State Early Warning Technology for UHV AC Substation Equipment

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Abstract. With the development of UHV power transmission and transformation projects in China, as a key technology to prevent power grid accidents caused by faults of power transmission and transformation equipment, the state early warning technology of UHV AC power transformation equipment urgently needs to carry out and perfect corresponding research. This paper introduces the key technology of state warning for UHV AC substation equipment, and analyzes the principle and method of state alarm technology. And put forward the views on the current problems and future development of UHV AC equipment status warning technology.

1. Introduction
The construction of UHV transmission and transformation project can meet the demand of Chinese rapid power growth in the future. With the development of ultra-high voltage power transmission and transformation, the scale of Chinese power grid has gradually expanded and cross-regional networking has basically taken shape, putting forward higher requirements for the safety and reliability of the power grid [1]. The analysis of the causes of large-scale blackouts at home and abroad shows that the failure of substation equipment is one of the main reasons for the safe operation of the crisis grid, and it accounts for a large proportion in the cause of grid failure [2]. At present, the analysis of the causes and main problems of power grid blackouts at home and abroad places more emphasis on power grid operation problems. However, insufficient attention has been paid to large-scale blackouts caused by faults of power transmission and transformation equipment. It is necessary to attach importance to and strengthen the research, development and application of online monitoring and diagnosis technology for power transmission and transformation equipment. As one of the key technologies of condition monitoring and fault diagnosis, state early warning has good development and application prospects [3].

2. State Early Warning Technology for UHV AC Substation Equipment
Complex climate environment and faults of power transmission and transformation equipment are one of the causes of large-scale accidents. As a key technology to prevent power grid accidents caused by faults of power transmission and transformation equipment, online monitoring and diagnosis technology, together with other technologies, forms the first defense system to ensure the safe operation of power grid [4]. With the acceleration of power grid construction and the advancement of the market economy, there is an urgent need for mature power-changing equipment to avoid operational reliability reduction and economic loss caused by periodic preventive testing and periodic maintenance team equipment maintenance transition or “Leakage”. State online monitoring and diagnostic techniques based on state maintenance [5].
At present, an on-line monitoring system has been installed for UHV AC power transformation equipment, and the related condition monitoring and diagnosis technology is in the stage of gradual development. On-line monitoring of main insulation indexes of UHV substation equipment has been realized, but the monitoring results are only at the level of simple data processing and lack necessary diagnostic functions. The ultimate goal of on-line monitoring and diagnosis technology for UHV transformer equipment is to realize on-line evaluation of operation status and on-line prediction of residual life of transmission and transformer equipment on the basis of this technology, and to warn timely when insulation defects may occur, so as to greatly improve the security and economy of power grid operation [6]. Therefore, state warning and diagnostic techniques are key breakthrough points.

State alarm technology is one of the key technologies for online monitoring and diagnosis. It refers to the online monitoring data according to the status of the equipment. It compares the characteristic quantity of the equipment at a certain moment with the previous monitoring results, or is different from similar equipment or unified equipment. The online monitoring results are compared horizontally, and the fault type, the time, location and degree of the fault are predicted according to the fault symptom, so that the reliability of the equipment is early warning [4]. The online monitoring system is required to have monitoring functions reflecting various characteristic quantities, rich expert systems and intelligent early warning and diagnosis capabilities. Relevant departments of the national power grid and colleges and universities have carried out relevant research, but there are still some technical difficulties in making the state early warning technology of UHV substation equipment reach the level of engineering application in the strong electromagnetic field interference environment. Further in-depth research and development are needed, and continuous improvement and perfection are made by accumulating data through grid connection operation and finding the problems existing in the monitoring system itself. At present and for a long period of time, it is necessary to systematically and continuously summarize and analyze a large amount of diagnostic data accumulated by equipment state diagnosis, summarize the diagnostic criteria and usage guidelines of various equipments, and after several years of trials and revisions and then online The monitoring results were comprehensively analyzed and compared.

3. Introduction of Related Concepts of Online Monitoring System

The on-line monitoring and fault diagnosis technology for UHV substation equipment includes: state monitoring, state early warning and state diagnosis. There is no strict limit on the content of the three. On-line monitoring and data analysis are required. The ultimate goal is to prevent accidents before they occur. However, the tasks of the three are different. Among them, condition monitoring is to record, classify and evaluate the operation status of the equipment, to provide decision-making for equipment maintenance and maintenance, and condition early warning is to predict the time, location and degree of possible failure according to the symptom of failure. The state diagnosis is based on the fault characteristics, positioning the faults that have occurred and judging the degree of fault development [8].

