Original Research Article

Feature extraction and analysis of ultra-high-frequency signals for partial discharges in power transformers

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Abstract: In the power system, the local discharge of electrical signal of power transformer are rich and complex, easy to noise interference, and the traditional analysis method has obvious limitations. To this end, the author innovatively puts forward the time frequency analysis and machine learning technology fusion of local discharge electrical signal diagnosis method, through the short Fourier transform and wavelet transform capture high frequency signal component, reuse support vector machine machine learning methods, greatly improve detection accuracy and reliability, provide scientific basis for power equipment on-line monitoring and fault early warning.

Keywords: Power transformer, local discharge, uHF signal, time-frequency analysis, machine learning

Foreword as a common

In the power system, the partial discharge is a common failure symptom of the power transformer, which seriously threatens the safe and stable operation of the equipment. The traditional detection method relies on low frequency signal analysis, which can be applied in practice, the signal is seriously disturbed by noise, and it is difficult to accurately determine the fault location and type. To this end, the researchers proposed to use UHF signal detection and diagnosis, and also discussed the electrical signal analysis method based on time-frequency analysis and machine learning technology, to help the intelligent detection of power transformers.

1. Overview of local discharge and UHF signals

During the operation of the power system, if the insulation system of the power equipment has local defects, once the electric field strength exceeds the breakdown strength of the insulating medium, the local discharge is very likely to occur[1]. Its generation is closely related to the aging of insulating materials, air gap and filth and has strong randomness. Under high pressure and high frequency operation, it not only interferes with the normal operation of equipment, but also may cause long-term damage. UHF signal is one of the signals generated by local discharge, with a frequency of 300 MHz-3GHz, which is related to the change of medium, temperature and electric field in the discharge of the UHF signal[2]. Due to its spectral characteristics, strong penetration, low attenuation and long-distance transmission, it has become an important means of monitoring and analyzing local discharge.

2. UHF signal feature extraction

2.1. Signal acquisition and pretreatment

When collecting the electromagnetic wave generated by local discharge, the high frequency voltage probe or special sensor is required for accurate measurement. The frequency range of these electromagnetic wave signals is usually between 300 MHz and 3GHz. In order to ensure the accuracy of signal acquisition, the sampling

frequency is generally set to more than twice the signal bandwidth, that is, at least 6GHz, and even a higher sampling rate can be selected according to the actual demand, so as to avoid the phenomenon of signal aliasing. In the complex power equipment environment, the collected original signal is often contain a large amount of noise, and other electromagnetic interference sources are likely to pollute the signal, so the pre-processing link is very important[3]. Usually, band pass filtering is used for preprocessing to remove low frequency and high frequency noise other than the ultra-high frequency signal. In order to further improve the signal quality, high-order FIR or IIR filter is often selected. This kind of filter has excellent frequency selectivity and can effectively filter out interference signals. After that, the fast Fourier transform (FFT) is used to analyze the frequency domain signal, further eliminate the background noise, and make the signal clearer through the spectrum correction method, so as to improve the accuracy of the subsequent analysis[4]. Due to the accuracy of sensor acquisition, ambient temperature change and other factors, the collected signal may also have a waveform distortion problem.

2.2. Time domain and frequency domain characteristics

During the analysis of local emission signals, the statistics of the calculated signals can be used to evaluate the signal intensity and fluctuation. In the normal working state, if the peak of the emitted signal is higher than the signal amplitude, and the variance fluctuates greatly, this indicates that the emission activity occurs. It can also analyze the time characteristics of the local emission with the help of the duration and lifting time of the signal. Because the local discharge usually shows short and violent fluctuations, the signal duration is generally short. In frequency domain feature analysis, fast Fourier transform (FFT) or wavelet transform is commonly used to extract frequency components. UHF signals have specific spectral characteristics and have different energy distributions in different frequency ranges. Analysis zing the frequency domain characteristics the spectral distribution, center frequency and bandwidth[5]. These frequency domain features can not only help identify the frequency characteristics of local discharge, but also help to evaluate the severity of discharge. In a specific frequency band, local discharge often has a strong energy concentration, and the spectrum peak can be used as an important indicator of discharge activity.

