Interference analysis and suppression technology of converter transformer partial discharge test based on field measurement

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Abstract. The field PD test of converter transformer is more difficult than that of common AC transformer. The most important difference is that the interference source in converter station is more complex. This paper measured the interference signals of the converter transformer field PD test in several converter stations, analyzed the characteristics of various typical interference, formulated the targeted interference suppression measures, simulation tests are carried out to verify the effectiveness of the suppression measures. Finally, the field application shows that the interference suppression measures proposed in this paper can effectively improve the efficiency and accuracy of field PD test of converter transformer.

1. Introduction
Converter transformer is one of the most important equipment in DC transmission system. Its operation state is related to the safety and stability of the whole power system. Partial discharge test (PD test for short) is a key field test to check the production process control and field installation quality of the converter transformer.

There are following problems exist in the field test of the converter transformer [1-2]. The background interference amplitude is very large (up to thousands of PC) and the component of interference is more complex than that of AC substation when all or part of the convert station is electrified [3-4]. This brings great difficulty to the calibration of standard pulse and PD measurement, which leads to the inefficiency of PD test and the difficulty in judging the test result.

In this paper, the background interference measurement is carried out in ±500kV convert station, ±800kV convert station and flexible direct converter station. The amplitude, frequency and phase characteristics of various interference in the PD test are analyzed. The interference suppression measures are put forward and the effectiveness is verified.

2. Measurement of interference in PD test

2.1. Measurement scheme
There are many kinds of interference in the field PD test, this paper divides these interference signals into two categories: ground signal and space signal according to the different transmission ways of the interference signal. Detailed measurement methods, instruments are shown in Table 1 and Fig. 1.
Table 1. Measurement scheme for interference signal.

| signal through the ground | spatial communication |
|---------------------------|-----------------------|
| measuring method          | Pulse current detection method | Broadband antenna method |
| Measuring instrument      | Wide band current transformer (10kHz-30MHz), Pulse calibration generator (1pC–2000pC) | Broadband antenna (0-030MHz), UHF antenna (0-6GHz) |
| Measuring position        | Neutral grounding of Operation transformer | around the operation converter transformer, valve hall and the tested converter transformer |

Figure 1. Measurement instrument for interference signal

2.2. Ground interference signals measurement

Taking a ±800kV convert station as an example, there are 8 measuring points for ground signals measurement. The layout of converter station and the location of each measuring point are shown in Fig. 2. Taken point 1 as a representative, the detailed waveform of the measured signal is shown in Fig. 3 (1 is time domain diagram, 2 is expansion diagram, 3 is frequency domain diagram, 4 is statistical diagram).

Figure 2. Location of each measuring point.
The amplitude frequency characteristics of interference signals at each measuring point are summarized in Table 2.

| point | relative PD value | frequency characteristic          |
|-------|------------------|----------------------------------|
| 1     | 256519.5pC       | 50kHz-150 kHz, peak: 97kHz        |
| 2     | 311384.2pC       | 40kHz-155 kHz, peak: 106kHz      |
| 3     | 128651.8pC       | 30kHz-191 kHz, peak: 84kHz       |
| 4     | 103513.6pC       | 50kHz-170 kHz, peak: 78kHz       |
| 5     | 287724.6pC       | 45kHz-160 kHz, peak: 83kHz       |
| 6     | 305257.8pC       | 30kHz-135 kHz, peak: 98kHz       |
| 7     | 122736.9pC       | 58kHz-160 kHz, peak: 82kHz       |
| 8     | 131187.1pC       | 30kHz-145 kHz, peak: 76kHz       |

According to the analysis of signal waveform measured at each measuring point, the signals transmitted through the ground have the following characteristic:

1) The main component of the interference signal is pulse interference. The closer to the valve hall, the stronger the pulse interference signal.

2) The frequency band of interference signal is concentrated in 30kHz-180kHz, and the peak frequency is about 100kHz.

3) The phase of interference signal is fixed, and the phase interval of each pulse is basically the same.

