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Evaluation of Insulation Aging Maintenance Technology for High-voltage Equipment Based on the Internet of Things

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Abstract: The construction and operation of power grids play an important role in people's lives. Due to the large scale and complex system of power grid construction, there is still a certain gap in the insulation level of high-voltage transmission lines. In order to meet the power supply demand and avoid unnecessary injuries, effective measures must be taken for safety maintenance. This article studied the maintenance technology for insulation aging of high-voltage equipment under the Internet of Things (IoT) technology. The purpose was to prevent unexpected situations and improve equipment inspection and repair capabilities. This article mainly used experimental testing and variable analysis to detect the insulation aging status of high-voltage equipment, and provided repair related technologies. Experimental data showed that phase Z tanδ was significantly greater than phases X and Y at the same frequency of 0.001 Hz. Therefore, the frequency domain dielectric spectroscopy method could effectively detect the state of equipment.

1. Introduction

In response to the issue of insulation aging maintenance for high-voltage equipment, this article mainly studied the high-voltage operation mode based on IoT technology, and conducted real-time monitoring and analysis of power equipment in the power grid. The outdated maintenance technology for high-voltage insulation aging, the low quality of maintenance personnel, and the lack of relevant testing instruments and systems have led to serious problems in high-voltage transmission lines. Therefore, it is of great significance to study the insulation aging maintenance technology for high-voltage equipment.

There are many theories related to the research of insulation detection systems for high-voltage equipment and maintenance techniques for insulation aging equipment. For example, some researchers have proposed maintenance techniques for insulation aging to ensure the stable operation of high-voltage equipment and the safety of people's electricity consumption [1-2]. Some researchers also believe that the effective processing of data information ensures that the application efficiency of high-voltage equipment insulation systems can be improved by applying detection technology to obtain data information of high-voltage equipment insulation systems [3-4]. Other researchers have stated that the status check of electrical equipment is mainly achieved through real-time monitoring of the operating status of the equipment [5-6]. In the power industry, the safe operation of the power grid is of paramount importance, and insulation failures can have a serious impact on power quality. Therefore, in order to ensure the normal, stable, and reliable transmission and distribution of electrical energy in the power supply system, it is necessary to strengthen the security of the power grid.

This article first studied the relevant technologies and methods of equipment insulation detection. Secondly, IoT technology was analyzed and its functions in system maintenance were proposed. The transformer condition based maintenance technology based on the IoT was described. Finally, data analysis was conducted on the insulation aging status of the equipment through experimental testing and relevant conclusions were drawn.

2. Insulation Aging Maintenance Technology for High Voltage Equipment

2.1 Equipment Insulation Testing

Capacitive equipment in high-voltage substations refers to equipment that has all or part of a capacitive insulation structure. The insulation of these equipment not only affects the reliability of power supply, but also endangers the safety of other equipment and personnel in the substation. Therefore, the research on online monitoring of capacitive device isolation is the core of online monitoring of high-voltage electrical equipment.

Due to the physical phenomena under the action of an electric field, electrical insulation materials are commonly referred to as dielectric insulation materials. Dielectric insulation loss mainly consists of polarization loss, free loss, and conductive loss, thus resulting in a certain leakage current of the insulating dielectric under high voltage. The functional loss of leakage current leads to the heating of the medium, and the conductivity of the medium increases with the increase of temperature, thus leading to a further increase in leakage current and greater dielectric loss. With the extension of service life, the aging rate of the insulation medium accelerates, and the loss increases until the insulation layer is damaged. The harmonic analysis method is the most commonly used method in insulation online monitoring products, because it has the advantages of simple circuit, free from the influence of power supply high-order harmonics, and electronic circuit zero drift. The core to solving the problem of blocking and leakage effects is to achieve “complete interception” of signals. One method is to use techniques such as phase-locked loops to achieve automatic frequency tracking by adjusting the sampling frequency. Another method is to align the actual frequency parameters by interpolating the calculated results [7-8].

2.2 IoT Technology

Based on existing information and network communication technologies, the core functions of the IoT can be summarized as reliable and comprehensive intelligent processing. Comprehensive perception mainly involves fully controlling objects and collecting the information contained within them using relevant information perception methods, such as relevant quick response codes, radio frequency identification, positioning systems, etc. Meaningful data in a large amount of information received by sensors are analyzed and processed, so as to further implement tracking analysis and management of existing collaborative processing and meet the different needs of different users, thus achieving intelligent global optimization.