2.3. Feature selection and dimension reduction

Feature selection aims to select the most valuable parameters for local discharge identification from the extracted time and frequency domain features[6]. Common methods such as information gain, chi-square test and correlation coefficient analysis can accurately select the characteristics like peak amplitude, such as spectral center frequency, and harmonic component, and screen out the characteristics of not strong or redundant correlation. Feature dimension reduction uses mathematical means to transform high-dimensional feature space into low dimension, retain key information and reduce computational complexity. Principal component analysis reduces noise interference and improves the efficiency of signal processing by extracting principal components[7]. During the operation, the dimension reduction algorithm parameters should be adjusted according to the data characteristics and application requirements to ensure the overhead reduction and leave key information. As shown in **Table 1**:

Table 1. Statistical parameters of ultra-high frequency signal feature extraction.

Feature Type	Feature Name	Value Range	Description
Time Domain	Peak Amplitude	0.5V - 3.5V	Maximum amplitude of the signal, reflecting discharge intensity.
	Mean Value	0.0V - 1.2V	Average voltage value of the signal.
	Variance	0.01 - 0.1 (V^2)	Magnitude of amplitude fluctuations of the signal.
	Duration	2μs - 10μs	Duration of the discharge signal.
Frequency Domain	Center Frequency	500MHz - 1.5GHz	The central frequency of the signal's frequency distribution.
	Bandwidth	10MHz - 500MHz	Spectrum range, reflecting the frequency extension of the signal.
	Harmonic Peak	100MHz - 3GHz	The peak value of harmonic components in the signal.
	Power Spectral Density	-80dB - -50dB	Power distribution in the signal's frequency spectrum.
	Frequency Resolution	0.01MHz - 1MHz	Resolution of the signal's frequency spectrum.

3. Signal analysis and diagnostic techniques

3.1. Time-frequency analysis

Time-frequency analysis plays a critical role in diagnosing local discharge electrical signals, especially in capturing transient changes in signals and frequency components. This analysis method mainly considers the distribution characteristics of signals in the time domain and frequency domain, so as to fully understand the frequency and time changes of the signal[8]. Common time-frequency analysis methods include short-time Fourier transform (STFT) and wavelet transform (WT). When applying the short-time Fourier transform, the signal is first divided into multiple time periods, and then the Fourier transform is performed on each time period, so as to obtain the spectral distribution in each time window, and then the instantaneous frequency characteristics of the signal are obtained, and the sudden frequency component in the local discharge electrical signal is effectively captured[9]. For the complex local discharge electrical signals, the wavelet transform can analyze the frequency changes of the signals of different scales, process the non-stationary signals, capture the rapid changes of the high frequency signals, and extract the relatively mild change characteristics of the low frequency band. As shown in **Figure 1**:

