Evaluation Research on "Anti-Electromagnetic Interference Performance" of Partial Discharge Detection Device in Complicated Strong Electromagnetic Interference Environment

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Abstract. In a strong electromagnetic environment, most of the current anti-interference methods for partial discharge signals of electronic transformers use digital notch filter, which has poor adaptability and stability. This article studies the source of interference and its impact on partial discharge detection, and has accumulated a relatively complete partial discharge sample database. On this basis, a high-performance arbitrary waveform generator is proposed to restore typical partial discharges, and a platform for quantitatively evaluating the anti-electromagnetic interference capability of partial discharge UHF detection devices through interference simulation is established. Experimental results show that the proposed method has high anti-interference performance.

Key words: Complex and strong electromagnetic environment, transformer partial discharge signal, anti-interference, electronic transformer.

1. Introduction
Partial discharge detection has become the most important technical method among the current state detection technologies. The State Grid Corporation has issued technical standards for high-frequency partial discharge detection equipment, and various provincial companies have established this high-frequency the inspection and comparison platform of partial discharge live detection instruments has preliminary inspection and comparison capabilities for sensor transmission impedance, detection frequency band, stability and other items. However, the existing standards have not given effective quantitative evaluation methods and means for the verification of partial discharge pattern recognition and anti-interference ability. For partial discharge detection, the anti-interference ability and pattern recognition ability of the detection device is very important. It is the key technology and difficulty to measure the ability of partial discharge detection and diagnosis. The performance of most detection instruments is far from meeting the needs of field testing. For example, pattern recognition is mainly to generate analog discharge signals through a typical partial discharge model pressurization method. This partial discharge simulation method has poor controllability and is very unstable. It cannot meet the consistency and comparability of device performance verification, and it is difficult to effectively carry
out discharge. Quantitative evaluation of type recognition accuracy [1]. As the biggest technical bottleneck in partial discharge detection, the "anti-electromagnetic interference performance" of partial discharge detection devices in a complex and strong electromagnetic interference environment is still in the stage of blank detection methods. The above-mentioned problems have restricted the in-depth development of the live detection business in the intelligent transportation inspection system.

To sum up, this project will analyse and study the characteristics and laws of abnormal data caused by electromagnetic field interference, leakage current induction, electrical equipment operation interference, power system high-order harmonic interference, mechanical interference, etc [2]. Through experiments and simulation methods, and propose corresponding the abnormal data identification and processing methods. Study different types of discharge partial discharge signals, typical interference signal simulation methods, and partial discharge detector pattern recognition capabilities and anti-interference performance verification methods, and realize the mode of diagnostic UHF, high frequency, ultrasonic, TEV partial discharge detection devices Recognition ability and anti-interference ability verification; research on-site verification technology of ultra-high frequency partial discharge on-line monitoring sensor, research sensor sensitivity verification method and sensor layout rationality evaluation method.

2. Construct partial discharge signal of electronic transformer

2.1. Experimental circuit and pressurization method

The schematic diagram of the experimental loop is shown in Figure 1. T1, T2, T3 are auto-voltage regulators, isolation transformers, and corona-free test transformers respectively, C is a coupling capacitor, which is used to couple the pulse current signal generated during the discharge of a typical partial discharge model, and Z is the detection impedance [3]. The detection system collects UHF, high frequency, ultrasonic, TEV signals. Firstly, the voltage is increased to the typical defect model and the partial discharge phenomenon begins to appear, analyse and save the data at this stage; then gradually increase the pressure until the sample breakdown or flashover occurs, and record the breakdown or flashover voltage of the sample; at the beginning of the partial discharge The voltage is gradually increased between the voltage and the breakdown voltage until a significant change in the statistical spectrum of the partial discharge is observed, and the detection system begins to save the waveform data.