High frequency identification technology is mainly used for indoor technology of electromagnetic waves. It can identify specific targets and read and write relevant data through radio signals. It allows information to be transmitted on a certain basis and can be analyzed based on automatically recognized functions and objects. ZigBee technology is a technology that allows for close range wireless communication. It has many advantages, including flexibility and efficiency. Intelligent road inspection requires the application of positioning systems and technologies in the field of equipment maintenance, thereby surpassing traditional methods and avoiding the drawbacks of traditional road inspection methods. On the one hand, it can improve the productivity of staff and overcome the problems of low efficiency and incorrect quantity of patrol information. On the other hand, it can also avoid issues such as loss of work ability, personnel and labor errors caused by a lack of experience in daily maintenance of patrol ships [9-10].

2.3 Transformer Condition Based Maintenance Technology Based on the IoT

Status revision is a more advanced revision system. With this system, people can better understand the development of national auditing. With the introduction of the concept of expert diagnostic systems and their gradual in-depth application in management systems, the reliability of reviews is ensured to be safe, and then feedback problems are further studied through specific examples. By studying these issues, the review under the management system has been raised at a deeper level. The process of errors occurring is a gradual accumulation. As the equipment continues to operate, the error slowly changes from the initial state to a more contemplative state, and develops into a true error state, thus leading to system paralysis and serious losses. All electrical equipment shall be free from defects in any part. Alternatively, although there are some local defects, they do not affect the normal operation of the equipment [11-12].

The electrical equipment fault mode classification system and online status analysis system can use the equipment data provided by the system database, and then make judgments based on different knowledge in the knowledge database. The development of maintenance strategies must be based on the collection of a large amount of data analysis. After rigorous analysis, based on knowledge judgment and relevant standards and combined with actual maintenance conditions, maintenance steps and methods have been developed. According to maintenance standards, several reliable maintenance plans can be selected first, and appropriate analysis and comparison can be conducted to select the most reliable implementation plan. Operators interact with the decision-making process through these interfaces and evaluation programs to exchange data. The status check process is shown in Figure 1:

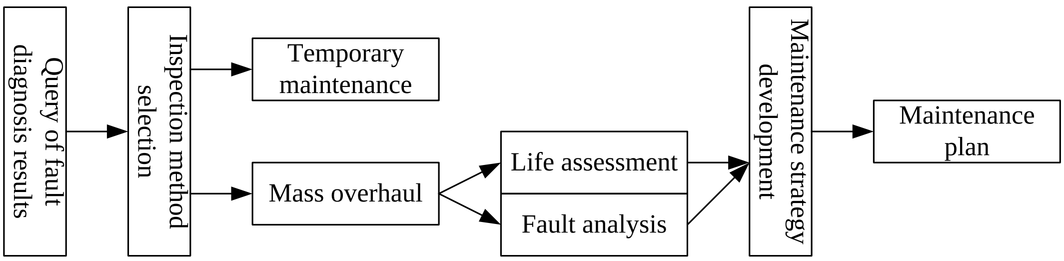

Figure 1: Status check process

The expert fault diagnosis system is one of the most important links in state repair. This system is both massive and complex. The process of developing a maintenance plan is relatively complex, but the key lies in how to make effective support decisions and how to optimize the maintenance management system. The system status information obtained through IoT technology and the optimal maintenance plan obtained through intelligent system analysis are important components of maintenance planning. After maintenance is completed, the maintenance personnel input the equipment testing parameters into the post maintenance database. The system compares these data with the pre maintenance data, and then provides an evaluation value for the maintenance effect.

3. Technology for Diagnosing Transformer Insulation Aging Based on Dielectric Response

3.1 Dielectric Response Testing Method

The on-site transformer testing was conducted using a dielectric response analyzer. The use of dual input channel transmission significantly shortens working time. The instrument is easy to carry and has a built-in processor, thus making it easy to operate on site. The principle of Dirana's evaluation of transformer moisture content is as follows: Data is measured. The instrument automatically adjusts the appropriate algorithm. The data is compared with the dielectric response model of the instrument and conclusions were drawn. The modes used to measure the dielectric response information of recording media are different.

