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Design of Insulation Online Monitoring and Anti-Condensation Control System for Distribution Switchgear

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Abstract: *The partial discharge and condensation in distribution switchgear seriously affect the insulation state, which can cause insulation failure and lead to the shutdown of electrical equipment. This paper designs and develops a set of insulation online monitoring and anti-condensation control system for distribution switchgear. By comprehensive use of transient earth voltage (TEV) technology and ultrasonic technology for partial discharge detection, temperature and humidity detection, control technology and wireless communication technology, the system realizes the online monitoring of insulation, temperature and humidity in switchgear. In addition, the system can automatically control the heater, fan or other environmental adjustment equipment and reduce the occurrence of condensation in switchgear.*

Keywords: *Switchgear, Partial Discharge Monitoring, Temperature and Humidity Monitoring, Condensation*

1. Introduction

Distribution switchgear is one of the most important electrical equipment in power distribution system and is widely used in power substations. In the long-term operation of the switchgear, there must be insulation deterioration caused by factors such as electricity, heat, and chemistry. With the insulation deterioration, partial discharge may emerge and its long-term existence will further deteriorate insulation. Ultimately, insulation failure will take place and the switchgear will be out of service, which have direct influence on the supply reliability of the power distribution system [1-4]. In addition, the adverse operating environment condition is one of the main factors bringing about insulation defects in switchgear. During the operation of the switchgear, due to insufficiency of the internal heat dissipation and dehumidification, temperature or humidity exceeding standard may take place. The partial discharge and condensation inside the switchgear will seriously endanger the normal operation of the switchgear.

At present, for the insulation testing of switchgear, partial discharge detection technology is mainly applied on site. The current methods used for the partial discharge detection in switchgear mainly involve ultrasonic method, transient earth voltage (TEV) method, pulse current method, ultra-high frequency (UHF) method, etc. [5-7]. Many relevant studies on partial discharge mechanisms, phenomena, and detection methods have been conducted and yielded some positive results. However, there are still many problems that need to be solved in on-site online monitoring application, like reducing the size of equipment, cutting hardware costs, and improving the ease of use and stability of the monitoring system.

The temperature and humidity sensors currently used can monitor the temperature and humidity in the switchgear. However, there is lack of connection between the existing switchgear temperature and humidity monitoring system and the switchgear temperature and humidity adjustment equipment, such as heaters, fans, condensers. And the scarcity of in-depth research on temperature and humidity adjustment strategies has led to poor results in preventing or reducing condensation [7].

The condition-based maintenance of electrical equipment is regarded as one of current development directions of power operation and maintenance. The research of equipment condition-based maintenance carried out is generally based on online monitoring of equipment, mainly applied to large equipment such as transformers, but less to distribution equipment. Due to the large number of distribution switchgears, the energized testing method is difficult to conduct timely test and meet the requirements of high efficiency in power system maintenance. Thus, it is very important to develop a new type of online

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monitoring system for distribution switchgears. Besides, the application of new technologies represented by advanced sensing and Internet of Things (IoT) technology will greatly enhance the equipment information perception and promote the intelligent development of the power distribution system [9].

Based on the discussion above, this paper designs and develops a set of insulation online monitoring and anti-condensation control system for distribution switchgears. The system comprehensively adopts the partial discharge detection technology of TEV and ultrasonic, temperature and humidity detection and control technology, wireless communication technology, etc. to monitor the internal insulation state, temperature and humidity of the distribution switchgears online. According to the data obtained by online monitoring of this system, the actual insulation state of the switchgear can be known, and environmental adjustment equipment such as heaters, fans, condensers can be controlled based on the temperature and humidity in order to achieve rapid and economic control of the operation environment and reduce the occurrence of condensation in switchgear. The development and application of this system can provide positive experience for the intelligent switchgear monitoring.

2. The Overall Design of the System

The schematic diagram of the system composition is shown in Figure 1. The system is mainly composed of three parts: sensors, data acquisition unit and concentrator. The sensors include ultrasonic and TEV sensors monitoring the partial discharge online of the switchgear, and temperature and humidity sensors acquire the internal temperature and humidity in the switchgear. The data acquisition unit collects the data of TEV, ultrasonic, temperature and humidity sensors and the switch state of heaters, fans, condensers and other equipment available. According to temperature and humidity in the switchgear, the unit automatically controls heaters, fans, condensers and adjusts the temperature and humidity of the operating environment of the switchgear and improves the local environment in the switchgear. Additionally, the data acquisition unit can transmit the data to the concentrator through RS485 wired or 433 MHz wireless communication technology. As for the concentrator, it exchanges data with the data acquisition unit and has functions of data statistics, display, alarm, system setting and data upload to the cloud platform.