![Figure 1. Schematic diagram of experimental loop](image)

2.2. Partial discharge signal

A large number of studies have shown that the partial discharge pulses of electronic transformers are exponential decay type or exponential decay oscillation type [4]. Assuming that the discharge voltage of the electronic transformer is represented by V, the pulse amplitude is described by F, the position of the pulse peak is represented by $t_0$, $t$ is the instant time, the constant is $\tau$, $\omega_0$, and 50kHz, then the single pulse of the electronic transformer can be described as follows: form
According to the antenna reciprocity theorem, the same antenna can be used as a receiving antenna or a transmitting antenna, and the basic characteristic parameters of the same antenna as transmitting or receiving are the same, that is, the transfer function $h(\theta, \omega)$ is unchanged [5]. In the experiment, assuming that the direction angles of the collected signal and the transmitted signal are fixed, the transfer function of the sensor is a constant value, ignoring the error, assuming that the transfer function of the UHF sensor used in the experiment is $H$, the signal reconstruction process is shown in the figure 2 shown.

![Figure 2. Signal reconstruction process](image)

In Figure 2, the UHF the sensor is used as a transmitting antenna and will generate an electromagnetic field with an electric field strength of $E_i$. The electromagnetic field generated by the partial discharge source is $E_0$, $H$ is the transfer function of the UHF sensor used to collect data, $U_i$ is the partial discharge voltage waveform stored in the oscilloscope, and the partial discharge voltage waveform $U_i$ is re-outputted by the arbitrary waveform generator (AWG). The output waveform is $U_2$, radiated by the UHF sensor, the electromagnetic field generated is $E_i$. Assuming that the transfer functions of the same type of UHF sensor $UHF_1$ and $UHF_2$ are equal, the relationship between $E_0$ and $U_i$ is.

$$E_0(j\omega)H(j\omega) = U_0(j\omega)$$  \hspace{1cm} (3)

3. Partial discharge joint anti-interference technology research

The paper adopts wavelet decomposition processing method, makes full use of the existing various signal spectrum characteristics, and aims at the multi-band interference and partial white noise interference with unknown centre frequency of the field. It realizes adaptive and effective filtering while processing the data in high-speed and real-time [6]. The partial discharge pulse signal can be accurately extracted with a certain threshold. The following takes the actual discharge signal measured in the laboratory as an example to analyse the adaptive interference suppression technology based on wavelet decomposition. Figure 3 is the original signal measured in the laboratory. The signal-to-noise ratio of the signal is SNR=1.25. There are strong narrowband periodic interference and white noise in the signal. The partial discharge pulse signal is basically annihilated in the interference signal and cannot be directly
extracted. The narrow-band interference spectrum is marked in the red box in the figure. Among them, the location and quantity of the centre frequency of narrowband interference are uncertain. Therefore, it is difficult to effectively filter through a filter that determines the centre frequency. The white noise has a wide frequency spectrum and cannot be eliminated by conventional filters.

![Figure 3. The measured signal waveform with noise](image)

The specific implementation steps are as follows:

1. First, perform wavelet decomposition on the digital signal sequence collected by AD.
2. The wavelet coefficients obtained after step (1) decomposition are: low-frequency coefficient $c_{A6}$, high-frequency coefficient $c_{D6}$–$c_{D1}$, and directly calculate the feature quantity of each level of wavelet decomposition coefficients, which are the peak value $V_{p,c_{A6}}$, $V_{p,c_{D6}}$–$V_{p,c_{D1}}$, and other the root mean square value $RMS_{c_{A6}}$, $RMS_{c_{D6}}$–$RMS_{c_{D1}}$. Taking the $c_{A6}$ coefficient as an example, the peak value calculation method of the wavelet decomposition coefficient is:

$$V_{p,c_{A6}} = \text{Max}(c_{A6})$$  \hspace{1cm} (4)

The root mean square value calculation formula is:

$$RMS_{c_{A6}} = \sum_{i=1}^{N} c_{A6}^2(i), i = 1,2,...,N$$  \hspace{1cm} (5)

Where: $N$ is the length of the wavelet coefficient. The white noise has a wide spectrum distribution. A large number of field measurements show that the white noise spectrum distribution is close to the Gaussian distribution, and the ratio of the peak value to the effective value is below 10. In this example, $c_{D6}$ and $c_{D5}$ are the wavelet coefficients of random white noise interference contained in the original signal, and the signal standard deviation to peak ratio is 18% and 27%, as shown in Figure 4.