Frequency domain dielectric spectroscopy is a frequency domain dielectric response testing technique. When the medium is linearly uniform, an alternating voltage u is applied to the medium, and the current is expressed as follows:

$$I = iuD^{*}(u)V^{*}(u) = [iuD(u) + H(u)]V^{*}(u) \tag{1}$$

In the formula, $V^{*}(u)$ is the dielectric complex capacitor. The complex relative dielectric constant E can be expressed as follows:

$$E_s^{*}(u) = E_s'(u) - iE_s''(u)E_s'(u) - i(E_s''(u) + \frac{\eta_0}{E_0 u}) \tag{2}$$

According to the formula, it can be seen that there are two factors that affect tanδ: One is the conductivity effect, and the other is the polarization characteristics of the material.

$$\tan\delta = \frac{E_s''(u)}{E_s'(u)} \tag{3}$$

Compared with traditional intermediate frequency losses, frequency domain dielectric spectroscopy is used to measure dielectric losses over a wide frequency range, thus obtaining more comprehensive data.

3.2 Transformer Dielectric Response Test Wiring Plan

The mode in this article is mainly used to test the dielectric behavior between transformer windings, while the commonly used mode is mainly used to detect the dielectric characteristics of the shell winding. Option 1: One end of the three-phase high-voltage and low-voltage windings is connected to the protection quality of the dielectric response tester, and the other end is tightened to the transformer earthing system. The port of the Dirana device is connected to the computer. Option 2: Three winding transformers are divided into high-voltage winding, medium voltage winding, and low-voltage winding. If the transformer winding has a neutral point, it must be shorted together. The high-voltage electrode is connected to the medium voltage side of the tested transformer. The high and low voltage sides of the electrode connected transformer are measured. The port of the device is connected to the computer. Option 3: Short circuit high-voltage and self-coupling three-phase windings, such as neutral and neutral windings; the three phases of the third winding are briefly closed. The high-voltage electrode is connected to the high-voltage and self-coupling windings of the tested transformer. The port of the Dirana device is connected to the computer.

3.3 Precautions and Evaluation of Main Insulation Status

If the website is too chaotic, it is recommended to choose testing mode. After connecting the instrument and transformer test line, the test line should be carefully checked for short circuits, errors, etc. To ensure the normal power supply of the instrument during testing, it is not allowed to turn it off in the middle. Real time testing is conducted and the temperature of the transformer insulation oil is recorded. During the testing period, non-professional personnel are not allowed to approach the equipment to avoid electric shock. In emergency situations, equipment protection is carried out.

The dielectric response technology is applied to on-site diagnosis of insulation aging status of transformers in operation. The evaluation process is shown in Figure 2:

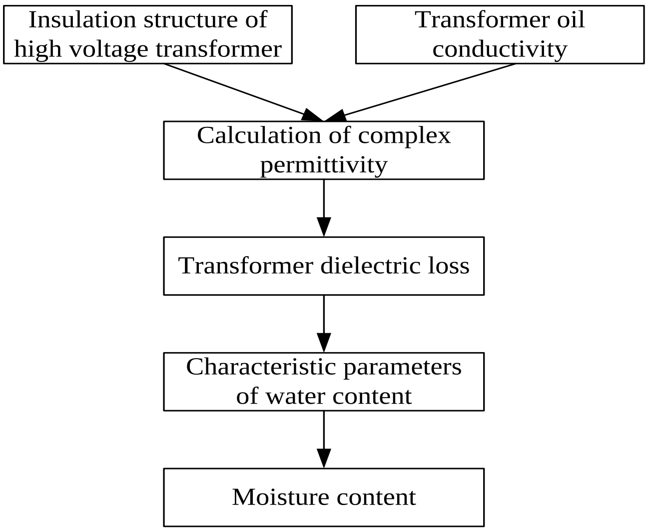

Figure 2: Evaluation process of insulation aging state

If this technology is applied to the evaluation of the primary insulation of on-site transformers, it is necessary to consider the structure of their primary insulation. The calculation of the complex dielectric constant spectrum is presented in the conducted tests and calculated in conjunction with the structural parameters of the insulation system. The conductivity of insulation oil is measured, and the spectrum within the dielectric constant range of the insulation board and the spectrum within the dielectric loss range are calculated. The equivalent X-Y model is used for calculations. From the characteristic frequency, the dielectric loss value is extracted and the water content is calculated using a formula.

