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On-line Monitoring Device for High-voltage Switch Cabinet Partial Discharge Based on Pulse Current Method

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Abstract. The pulse current method for partial discharge detection is generally applied in type testing and other off-line tests of electrical equipment at delivery. After intensive analysis of the present situation and existing problems of partial discharge detection in switch cabinets, this paper designed the circuit principle and signal extraction method for partial discharge on-line detection based on a high-voltage presence indicating systems (VPIS), established a high voltage switch cabinet partial discharge on-line detection circuit based on the pulse current method, developed background software integrated with real-time monitoring, judging and analyzing functions, carried out a real discharge simulation test on a real-type partial discharge defect simulation platform of a 10KV switch cabinet, and verified the sensitivity and validity of the high-voltage switch cabinet partial discharge on-line monitoring device based on the pulse current method. The study presented in this paper is of great significance for switch cabinet maintenance and theoretical study on pulse current method on-line detection, and has provided a good implementation method for partial discharge on-line monitoring devices for 10KV distribution network equipment.

1. Introduction
High voltage switch cabinets are critical electrical equipment in power system distribution networks. The safe operation of high-voltage switch cabinets is of great significance for grid security. Defects or deterioration of the internal insulation components of high voltage switch cabinets or poor contact at conductive connection parts will threaten their safe operation and directly affect the safe and reliable operation of the power grid. Relevant data show that the failures caused by insulation and current-carrying errors account for 40% of the total 6-10kV switch cabinet accidents in China’s power system. Among these, accidents arising from insulation flashovers account for 79% of the total number of accidents caused by insulation failure. The status of the insulation within the switch cabinet can be analyzed based on relevant information obtained through partial discharge on-line monitoring since partial discharge may be present during the accident incubation period[1-8].

2. Significance of high voltage switch cabinet partial discharge
The internal components, supporting insulator and busbar are installed into the switch cabinet after arrival at the site, and can only be tested after on site assembly. However, carrying out high-voltage
withstand testing or partial discharge testing on site is much more difficult than in the plant. Generally, high voltage equipment presents higher integration. Once an accident happens, the hazard rating will be much higher than that of previous discrete and open-type equipment. The failure of one equipment component will endanger the adjacent components, and the maintenance cycle will be much longer. Furthermore, switch gear products are becoming increasingly compact, which leads to a corresponding reduction in insulation margin. Especially in South China, the hot and humid summer air is prone to causing surface creepage of internal insulation components which can hardly be detected outside the cabinet. In recent years, many surface creepage failures have been detected. Therefore, it is necessary to monitor the insulation state of high-voltage switch cabinets [9-10].

The most common high voltage switch cabinet partial discharge detection method is the transient earth voltage (TEV) method which is adopted for routing inspection. However, quantitative analysis cannot be carried out while using this method for partial discharge detection. Furthermore, it shows poor technical and economic performance since it can be easily disturbed by ultrahigh frequency (UHF) or acoustic emission (AE), and requires a lot of equipment if electro-acoustic methods are adopted. Long-term on-line monitoring and partial discharge source localization cannot be widely used for switch cabinets with this method[11-15]. Consequently, a more efficient high-voltage switch cabinet partial discharge on-line monitoring system is needed.

3. Pulse current detection principle for VPIS

The pulse current method is the first developed and most widely used method for detection at present. The International Electrotechnical Commission (IEC) formulated a specific detection standard for it in 2000. Each partial discharge will lead to the neutralization of positive and negative charge, accompanied by a sharp current pulse. Thus, the pulse current method is detecting the occurrence of partial discharge by measuring this pulse current. This method is generally applied in type testing and other off-line tests of electrical equipment at delivery. In spite of the high sensitivity of off-line measurement, it is prone to be affected by external noise on site and shows poor immunity from interference[16-20].