![Figure 4. Wavelet decomposition coefficient and characteristic distribution of random white noise signal](image)
Partial discharge is a transient pulse signal with a wide frequency spectrum. The ratio of the peak effective value of the wavelet decomposition coefficient is much higher than that of the narrowband interference signal and the white noise signal [7]. The measured results are all above 20, the minimum is 24.9, the maximum is 51.8, and the standard deviation and peak percentage of cD4–cD1 coefficients are 3.4 respectively. %, 4.2%, 1.56% and 1.95%, as shown in Figure 5.

Figure 5. Wavelet decomposition coefficient characteristics of partial discharge signal

Because the partial discharge signal has a short duration of only a few hundred ns, the AD used in this device is 100MS/s high-speed sampling, so if pulse extraction is not performed, it will greatly increase the cost of subsequent processing. The most important information of the partial discharge signal is the original pulse waveform and its phase amplitude. Therefore, the automatic threshold calculation is used here to extract pulse segments for processing. The adaptive threshold is taken as Vth=mean(s)+3σ, where mean(s) is the waveform of the reconstructed signal, and σ is the standard deviation of the reconstructed signal.

4. Conclusion
This paper studies the source of interference and its impact on partial discharge detection, and has accumulated a relatively complete partial discharge sample database. On this basis, a high-performance arbitrary waveform generator is proposed to restore typical partial discharge. A platform has been established to quantitatively evaluate the anti-electromagnetic interference capability of the partial discharge UHF detection device by means of interference simulation. A method for quantitatively evaluating the anti-electromagnetic interference capability of UHF detection devices based on the principle of signal-to-noise ratio is proposed for the first time. After actual testing, the platform has preliminarily verified the feasibility and application effect of evaluating the anti-electromagnetic interference performance of the partial discharge UHF detection device. The evaluation method proposed in this paper is of engineering practical value for filling the gap in the quantitative evaluation of the anti-interference performance of partial discharge detection devices and improving the technical standards for partial discharge state detection.

References
[1] Song, Z., Guo, M., & Wang, Q. A partial discharge detection and localization system for high voltage cable based on long-tailed Sagnac interferometric fiber optic sensor. Microwave and Optical Technology Letters, 59(9) (2017) 2132-2136.
[2] Zhou, H. Y., Ma, G. M., Wang, Y., Qin, W. Q., Jiang, J., Yan, C., & Li, C. R. Optical sensing in condition monitoring of gas insulated apparatus: a review. High Voltage, 4(4) (2019) 259-270.
[3] Zhong, L., Liu, K., Ji, S., Wang, F., Sun, Q., Chen, S., & Liu, J. Effects of voltage forms, pressure,
and adsorbent on the SF6 decomposition characteristics under corona discharge. IET Science, Measurement & Technology, 14(4) (2020) 486-493.

[4] Zhou, F., Zhu, J., An, N., Wang, C., Liu, J., & Long, L. The anti-icing and deicing robot system for electricity transmission line based on external excitation resonant. IEEJ Transactions on Electrical and Electronic Engineering, 15(4) (2020) 593-600.

[5] Wang, R., Wu, Q., Xiong, K., Ji, J., Zhang, H., & Zhai, H. Phase-shifted fiber Bragg grating sensing network and its ultrasonic sensing application. IEEE Sensors Journal, 19(21) (2019) 9790-9797.

[6] Shen, T., Li, B., Dai, X., & Feng, Y. A Temperature Sensor Based on the Graphene-Oxide-Coated Micro-Nano-Fiber Mach–Zehnder Interference Structure. Journal of Russian Laser Research, 41(6) (2020) 638-644.

[7] Zhang, X., Yin, G., & Qi, N. Research on high-resolution improved projection 3D localization algorithm and precision assembly of parts based on virtual reality. Neural Computing and Applications, 31(1) (2019) 103-111.