The relationship between the above concepts is classified according to the time course of fault development, as shown in Figure 1. Failure early warning and diagnosis can not be called if the time and location of the failure that has not occurred can not be predicted and the location and degree of the failure that has occurred can not be accurately judged. The three key technologies form an on-line monitoring system and complement and support each other to form an organic system.
4. Key Technologies of State Early Warning for UHV Substation Equipment

UHV substation equipment condition early warning is mainly aimed at analyzing and comparing the effective data and rules, historical data, operation experience and experts, which are extracted by online monitoring system, to determine the classification and severity of equipment fault. The decision support system gives an alarm according to the preset threshold value or the prediction analysis software evaluates and speculates on the development trend of the fault and the safe operation time of the equipment insulation.

The existing on-line monitoring technology only realizes the extraction of characteristic quantities of main transformer equipment and simple data processing, and lacks necessary diagnostic analysis functions. At the same time, due to the on-line monitoring system operation period, the accumulation of expert experience knowledge is less. For the state early warning of UHV substation equipment, only a single characteristic threshold range is simply preset. However, the actual insulation status and fault degree of substation equipment often need to be analyzed comprehensively by multiple indicators. In addition, the sub-characteristic quantities currently used basically follow some characteristic parameters of preventive tests, but the operating voltage of UHV substation equipment is much higher than that of preventive tests. Therefore, it is necessary to study the credibility of the original characteristic parameters and diagnostic methods for on-line evaluation and state early warning of UHV substation equipment.

4.1 Stability of on-line monitoring device

The stability of the on-line monitoring device is the primary condition for realizing the state early warning of UHV substation equipment, among which the technical problems mainly include:

Electromagnetic compatibility. From the point of view of current technology level, there are many measures to extract weak characteristic signals from strong electromagnetic field interference by using the dominant idea of hardware and software collection and software as the main method, which have achieved very high accuracy in the laboratory. The problem is that the interference sources in different substations and their transmission paths need to be analyzed and corresponding measures taken. Therefore, it is necessary to formulate corresponding EMC test standards for ex-factory and installation handover on the basis of summarizing operation experience.
Site maintenance. During the auxiliary period of on-line monitoring sensors, preamplifiers and the like, after running in a complex and harsh environment for a long time, the corresponding characteristics and sensitivity of electronic devices are changed due to aging, the sensitivity of sensing elements such as light sensors and gas sensors is reduced, and the mechanism components are ineffective, etc., all of which will cause the detected data to deviate, requiring periodic resetting of calibration, overhaul or update. Therefore, it is necessary to give the reliable maintenance-free time or replacement period of the on-line monitoring device.

4.2 Data analysis technology

In the condition monitoring system, the task of data analysis is to get information about equipment operation from the collected data. The data analysis process is divided into four parts: data preprocessing, feature extraction, state classification and processing decision, as shown in Figure 2.

Data preprocessing includes data selection, noise elimination and other pre-processing processes. Feature extraction refers to the use of mathematical statistics, signal processing (FFT, wavelet analysis, fractal and chaos) and other methods to extract signal features. State classification and processing decision-making are the core parts of data analysis and are also difficult parts. Among them, the decision-making is to draw the final conclusion, such as determining whether the equipment has a fault, what kind of fault exists, the location and extent of the fault, and whether to check and repair. In many cases, manual processing is needed. The computer can only analyze and make decisions on a few faults. Because of the specific problems involved in the equipment, accurate conclusions are based entirely on the understanding of the mechanism of equipment failure and the accumulation of experience. This is a complex process that is generally difficult to solve by modeling or simulation.

State classification is a pattern recognition problem. For example, a one-dimensional state classification problem, let $x$ be the feature index and $x_0$ be the threshold of the feature index. Then: $x < x_0$ is the normal state; $x > x_0$ is the fault state. For multi-dimensional problems, there is more than one characteristic index, and state classification is not a simple region division problem in multi-dimensional space. This process generally adopts artificial intelligence technology, such as pattern recognition, artificial neural network, fuzzy mathematics, expert system, etc.

No matter which method is adopted, the reasoning process can be divided into inductive reasoning and deductive reasoning, as shown in Figure 3. A complete cognitive process should include inductive reasoning and deductive reasoning. The inductive reasoning stage is a sample learning process, and the state classification process is deductive reasoning. Therefore, the knowledge of classification will not exceed the scope provided by the sample, and the knowledge provided by the sample is also called prior knowledge. In expert systems, this prior knowledge consists of a knowledge base.
Figure 3  Sample learning and classification

The source of knowledge in knowledge base is a problem. Although knowledge can be acquired through many channels in theory, it is difficult to establish an expert knowledge base in practice. The basic reason is that the classification of equipment condition monitoring is different from that of character recognition. Text recognition samples are not a problem, while for a specific device's status monitoring classification problem, except for normal status samples, complete fault status samples are generally not available. Therefore, the first thing that can be done is to identify normal and abnormal states.