![Figure 1. VPIS Partial of discharge detection circuit](image)

As shown in Figure 1, $u_b$ is the rated voltage of the switch cabinet busbar; $C_x$ is the capacitance of the test sample; $C_1$ is the level 1 capacitance of the insulator; $C_2$ is the level 2 capacitance of the
insulator; $C_{2m}$ is the matching capacity of the VPIS; $C_i$ is the coupling capacitance of the PD; $Z_m$ is the detecting impedance; $A$ is the amplifier; and $M$ is the test system.

Detecting impedance $Z_m$ is obtaining the high-frequency pulse signal generated by partial discharge. Since the signal amplitude is small and requires amplification with an amplifier, $Z_m$ and the amplifier must match perfectly, which determines detection sensitivity and pulse resolution.

Figure 1 shows that the total impedance $Z_0$ of $C_1$, $C_{2l}$, $C_{2m}$, $C_{2k}$ and $Z_m$ is:

$$
C_2 = C_{2l} + C_{2m}
$$

(1)

$$
Z_0 = \frac{1 - jwC_i Z_m}{w^2 C_k C_2 Z_m - jw(C_k + C_2)} - j \frac{1}{wC_i}
$$

(2)

The signal collected by the test system is a partial discharge pulse voltage signal, the voltage amplitude of which is $u_m$. The known rated operating voltage of the primary busbar of the switch cabinet is $u_n$. The transitive relation between $u_m$ and $u_n$ can be derived via formula (1) and (2):

$$
u_m = \frac{u_n C_1 Z_m (jwC_i + w^2 C_k^2)}{C_1 - C_2 - C_k - jwZ_m (2C_k C_2 + C_k^2) + w^2 C_k^2 Z_m (C_1 + C_2)}
$$

(3)

The partial discharge pulse detected by the test system is in proportion to the actual partial discharge quantity in electric charge. The specific proportional relation is related to the measuring circuit, amplifier etc. It is very difficult to calculate the quantity of electric charge from the indicated value. Instead, it is determined via experiment. That is, the measuring device for the pulse current method must be calibrated. The calibration method involves applying a pulse of a certain discharge capacity which simulates a partial discharge, and observing if the partial discharge amount displayed on the measuring device is consistent with that applied on the test sample. In case of any inconformity, the measuring device is adjusted with the calibration coefficient $k$ until the inconformity is eliminated. The measurement and calibration with this technology can be performed when the high voltage switch cabinet is online, which is more advanced than the traditional off-line calibration. Online calibration positions and pictures are as shown in Figure 2.

![Figure 2. On-line calibration wiring diagram](image)

During the partial discharge calibration process, if a pulse signal with a discharge capacity of $q_i$ is injected at both ends at the matching capacitance $C_{2m}$ of the VPIS, the relationship between the actually measured voltage amplitude and injected signal can be obtained as shown below:

$$
q_i = k \int_{t_0}^0 u_m dt
$$

(4)

Where in Formula (4), $k$ is the calibration coefficient, $t_0$ is voltage duration of the partial discharge, and $u_m$ is the actually measured voltage amplitude.
4. Device configuration and implementation

4.1 Compositions and installation

The system established in this paper mainly includes the VPIS, amplifier, collection and display unit, analysis software and local storage unit and the background summary display unit. A system composition block diagram and connection relationships are shown in Figure 3. In the stable operation of the system, the system parameter table is shown in table 1.

![Figure 3. Block diagram of VPIS partial discharge measurement system.](image)

**Table 1. System parameter table**

| System project             | Parameter       |
|----------------------------|-----------------|
| Primary system voltage     | 10kV            |
| Detection voltage          | AC 100±5V       |
| Auxiliary power            | DC 110V         |
| Power supply               | AC 220V         |
| Detection sensitivity      | ≤50pC           |
| Alarm function             | Available       |
| Continuous detection function | Available   |
| Phase analysis function    | Available       |

![Figure 4. Secondary interface insulator sensor location diagram](image)

This equipment and the switch cabinet indicating system share one set of insulator type capacitance sensors. The connection position is as shown in the red blocks of Figure 4. The PD signal amplifier can be connected to the three-phase interface on the back plate of the charge display device. The PD signal is transferred to the analyzing host for data analysis after being amplified with a signal amplifier.
4.2. Noise suppression
The device can only be powered on for debugging after being installed properly. After power on, the analysis and display unit will display ambient noise. After judging the noise size, adjust the appropriate noise suppression device via analysis software.

