Research on Calibration Technology of TEV Partial Discharge Smart Sensors

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Abstract. TEV partial discharge detection is an important method to judge the insulation status of the switchgear. However, the quality of TEV smart sensors produced by different manufacturers on the market is uneven. Some TEV smart sensors that have been put into operation have deficiencies in measurement sensitivity, data stability, and long-term operational reliability. In response to these problems, this paper proposes a TEV smart sensor calibration method and builds a test platform, which is composed of program-controlled signal source, signal coupling device, protocol conversion device, host computer and corresponding integrated control software. On the basis of the existing standards such as sensitivity and linearity, the evaluation of the data stability, reliability and battery lifetime of the TEV smart sensor has been added. It provides a more comprehensive and effective implementation plan for TEV smart sensor performance verification in power grid access test.

1. Introduction

Partial discharge is an important factor leading to the failure of the switchgear [1]. Common detection methods for partial discharge include ultra-high frequency method, high-frequency current method, TEV method, ultrasonic method [2-3], etc. Among them, the TEV method is more sensitive to the changing speed of the pulse and is more suitable to detect the discharge inside the medium, so it is widely used in the partial discharge detection of the switchgear [4-5]. In the process of factory test, power grid access test, and arrival test of these TEV smart sensors, manual operation is generally required. This method requires manual setting of the signal generator, recording data and judging whether the sensor is qualified. Also there is a certain possibility of misoperation. Generally speaking, the test efficiency is not ideal. Therefore, a mature automatical platform and evaluation method for TEV smart sensors are needed to improve the efficiency of calibration. This paper proposes a TEV smart sensor evaluation method, combined with the host computer software compiled in the LabVIEW environment, which can reduce personnel operations, simplify the test process, and improve the efficiency of verification.

2. Calibration items analysis

TEV partial discharge smart sensor, as the secondary monitoring equipment of power grid equipment, must not only meet the environmental conditions of conventional electronic equipment test (such as enclosure protection, safety, environmental adaptability, electromagnetic compatibility, etc.), should also achieve requirements of special functions and performance characteristics. At present, the China Electric Power Research Institute has formulated the corporate standard ‘Q/GDW 11063-2013 Technical Specification for Transient Earth Voltage Partial Discharge Detector’, but the specification

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does not put forward clear technical requirements for TEV partial discharge smart sensors. Take data stability, reliability, and battery lifetime as examples, these points are the key factors that affect the normal operation of the sensors, but there is still a lack of verification methods. Therefore, after comprehensive consideration, the selected calibration items are: partial discharge smart sensor sensitivity, linearity, data stability, reliability (environmental adaptability and EMC) and battery lifetime.

3. Calibration scheme
In order to realize the automatic calibration of TEV partial discharge smart sensors and simplify manual operations, the calibration operations should be controlled by the host computer as much as possible (hereinafter referred to as sensor). Among the above five indicators, the sensitivity and linearity calibration requires the establishment of a fixed traceable signal coupling channel for testing. Thus a host computer, radio frequency combiner, signal coupling device, smart sensor to be verified, protocol conversion device and other basic components are required. The overall test loop diagram is shown in Figure 1.

3.1. Sensitivity
1) First, record the background noise level of the smart sensor to be tested and record it as \( V_{\text{noise}} \).
2) The host computer controls the program-controlled signal source to send out a certain amplitude \( V_{\text{host}} \) standard discharge pulse waveform, and at the same time the host computer communicates with the smart sensor, and calls the smart sensor to upload the current detected signal amplitude, which is recorded as \( V_{\text{test}} \). If \( V_{\text{test}}>2*V_{\text{noise}} \), it is considered that the current input amplitude of the smart sensor can be measured.
3) Reduce the output amplitude of the programmable signal source, and use the same method in 2) to determine whether the smart sensor is measurable under each amplitude \( V_{\text{host}} \).
4) Find the minimum measurable value of the smart sensor that meets the conditions of \( V_{\text{test}}>2*V_{\text{noise}} \).
and record it as $V_s$. The smart sensor detection sensitivity test diagram is shown in Figure 3.