4.3 Standardization of online monitoring devices and early warning and diagnosis systems.

Online monitoring technology and devices are still in the research and development stage. New monitoring technologies, new methods and diagnostic software are constantly improving and improving. In addition, market competition leads to less communication. Therefore, standardization of online monitoring devices and diagnostic thresholds cannot be established soon.

Monitoring device. Judging from the development trend, an industry standard and data communication protocol adopting fieldbus technology should be formulated as soon as possible, and a standardized database standard and a perfect information management system should be established. For this reason, a front-end computer based on intelligent sensing technology and a standardized bus interface can be used to communicate. The main function of the back-end industrial control computer (host) is diagnosis, so as to improve the highly intelligent diagnostic ability of the on-line monitoring device.

Diagnostic system. There are some differences between on-line monitoring data and off-line testing data under operating conditions. The data in the diagnostic criteria of off-line testing can not be used as the diagnostic criteria of on-line monitoring data. Due to the influence of operating conditions, environmental conditions and electromagnetic interference, there is still a long accumulation of experience in the diagnostic criteria of online monitoring data. The current thinking is to combine horizontal ratio (compared with similar equipment), vertical ratio (trend analysis of the same equipment) and comprehensive analysis (previous data and operating experience of online and offline).

Early warning system. Because the threshold of fault diagnosis is mainly from the simulation experiment results of typical physical electrode models, the real model and industrial model experiments are still in the initial research stage. At the same time, there are great differences in the technological level and materials used by the same type of substation equipment from different manufacturers. In fact, it is difficult to specify a unified early warning threshold for different types of substation equipment. From the current situation, firstly, the new equipment is installed in the on-line monitoring device and put into operation at the same time, or the self-warning electrical equipment (in the process of transformer equipment manufacturing, the on-line monitoring device and equipment will be integrated) can be put into operation as a feature, referring to the maximum allowable value of the relevant equipment design specifications as the most threshold; Secondly, the online monitoring device is installed on the already-operated equipment, and the threshold intelligent value is determined according to the existing operating experience and the data change law of the continuous monitoring after the installation of the online monitoring device by the same type of equipment or the data of the
accident. With the popularization and application of online monitoring devices, after mastering a large number of data change rules and practical experience of equipment failure, the early warning threshold range of different substation equipment can be finally determined.

4.4 On-line assessment of health status and early warning technology of remaining life status

The advantage of online monitoring is that it can monitor the health status of power transmission and transformation equipment. Therefore, after accumulating a large amount of data and summarizing the state change rule, the diagnosis system should have the function of real-time or regular on-line evaluation of health state and on-line prediction of remaining life, which should be one of the key contents of research.

As can be seen from fig. 4, the faults of power transmission and transformation equipment in the whole service period are usually divided into 4 stages: In the initial stage of equipment commissioning (about 1a), the defects that are omitted in the process of manufacture, installation and commissioning will be exposed, and the inappropriate operation or maintenance of new equipment by operators can also lead to unexpected failures. Therefore, the online monitoring device preferably performs continuous real-time monitoring to detect and eliminate faults in time; during the stable period (running 5~10a), in order to extend the service life of the online monitoring device, a timed inspection can be implemented; In the deterioration stage (operation 10~20a), the regular follow-up inspection time (preferably 1d follow-up inspection for many times) shall be shortened according to the monitoring conditions in the stable period, and the operation state and remaining life shall be continuously evaluated and predicted according to the change rule of monitoring characteristic quantity.

![Figure 4 On-line health status assessment and residual life prediction sketch of substation equipment](image)

It can be seen from Fig. 5 that different device insulation health states can select two most representative feature quantities x1 and x2 (such as transformers to select oil gas and partial discharge). According to a large number of on-line monitoring results, the attention level C(x1, x2) and the danger level D(x1, x2) are summarized. The information management system and operating personnel should grasp the past and present value changes of the characteristic quantity (x1, x2) and the time (tc, td) to enter the attention and danger level at any time. The time to carry out state maintenance can be estimated by relevant on-line evaluation and residual life prediction methods.
5. Conclusion

As one of the key technologies for on-line monitoring and diagnosis of UHV AC substation equipment, the state early warning technology can predict the type, time, location and degree of equipment failure by exploring the signs of equipment insulation failure. At present, the domestic UHV substation has the preliminary conditions to realize the state early warning technology. However, the lack of expert experience and knowledge and the weak research on insulation mechanism of equipment hinder the application and improvement of early warning technology to some extent, which still needs to be explored and practiced continuously. With the continuous research and operational experience of UHV substation equipment insulation degradation, insulation level assessment, life prediction, etc. And the improvement of related product manufacturing processes, the reliability and height intelligent of UHV AC substation equipment state warning technology will be promoted. The UHV AC substation equipment state warning technology has become one of the powerful means to prevent the insulation fault of UHV substation equipment.

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