer's requirements during transportation and installation. | 5          |
| Previous equipment operation data, 15       | The working humidity and temperature of the equipment meet the requirements       | 5          |
|                                              | Non-destructive appearance                                                        | 5          |
|                                              | Function indicator is intact                                                       | 5          |
|                                              | Insulation detection is normal                                                     | 5          |
| Previous equipment tests, 20                | Input circuit inspection passed                                                   | 5          |
|                                              | Analog conversion test passed                                                     | 5          |
|                                              | Complete transmission test passed                                                 | 5          |
| Equipment operation records, 10             | Full score of 10 points, 2 points for failure                                    | 10         |
| Equipment service life, 10                  | 10 points have been put into operation, the equipment to be replaced is 0 points, and the score is proportional to the life cycle curve of the equipment. | 10         |
| Total                                        |                                                                                  | 100        |

The equipment history score is represented by \( B_i \), and the comprehensive scores in Table 3.1 are the equipment history scoring records.

4.3. **Overall score**

The comprehensive health evaluation of equipment is the weighted \( H_i \) of equipment basic score and score, and the expression is:

\[
H_i = (C_i, B_i)
\]  

4.4. **Maintenance strategy**

This article mainly considers the maintenance costs and benefits of the equipment. Therefore, the status maintenance mode of the equipment is established based on the equipment status model. The specific status maintenance process is shown in Figure 2 below. The steps include the following:

The first step is to use the data related to the equipment aging failure model to evaluate the reliability of the equipment, including the equipment state conversion rate and average state duration, and equipment maintenance costs. The second step is to set the development direction probability for the monitoring and maintenance decision points. The third step is to use random variable theory to set
parameters for the steady-state duration probability and time of each state, and obtain the remaining operating time of the equipment according to the current reliability indicators. The fourth step is to analyze the current health status index based on the historical operation and maintenance status of the equipment [7]. The fifth step is to formulate different maintenance plans based on the status of the equipment and combined with previous maintenance experience, and calculate the corresponding costs and benefits according to the different maintenance plans, so as to select the best maintenance method. The sixth step is to select the sensitivity analysis of the maintenance strategy, and then optimize the decision on this basis. The seventh step is to determine the optimal index of the parameters for the optimization goal. The eighth step is to use Monte Carlo rules to find the corresponding rules for the time distribution of each continuous state, and then optimize the parameters in the equipment state model to provide historical data and operation and maintenance reference for the next maintenance decision.

5. Conclusion
The thesis puts forward an overall evaluation framework for equipment condition maintenance, including signal analysis system, condition diagnosis expert system, equipment business loop visual monitoring system and equipment condition maintenance management system. Secondly, through the establishment of a data processing platform that organically combines online monitoring, historical data, and family defects, the scientific and reliability of equipment health assessment and condition maintenance decision-making are realized. The equipment health assessment provides a basis for decision-making on condition maintenance. At the same time, it is also an indicator that comprehensively considers the historical operation and maintenance status of the equipment and the current health index. It can predict the health status of the equipment for a certain period of time in the future based on data processing and analysis. Finally, the paper provides a corresponding optimization method for the primary equipment maintenance decision of the smart substation. Based on the original research, the cost investment and the profit return of the state maintenance are considered, and better decisions are made for different optimization goals.

References
[1] Nan, D., Wang, W., Mahfoud, R. J., Haes Alhelou, H., Siano, P., Parente, M., & Zhang, L. Risk assessment of smart substation relay protection system based on markov model and risk transfer network. Energies, 13(7) (2020) 1777-1789.
[2] Popa, C. Impact of substations equipment to the environment. International Journal of Global Warming, 21(2) (2020) 155-172.
[3] Bolotinha, M. Substations equipment inspection and periodic maintenance. Transformers Magazine, 6(5) (2019) 74-83.

[4] Shunmugam, S. Successful implementation of hotline maintenance for high voltage transmission lines and substations in Malaysia. Journal International Association on Electricity Generation, Transmission and Distribution, 30(2) (2017) 28-32.

[5] Sparling, B. On-line monitoring of HV substation equipment: Myths and truths. Transformers Magazine, 4(2) (2017) 54-58.

[6] Chen, K., Mahfoud, R. J., Sun, Y., Nan, D., Wang, K., Haes Alhelou, H., & Siano, P. Defect Texts Mining of Secondary Device in Smart Substation with GloVe and Attention-Based Bidirectional LSTM. Energies, 13(17) (2020) 4522-4539.

[7] Cheng, L., Hu, W., Liu, Z., & Cai, W. On-site Smart Operation and Maintenance System for Substation Equipment Based on Mobile Network. International Journal of Online Engineering, 14(3) (2018) 15-29.