![Detection sensitivity test diagram](image1)

**Figure 3. Sensitivity test diagram**

### 3.2. Linearity

1) First, set the frequency of the sine signal output by the programmable signal source to be fixed to $f$.
2) The host computer controls the program-controlled signal source to send out a standard discharge pulse waveform of the amplitude of $V_{\text{Host}1}$ to make the value of the sensor to be verified close to the full range, which is recorded as $V_{\text{test}1}$.
3) Gradually reduce the output amplitude of the program-controlled signal source, and call the smart sensor to upload the current detected signal amplitude, which is recorded as $V_{\text{test}n}$, and judge whether $V_{\text{Host}n}$ and $V_{\text{test}n}$ can form a pair of valid test data under each $V_{\text{Host}}$.
4) When the $V_{\text{Host}}$ increases, the measurement point where the rate of change of the two adjacent $V_{\text{test}n}$ is less than 5% is found, and the test is terminated.
5) Draw all $V_{\text{Host}}$ (x-axis) and $V_{\text{test}}$ (y-axis) into a graph, as shown in Figure 4. The $V_{\text{Host}}$ value corresponding to the vertex of the linear relationship trend between $V_{\text{Host}}$ and $V_{\text{test}}$ in the figure is recorded as $V_e$, and $V_e$ is recorded as the linearity peak point of the smart sensor to be tested.

![Relationship curve between VHost and Vtest](image2)

**Figure 4. Relationship curve between VHost and Vtest**

### 3.3. Data stability

1) The smart sensor is adjusted to the normal working mode and runs for 2 hours. During the two hours, the background noise test value of the smart sensor is called regularly (every 10 seconds) through the host computer software according to the specified protocol.
2) After the test, calculate all data and record the average $\mu$ and the standard deviation $\sigma$. If the proportion of the measured value within a distance of $3\sigma$ exceeds 95%, the smart sensor is deemed
to have passed the stability evaluation, otherwise it is deemed to be failed.

The criterion for passing the stability assessment is shown in Figure 5.

Figure 5. Data stability evaluation test criteria

3.4. Data reliability

1) Adjusted the smart sensor to the normal working mode, and then place in temperature humidity test chamber for 1 hour (the temperature is kept at 20°C, and the relative humidity is kept at 45%RH).

2) During the entire temperature and humidity experiment, the background noise test value of the smart sensor is called regularly (every 10 seconds) by the host computer. After the test all data are calculated to find the average value. If the error between each measurement value and the average value is within 10%, the smart sensor is deemed to have passed the reliability test, otherwise it is deemed to be failed.

3) Perform electromagnetic compatibility test on smart sensors (taking the electrostatic discharge immunity test as an example). Before the test, the surface of the sensor needs to be fully and quickly discharged at a rate of 20 times per second to roughly explore specific locations where the sensor’s sensitivity is low. After the start of the test, conduct a single discharge for each confirmed point, and conduct more than 10 experiments.

4) During the entire EMC test process, the background noise test value of the smart sensor is called regularly (every 10 seconds) by the host computer. After the test all data are calculated to find the average value. If the error between each measurement value and the average value is within 10%, the smart sensor is deemed to have passed the reliability test, otherwise it is deemed to be failed.

3.5. Battery lifetime

1) Lead the measurement wire from the battery pack of the smart sensor into the digital power meter.

2) Modulate the smart sensor in the normal working mode for 15 minutes, and measure the power of the smart sensor in the normal working mode. The average power within 15 minutes is used as the normal working power value of the smart sensor.

3) Modulate the smart sensor in the sleep mode for 15 minutes, and measure the power of the smart sensor in the sleep mode. The average power within 15 minutes is used as the sleep mode power value of the smart sensor.

4) Calculate the total battery capacity. Modulate the smart sensor in the normal working mode and perform the continuous aging test of the total battery capacity. The average power of the previous 15 minutes is used as the reference (P_{ave}). When the real-time power displayed by the digital power meter is lower than the 3dB attenuation range of P_{ave}, record the time at this time and record it as tm. Calculate the instantaneous power curve from 0 to tm. The envelope area of the time axis is the total battery capacity value, record it as W_b.

5) According to the working and sleeping time period of the smart sensor provided by the manufacturer, suppose it is T, and calculating the total power consumption in each time period T by the working and sleeping power values, record it as W_h.

6) The battery lifetime can be calculated by the following formula:
\[ y = \frac{W_b}{W_h \cdot T} \]

Figure 7 shows an example of a data test chart for battery lifetime evaluation.

![Figure 6. Test loop for battery lifetime evaluation](image)

4. **Host computer software design**

The core purpose of the host computer software is to cooperate with the hardware platform to simplify the calibration process, reduce personnel operations, and improve the accuracy of sensor evaluation. Therefore, the overall design of the software should be as clear as possible, and intuitively displays key data such as verification items, parameter settings, and test results.

The software overall function distribution block diagram is shown as in Figure 8.
5. Conclusion
Discussed the technical requirements of the power grid access test for TEV partial discharge smart sensors, and proposed a set of TEV partial discharge smart sensor calibration system based on LaView, which uses the host computer to control the calibration platform to complete the automatic calibration. Reduced the repetition of personnel operations during the verification process, and improved the verification efficiency.

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