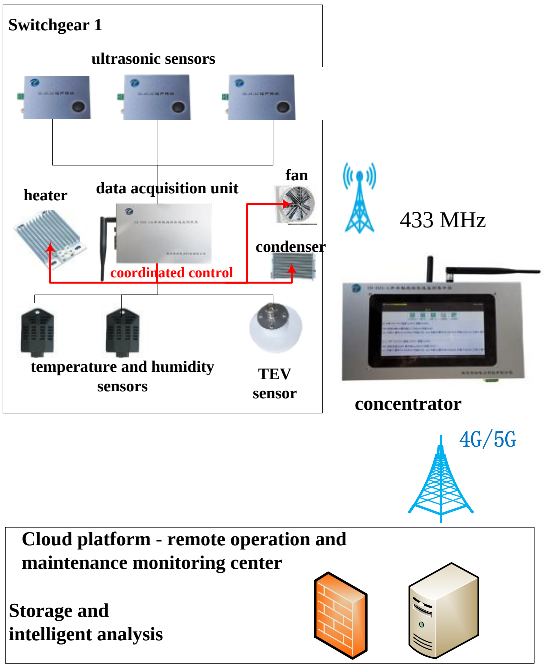

Figure 1: Schematic diagram of system composition.

3. Technical Development of Key Parts of the System

3.1. Sensors

Ultrasonic and TEV detection technology are most frequently used in the field switchgear partial discharge detection. Ultrasonic detection technology collects ultrasonic signals of upper 20 kHz

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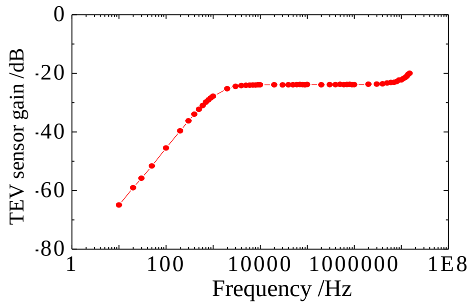
frequency generated by partial discharge in switchgear, so as to judge the occurrence and location of partial discharge. If installed inside the switchgear, the ultrasonic sensor is not sensitive to external interference signals because of the relatively enclosed environment isolated by the switchgear cabinet. Therefore, if the suspected partial discharge signal is detected by ultrasonic method, there is high probability of partial discharge in the switchgear.

TEV pulses were first observed by Dr John Reeves in 1974 [3]. The electromagnetic pulses produced by internal partial discharges are conducted away in every direction by the surrounding metalwork. This charge in motion generated from partial discharges gives rise to an electric current which leads to a very high frequency voltage pulse, when it impinges on the impedance of the metal casing. These high frequency voltage pulses escape through joints in the metalwork and pass from the inner to the outer surface of the equipment and then down to ground. The voltage pulse, namely TEV signal can be used as the basis for the detection of partial discharge in switchgear [5-7]. TEV method has high detection sensitivity for partial discharge. However, due to many on-site interference sources in the substation its measurement effect may be affected.

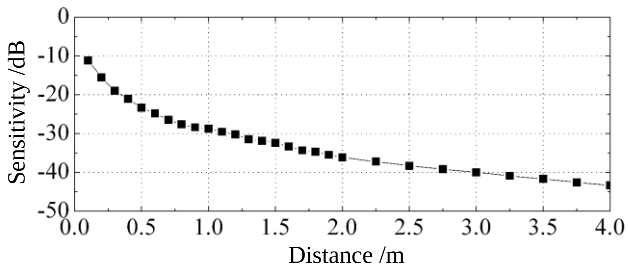
In order to improve the sensitivity and reliability of partial discharge detection, ultrasonic and TEV methods are adopted in this system. The sensors used are shown in Figure 2. The center frequency of the ultrasonic sensor is 40 kHz, and the minimum sensitivity is -68dB. The amplitude frequency characteristic curve of the TEV sensor and the sensitivity curve of the ultrasonic sensor with distance through testing are given in Figure 3.