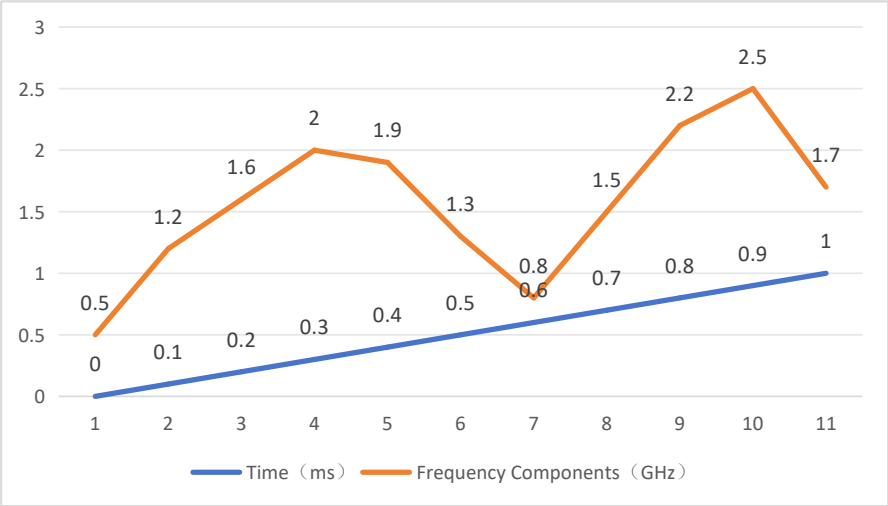

Figure 1. Time and frequency components of the local emission of electrical signals.

3.2. Detection and recognition based on machine learning

The researchers collected a large number of local emission electrical signals, from which the time domain and frequency domain features were extracted, and then used machine learning algorithms to classify and identify the signals. Common algorithms include support vector machine (SVM), random forest (RF), K nearest neighbor (KNN) and so on. After data preprocessing, feature selection and dimension reduction can greatly reduce the data dimension and optimize the computational efficiency[10]. As an effective classification method, SVM improves the optimization of non-linear feature space with high-dimensional kernel function. Facing more complex discharge patterns, the random forest and KNN algorithms further enhance classification capabilities through ensemble learning and instance similarity comparison.

4. Epilogue; peroration

Researchers innovative time-frequency analysis and machine learning technology depth fusion, put forward a method can effectively deal with local electrical signal, successfully solved the traditional method in complex signal analysis accurately accurate signal, low fault accuracy, not only develop new path, also promote the development of power equipment monitoring and early warning technology, provide technical support for the electric power industry intelligent upgrade.

About the author

Zeyu Cui, born in March 2000, is a native of Luliang City, Shanxi Province, with a graduate degree, and his research direction is: transformer partial discharge detection.

References

[1] Rajamayil M ,Basharan V .A novel semi-supervised power transformer defect monitoring technique using unreliable pseudo-labels with highly imbalanced partial discharge signals[J].Electrical Engineering,2024,(prepublish):1-19.

[2] LiuH ,YangT ,ZhangZ , et al.Ultrasonic localization method based on Chan-WLS algorithm for detecting power transformer partial discharge faults by fibre optic F-P sensing array[J].High

Voltage,2024,9(6):1234-1245.

[3] ShangH ,ZhaoZ ,ZhangR , et al.Transformer partial discharge fault diagnosis based on improved adaptive local iterative filtering-bidirectional long short-term memory[J].IET Electric Power Applicatio ns,2024,18(10):1214-1232.

[4] Thobejane T L ,Thango A B .Partial Discharge Source Classification in Power Transformers: A Systematic Literature Review[J].Applied Sciences,2024,14(14):6097-6097.

[5] Shang H ,Zhao Z ,Li J , et al.Partial Discharge Fault Diagnosis in Power Transformers Based on SGMD Approximate Entropy and Optimized BILSTM[J].Entropy,2024,26(7):551-551.

[6] Farzin K ,Hamidreza K ,Zarei M K , et al.Partial discharge localization in power transformer tanks using machine learning methods[J].Scientific Reports,2024,14(1):11785-11785.

[7] Beura P C ,Wolters J ,Tenbohlen S .Application of Pathfinding Algorithms in Partial Discharge Localization in Power Transformers[J].Sensors,2024,24(2):

[8] JangjooA M ,AllahbakhshiM ,MirzaeiR H .Ultra-high frequency sensors positioning on the power transformer to mitigate the negative effects on the partial discharge localization accuracy[J].IET Generation, Transmission & Distribution,2024,18(3):585-595.

[9] S. W S ,H. A G ,A. M A , et al.Design of a compact ultra-high frequency antenna for partial discharge detection in oil immersed power transformers[J].Ain Shams Engineering Journal,2022,13(2):

[10] Akbari M A ,Mohamadreza A ,Peter W , et al.Optimal frequency selection for detection of partial discharges in power transformers using the UHF measurement technique[J].Measurement,2021,172