2.3. Space interference signals measurement
Taking a ±800kV convert station as an example, there are 38 measuring points for ground signals measurement. The layout of converter station and the location of each measuring point are shown in Fig. 4. The waveform of typical measuring points is shown in Fig.5.
According to the analysis of signal waveform measured at each measuring point, the signals transmitted through the space have the following characteristic:

1) There are various types of space interference signals, including 10kHz-200kHz interference radiated by valve hall, 20mHz-30mHz interference generated by radio wave (broadcast), 70Mhz-90Mhz interference generated by corona and interference generated by radio (mobile phone communication).

2) The signal intensity of space radiation of 10kHz-200kHz is stronger when it is closer to the valve hall, while the signal intensity of radio wave is basically the same at all positions.

3. Analysis of typical interference in PD test

According to a large number of field measured data, it is found that the main interference in PD test under the condition of electrified converter station are pulse interference, space stray interference and ground current interference.
3.1. Pulse interference
Pulse interference is the most typical interference signal in HVDC transmission system, which is 12-puls in ±800kV DC system and 6-puls in ±500kV DC system. The waveform and expansion of pulse interference are shown in Fig. 6. The characteristics of pulse interference are as follows:

1) The phase of the pulse signal is fixed, the phase interval between two signal is basically equal, and the pulse width is about 1°.
2) The amplitude of each pulse is different, and the amplitude of single pulse is stable relatively.
3) The expansion waveform of the pulse signal is like jujube nucleus. The time from head to tail is about 60us, and the positive and negative polarity of each pulse are different.
4) The frequency band of the pulse signal is 30kHz-180kHz, the peak frequency is about 100kHz.
5) The time-domain waveform and frequency band of the pulse signal are slightly different at each measurement point because of the different transmission path. The amplitude of pulse signal is smaller at the measurement which far from the valve hall.

![Figure 6. Waveform and expansion of pulse interference.](image)

3.2. Space interference
The waveform and fingerprint of typical space interference are shown in Fig. 7. The characteristics of space interference are as follows:

1) There are many frequency band interference in converter station space, mainly 10khz-1000khz interference radiated from valve hall, 1500khz-2500khz interference generated by corona, and fixed frequency interference generated by radio.
2) The interference of 10kHz-1000kHz is stronger when it is closer to the valve hall. The corona interference of 1500khz-2500khz is stronger when it is closer to the AC field. The interference generated by radio is basically the same in signal strength, pulse waveform and frequency at all positions, but the phase is not fixed, and the pulse appears randomly.

![Figure 7. Waveform and expansion of space interference.](image)

3.3. Ground current interference
The waveform and expansion of typical ground current interference are shown in Fig. 8. The characteristics of ground current interference are as follows:
1) The ground current interference is a burst pulse generally, and the amplitude of the pulse varies greatly. 
2) The phase of ground current interference is unfixed. The pulse appears randomly, and there will be interference pulse at 0°-360°. 
3) The slope of the rising edge of the earth current interference is relatively large, the oscillation period is less, and the phase width is relatively narrow (about 0.3°). 
4) The frequency band of ground current interference signal is mainly concentrated in 10kHz-100kHz, the peak frequency is about 50kHz, and the high frequency signal is less. 
5) The waveform characteristics and frequency domain characteristics of ground current interference are different at different measuring points due to the influence of transmission characteristics.

4. Interference suppression technology
This paper proposes targeted suppression techniques based on characteristics analysis of the above three typical interference.

4.1. impulse interference
In view of the impulse interference, manual window opening is generally used in the field PD test, but it needs rich experience, and some signals are selected in the window while some signals are lost. The coupling polarity method is used to eliminate the impulse interference in this paper. The principle is shown in the Fig. 9.

Through the phase-shifting circuit and the signal conditioning circuit, the pulse signal is modulated into a signal with the same phase, the same amplitude and the opposite polarity as the pulse interference signal in the measured signal. In the signal coupling circuit, the pulse interference signal in the measured signal is offset and the real partial discharge signal is output. The coupling polarity method can filter...
out the impulse interference accurately without affecting the real PD signal and ensure the measurement accuracy.

4.2. space interference
At present, the antenna gating technology is generally used to eliminate the fixed phase space interference, but the antenna gating technology may eliminate the real PD signal, resulting in inaccurate measurement. There is no good way to deal with the spatial interference of the unfixed phase.