4.3. Calibration setting
Since the device is based on the pulse current method, calibration setting shall be carried out before monitoring. The calibrator is specifically used for on-line calibration and measurement accuracy. Specifically, the on-line calibration method is as follows:

- Check whether the calibrated switch cabinet and adjacent ones are equipped with electrophase-checking interfaces, and are normally energized.
- Connect the partial discharge calibrator and the electrophase-checking interface of the calibrated switch cabinet and adjacent ones. The positive pole of the calibrator signal output wire is connected to any phase of the three-phase electrophase-checking interface. The negative pole is connected to the grounding interface to ensure reliable connection of the calibrated signal wire and electrophase-checking interface.
- The capacitance of the capacitance sensor of the running switch cabinet can be tested online by inputting the grid operating voltage to the calibrator. Rotate the voltage adjusting knob to emit a corresponding partial discharge pulse. Then equip the analyzing host with partial discharge analysis software, and adjust the power value as indicated by the analysis software to be consistent with the calibrator to complete calibration.

4.4. Software analysis
As shown in Figure 5, we can process and analyze the collected data via analysis software, and check the partial discharge phase diagram and discharged power of each channel. Identify the switch cabinet with partial discharge through comparing the size of partial discharge of each switch cabinet.

![Switch cabinet partial discharge on-line monitoring system](image)

**Figure 5.** Analysis software interface of switch cabinet partial discharge on-line monitoring system
5. Verification test
In Dec. 2016, the device was installed on the partial discharge defect simulation platform of a 10KV switch cabinet belonging to the State Grid Beijing Electric Power Research Institute to verify the defect test effects, including PD monitoring effect, sensor sensitivity, repeat ability, partial discharge mode recognition etc.

The test established an air gap insulator defect with low power discharge in the 222 switch cabinet as shown in Figure 6.

Figure 6. Defect insulator within the 222 switch cabinet

After applying voltage to the switch cabinet, the device was subject to on-line calibration by utilizing the partial discharge calibrator. During the test process, a certain grade of voltage was applied to the 222 switch cabinet until an obvious PD signal was obtained. The device was calibrated by utilizing the PD calibrator and performing partial discharge monitoring. The voltage $u_0$ applied to the 222 switch cabinet was 10KV. Testing with the device presented in this paper was carried out. The test results are as shown in Figure 7 and 8. When the switch cabinet was under 50pC, the internal defect discharge was 121pC. The phase of the discharge spectrogram was narrow. While compared to the voltage phase level applied in switch cabinet A, the discharge phase was distributed between 270 and 300°. Due to the 50pC background interference of the switch cabinet simulation platform, the discharge spectrogram complied with the phase distribution features of phase 1 and 3. Therefore, it can be determined that the discharge is from phase A of the switch cabinet and is in line with the actual defect setting.

Figure 7. PRPD spectrogram of partial discharge signal.

Figure 8. PRPD 3D spectrogram of partial discharge signal (20ms).
6. Conclusions
The simulation status within the switch cabinet can be reflected effectively and intuitively via a VPIS partial discharge monitoring device which can not only effectively prevent a catastrophic failure, but also optimally control the O&M cost of the entire system. This paper obtained the following conclusions through establishing the monitoring circuit, formula, device development and platform verification:

- The detection circuit has a partial discharge signal calibration and detection function through the designed pulse current partial discharge detection circuit and formula. This method is consistent with the traditional pulse current partial discharge measurement.
- The device can effectively monitor the actual partial discharge signal in the switch cabinet as verified by the simulation platform of the State Grid Beijing Electric Power Research Institute.
- The three-phase common-mode suppression circuit of the device amplifier can effectively filter external interference signals. The actual detection sensitivity is no greater than 50 pC.
- The background analysis software developed in this paper can perform phase spectrogram analysis. The discharge source phase can be determined through comparing with the actual operating phase.

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