4. Experimental Test Results

4.1 Evaluation of Water Content under Different Cut-off Frequencies under Different Wiring Methods during Testing

It is accurate to determine the moisture content of transformer boards by evaluating the average value of moisture content at different separation frequencies. If the separation frequency is not well detected, the average value is more reliable. For the three connection modes H-L, H-L and H-wire, H-L and L-Wire, the nominal water content at different limit frequencies is basically close to the actual value. For H-L and H and H-L and L-land connection modes, the difference in nominal water content at different extreme temperatures is relatively large. Therefore, it is recommended to use H-L, and H-L and H-land connection modes. The specific situation is shown in Table 1:

Table 1: Water content assessed at different cut-off frequencies under different wiring modes

	H-L	H-Land H-wire	H-L and L-Wire	Average Moisture Content
100	2.5	2.6	2.8	2.63
300	2.7	2.6	2.6	2.63
500	2.6	2.7	3	2.76
700	2.7	2.5	2.3	2.5
900	2.6	2.6	3.2	2.8

As shown in Table 1, based on the above analysis, the optimal connection modes for testing on running transformers were H-L, H-L and H-L and H-wire, and the optimal stop frequency for testing was 300MHz. If the testing time was sufficient, testing could also be conducted at five extreme frequencies and the average value could be taken. The transformer was evaluated based on the average moisture content of the cardboard.

4.2 Dielectric Characteristic Values of Three Phases of an Autotransformer

The tangent value of the dielectric loss angle represents the oil paper insulation loss of the transformer. The value of tanδ increases and reaches its maximum as the frequency decreases. Meanwhile, the degradation of insulation paper leads to significant changes in tanning value at low frequencies. The three-phase analysis results of the autotransformer at different frequencies are as follows:

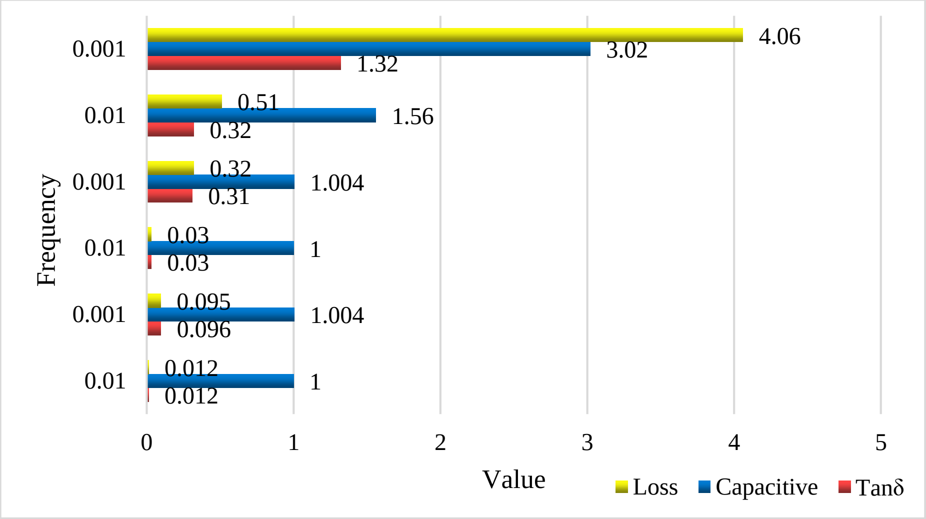

Figure 3: Dielectric characteristic quantity of the three phase of the autotransformer

As shown in Figure 3, it could be seen that at a frequency of 0.001 Hz, the tanδ value of phase Z was 1.32, which was 13.75 times the tanδ value of phase X and 4.26 times the value of phase Y. The tanδ value of phase Z at 0.01 Hz was 0.32, which was approximately 26.7 times the tanδ value of phase X and 10.7 times the value of phase Y. It could be concluded that the dielectric characteristic curve FDS under the characteristic frequency could be used to determine the aging state of the transformer oil paper insulation system.

5. Conclusions

There are more and more high-voltage equipment in the power grid, and their insulation aging is one of the important factors affecting the normal operation and safety accidents of high-voltage transmission lines. This article analyzed and studied the maintenance methods for high-voltage insulation aging based on IoT technology, and proposed targeted suggestions for the analysis of maintenance characteristics and related standards for high-voltage electrical equipment based on IoT technology. The withstand voltage performance of high-voltage components in the power grid should be strengthened. At the same time, attention should also be paid to making corresponding adjustments to its operating status and parameters in different environments to adapt to various working conditions. In addition, it was necessary to improve the technical level of maintenance personnel when carrying out equipment insulation aging maintenance.

Acknowledgements

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