(a) Ultrasonic testing module. *(b) TEV sensor.*

Figure 2: Pictures of sensors.



(a) TEV sensor amplitude frequency characteristics.



(b) Ultrasonic probe sensitivity curve with distance.

Figure 3: Characteristic curves of sensors.

The high-precision SHT20 temperature and humidity sensor is used for the temperature and humidity detection in the switchgear. SHT20 sensor adopts RS485 hardware interface and its protocol layer is compatible with the standard industrial Modbus-RTU protocol, as is shown in Figure 4.

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(a) SHT20 Chip. *(b) The shape of Temperature and humidity sensor.*

Figure 4: Temperature and humidity sensor.

3.2. Data Acquisition Unit

The data acquisition unit mainly implements multi-channel data collection and preprocessing of partial discharge, temperature and humidity sensors. According to the environmental parameters, it automatically controls the heater, fan, condenser. The data acquisition unit adopts Cortex-A9 CPU, with 4 analog voltage acquisition channels, which can acquire the data from 1 TEV channel and 3 ultrasonic channels at the same time. And 2 switching inputs and 4 relay outputs are designed, which can gain automatic control of heaters, fans, condensers and other available equipment.

The data acquisition unit is installed on the surface of the steelwork inside or outside the switchgear. Since the metalwork of the switchgear has a strong shielding effect for the transmission of the electromagnetic wave, the 433 MHz wireless communication module is used for wireless data communication. Compared with the 2.4 GHz technology, its main advantages lie in its long distance, strong penetration, and excellent diffraction ability, which is very suitable for wireless communication of the switchgear online monitoring system [10]. Its main drawback is the small data transmission rate, so in order to reduce the data transmission pressure, it is necessary to extract the features of the obtained ultrasonic and TEV signals of partial discharge before uploading them to the concentrator.

The feature parameters extracted by the data collector for ultrasonic signals are mainly pulse amplitude, pulse duration and 2-second pulse count. First, the original signal is filtered by determining the amplitude threshold according to the noise level. Since the ultrasonic signal behaves as oscillatory decay, only positive values are retained in the filtered data, and then the filtered data are tested for extreme values. Figure 5 shows the waveform comparison and signal feature extraction diagram before and after pre-processing of ultrasonic signal.

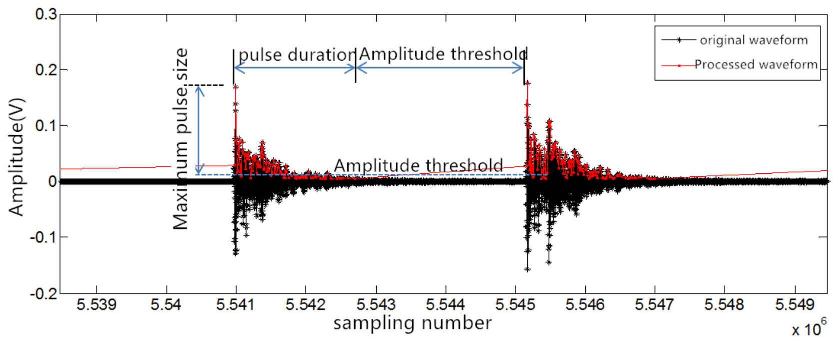

Figure 5: Ultrasonic signal feature extraction.

The pulse duration is the time interval experienced from the first time the ultrasound signal exceeds the threshold to the last time it is above the threshold, and this time interval can be considered as corresponding to a partial discharge. The maximum amplitude of the ultrasonic signal pulse is recorded as the amplitude of the ultrasonic signal pulse. The test observation shows that the duration of a single ultrasonic pulse signal generally does not exceed 4ms, with typical values between 0.5 and 2ms. The pulse interval time is the time interval between the ultrasonic signals triggered by two discharges. If the pulse interval time does not exceed 0.1ms, the waveform will be judged as the ultrasonic signal triggered by the same partial discharge, otherwise it will be considered as the ultrasonic signal triggered by two partial discharges. By continuously recording the ultrasonic signals within a period of time, the duration of all pulses within the period is counted, and the number of pulses can be obtained at the same time; if the duration of a pulse exceeds 4ms, the pulse is considered as the superposition of multiple ultrasonic pulses, and when there is the superposition of multiple ultrasonic pulses, the number of pulses is estimated according to the pulse duration.