Wavelet technology is used to eliminate space interference in this paper. Wavelet technology can eliminate different interference signals in different time windows. It can retain most of the characteristics of PD signals and solve the sudden external random interference [5]. Wavelet transform includes wavelet decomposition and wavelet reconstruction as shown in Fig. 10.

According to the field measurement, space interference is higher in high frequency band, while the real PD signal is higher in low frequency band. DB2 wavelet is optimized in this paper, and threshold mode synthesis method and intelligent matching method are used to retain more low-frequency information and filter out high-frequency information.

4.3. Ground current interference
In view of ground current interference signal has narrow frequency range (up to 1MHz) while the real PD signal has wide frequency range (up to tens of MHz), this paper adopts the interference elimination method combining the FIR (finite impulse response) digital filter and FFT (fast Fourier transform) spectrum analysis. the FIR is used for the interference signal which frequency range does not overlap with the real PD signal, the FFT is used for the signal which frequency is fixed and single [6].

4.3.1. FIR digital filtering. The key of FIR digital filter is to obtain the unit impulse response of ideal filter by inverse Fourier transform.

\[
h_d(n) = \frac{1}{2\pi} \int_{-\pi}^{\pi} e^{j\omega n} d\omega = \frac{\sin[\omega_d(n-n_d)]}{\pi(n-n_d)}
\]  

(1)

According to the measured frequency characteristics of ground current interference, this paper adopts the combination of digital filtering and hardware filtering of the instrument itself, which makes it more flexible to set the frequency bands of different interference sources, and the filtering effect is more obvious.

4.3.2. FFT spectrum analysis. The original data collected by the system is transformed into discrete spectrum signal by Fourier transform, the interference signal is cleared in frequency domain, and then it is recreated by inverse Fourier transform. The time domain waveform after FFT spectrum analysis is the effective waveform of PD signal.
According to the actual situation of PD test site, this paper increases the frequency cancellation points to 9 (original maximum 3), which can more effectively deal with the situation of multiple fixed frequency interference sources.

5. Validation of interference suppression technology
The above methods were applied in a PD measuring apparatus, and an experiment platform was set up in the laboratory to carry out experiments to verify the effectiveness.

5.1. impulse interference
The PD of insulating paper and the suspended discharge in oil are generated by a transformer discharge simulation platform, and the impulse interference is generated by the rectifier unit. Using the coupling polarity technology to eliminate interference. As can be seen from Fig. 12 and Fig. 13, the coupling polarity method can well eliminate the impulse interference in the discharge signal (Interference in red frame).

\[ f'(t) = \frac{1}{2\pi} \int_{-\pi}^{\pi} e^{-ixa} f(t) dt \]  
(2)

\[ f(t) = \frac{1}{2\pi} \int_{-\pi}^{\pi} e^{ixa} f'(t) dt \]  
(3)

Figure 11. Experiment for validation of coupled polarity method.

Figure 12. Eliminating the interference in insulating paper PD signal.

Figure 13. Eliminating the interference in suspended discharge in oil.

5.2. space interference
PD of insulating paper and surface discharge in oil are produced by oil paper discharge device, space interference is produced by radio interference source. Using wavelet technology to eliminate interference. As can be seen from Fig. 15 and Fig. 16 that wavelet technology can well eliminate the space interference in the discharge signal (Interference in red frame).
Figure 14. Experiment for validation of Wavelet method.

Figure 15. Eliminating the interference in insulating paper PD signal.

Figure 16. Eliminating the interference in surface discharge in oil.

5.3. Ground current interference
The suspended discharge and the surface discharge in oil are generated by the transformer discharge simulation platform. The ground current interference is generated by the interference source. Combining FIR digital filter with FFT spectrum analysis to eliminate interference. As can be seen from Fig. 18 and Fig. 19 that FIR and FFT technology can well eliminate the ground current interference in the discharge signal.

Figure 17. Experiment for validation of FIR and FFT.

Figure 18. Eliminating the ground current interference in suspended discharge in oil.
Figure 19. Eliminating the ground current interference in surface discharge in oil.

6. Conclusion
A new PD instrument developed based in the above interference suppression methods was used to carry out the field PD test in ±800kV Xindong DC and ±500kV Luxi flexible project. The results show that methods and instrument can improve the accuracy and efficiency of PD test effectively.

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