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TEV detection sensors usually use capacitively coupled sensors, and relevant experimental tests show that the original TEV signal amplitude of switchgear partial discharge is generally less than 100 mV, with a frequency distribution range of 3 MHz to 100 MHz, which requires high-cost data acquisition hardware to complete the complete acquisition of the original TEV discharge signal, so detection devices are incorporated with amplification detector processing circuits. The TEV signal amplification and detector processing circuit is integrated in the data collector. In this system, the amplification factor is 10 times, and the amplification frequency range is 10kHz~500MHz; the detection method is positive polarity envelope detection, and the detection frequency range is 10kHz~200MHz; the TEV signal after detection can significantly reduce the requirements of the data collector, and it is convenient to obtain the amplitude and the number of pulses of the local discharge signal. The data collector counts the number of 2s pulses, the maximum amplitude and the average amplitude of the TEV signal and uploads them to the concentrator.

3.3. Concentrator

The concentrator is mainly responsible for the information exchange with the data acquisition unit, including receiving online monitoring data from the data acquisition unit and sending configuration and control information to the data acquisition unit, coupled with data statistics, display, alarm, system settings and data upload. The concentrator is an embedded device based on the Linux system and uses a capacitive touch screen to interact with the user. Figure 6 displays the system interface of the concentrator.

Figure 6: System interface of concentrator.

The common analysis methods of the partial discharge test results of switchgear include threshold analysis, statistical analysis, horizontal and vertical analysis. The concentrator first uses threshold analysis to make rapid judgment of partial discharge faults, and at the same time establish a database. Through the statistical, horizontal and vertical analysis methods of the monitoring data, further comprehensive diagnosis and analysis of the switchgear insulation state can be conducted. In addition, the concentrator has an interface function for uploading data and can also be integrated with other monitoring systems.

3.4. Anti-Condensation Control

The occurrence of condensation in the switchgear is mainly attributed to the temperature difference between the inside and outside of the cabinet, the relative humidity in the cabinet, and the dew point temperature of the water vapor [8]. Therefore, by controlling the temperature and humidity inside the switchgear, condensation can be prevented. The concentrator of this system detects the temperature and humidity inside and outside the switchgear based on the temperature and humidity sensor, then analysis of the condensation probability according to the temperature and humidity measured will be done and the corresponding command for temperature and humidity control can be send to the data acquisition unit. The data acquisition unit automatically controls the switch or relay for the heater, fan, condenser, etc., and then realizes anti-condensation control of the switchgear. The system control model is shown in Figure 7.

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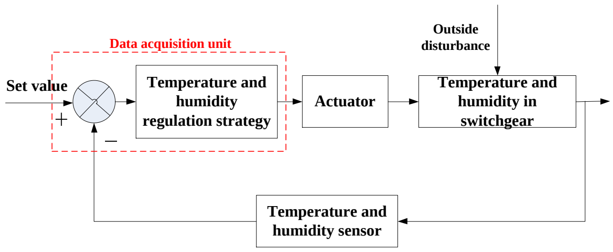

Figure 7: Principle of temperature and humidity control.

4. Field Application

This system was installed and operated on site at a 35kV switchgear in a substation. The on-site installation of each part of the system is revealed in Figure 8. Field operation and testing show that the system functions meet the design requirements.

(a) Ultrasonic and temperature & humidity sensors.

(b) Ultrasonic sensor and heater installation.

(c) TEV sensor installation.

(d) Data acquisition unit installation.

(e) Concentrator installation.

Figure 8: Field installation of the system.

5. Conclusion

A set of insulation online monitoring and anti-condensation control system for distribution switchgear is designed and developed in this paper.

Consisting of three parts, sensors, data acquisition unit and concentrator, the system adopts ultrasonic, TEV, temperature and humidity detection technology and wireless communication technology to achieve multi-directional information acquisition of switchgear. The partial discharge is online detected by ultrasonic and TEV methods. Based on the temperature and humidity measurement, the heater, fan, condenser, etc. can be controlled automatically and the occurrence of condensation in the switchgear can be reduced.

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