Postprint: Partial Discharge Identification Method for Three-Phase Common-Tank GIS Based on Power-Frequency Synchronous Signal

Authors: Guo Xu, Mu Jiqing, Wang Qingjun, YONG Mingchao, Wang Weijie, Mao Lina

Date: 2019-03-05T00:00:00+00:00

Abstract

Power frequency phase constitutes an important foundation for pattern recognition in partial discharge monitoring. Currently, the recognition rate of partial discharge types in GIS partial discharge monitoring equipment is relatively low, with this problem being more pronounced in three-phase common-tank GIS. To address this phenomenon, a partial discharge recognition method for three-phase common-tank GIS based on power frequency synchronization signals is proposed. Without altering the existing power frequency synchronization signal access, this method triggers the acquisition of partial discharge signals via the power frequency synchronization signal, converts them into partial discharge data of other phases through phase-shifting factors, compares them respectively with the partial discharge type database in the system, and outputs the type with the highest recognition rate, thereby achieving the purpose of pattern recognition. The proposed scheme is simple to implement, featuring flexible application and high fault type recognition rate.

Full Text

A Partial Discharge Recognition Method for Three-Phase Cylindrical GIS Based on Power Frequency Synchronization Signals

Guo Xu[1], Mu Jiqing[1], Wang Qingjun[2], Yong Mingchao[1], Wang Weijie[1], Mao Lina[1] [1] XJ Group Co., Ltd., Xuchang 461000, China
[2] State Grid Anhui Electric Power Research Institute, Hefei 230000, China

Abstract: Power frequency phase serves as a critical foundation for pattern recognition in partial discharge (PD) monitoring. Current PD monitoring equipment exhibits low recognition accuracy for discharge types, with this problem becoming particularly pronounced in three-phase cylindrical GIS. To address this issue, this paper proposes a PD recognition method for three-phase cylindrical GIS based on power frequency synchronization signals. Without altering the existing power frequency synchronization signal access, the method triggers PD signal acquisition using the synchronization signal and converts it into other-phase PD data through phase-shift factors. Each phase is then compared against the system' s PD type database, outputting the type with the highest recognition rate to achieve pattern recognition. The proposed scheme is simple to implement, offering flexibility in application and high fault type recognition accuracy.

Keywords: Partial discharge monitoring; Power frequency synchronization; Pattern recognition; Three-phase cylindrical GIS; High voltage equipment

1 Introduction

Partial discharge monitoring represents a crucial technology for intelligent condition monitoring of high-voltage equipment, enabling timely detection of insulation problems during equipment operation. This capability provides essential data and references for power system optimization and condition-based maintenance, thereby reducing losses from both fault-induced and maintenance-related outages. When partial discharge occurs in high-voltage switchgear, the PD signal exhibits strong correlation with the power frequency phase of equipment operation—a characteristic that forms the basis for identifying different discharge types such as floating discharge, gap discharge, surface discharge, metal tip discharge, and particle discharge in GIS equipment.

Current PD monitoring devices relying on power frequency synchronous phase identification suffer from several problems: (1) Voltage signals accessed from the secondary side of voltage transformers generate standard square wave signals that trigger simultaneous sampling across all acquisition channels. While effective in laboratory settings, this method often leads to phase misalignment between the synchronous signal and sensor acquisition phase in practical applications, causing PD signal phase deviation and resulting in low recognition rates. (2) Introducing 220V AC voltage signals from the device' s AC power supply through a transmitter to the high-speed acquisition card works for single-phase GIS but fails for three-phase cylindrical GIS—accurate identification only occurs when the synchronous phase matches the monitored phase, while discharges in the other two phases yield incorrect judgments. (3) Internal synchronous triggering, where the device generates its own fixed 50Hz synchronization signal, suffers from inherent crystal oscillator drift that causes synchronization signal offset over time, further reducing PD recognition accuracy.

To overcome these limitations, this paper proposes a PD recognition method for three-phase cylindrical GIS based on power frequency synchronization signals. The approach utilizes peripheral circuits to generate synchronization signals for triggered acquisition, with signal generation involving conversion through voltage transformer secondary terminals into standard square waves [Figure 1: see original paper].

---

2 Data Acquisition and Processing Based on Synchronization Signals

The data processing module receives raw PD data. Taking phase A as the reference, raw data is stored in the corresponding memory as Pa = {Da , Da , Da , ···, Da }. According to phase correction factors, proportional phase-shifting operations are performed on the data, which is then stored in the respective phase memory. The correction factors for phases B and C are given by:

!” = ±Φ_bc / (360°/n)

where Φ_bc represents the phase displacement of phase B or C relative to phase A, and n is the number of data points sampled per cycle by the PD acquisition card.

Based on these correction factors, the three-phase raw data can be obtained as:

Pa = {Da , Da , Da , ···, Da }
Pb = {Db , Db , Db , ···, Db }
Pc = {Dc , Dc , Dc , ···, Dc }

The specific generation process is illustrated in [Figure 2: see original paper]. Statistics are collected over 50 cycles with amplitude normalization, with each cycle comprising 640 data points, generating a 50×640 two-dimensional array. Discharge counts are statistically analyzed across 50 cycles, and based on phase, amplitude, and discharge frequency, three-phase PRPS (Phase-Resolved Pulse Sequence) 3D spectra are obtained for phases A, B, and C. These are then converted into PRPD (Phase-Resolved Partial Discharge) spectra, N-P spectra, and Q-P spectra. Feature vector extraction is performed on each spectrum, with 22 features selected after optimization [9-10], as listed in .

---

3 Feature Extraction and Recognition of Partial Discharge Signals

3.1 Grayscale Image Features

To extract relevant features, PRPD spectra are converted into 64×100 pixel grayscale images, where 64 represents the amplitude range, 100 represents the phase range, and the grayscale value at each point indicates discharge frequency. Fractal features of PD grayscale images include the fractal dimension of both the original and high-value grayscale images, plus the second-order generalized dimension of the original image. The high-value grayscale image is obtained through:

I (i, j) = I (i, j) if I (i, j) L , otherwise 0

where I (i, j) is the original PD image and L = g__min + ḡ/2, with g__min and ḡ representing the minimum and average grayscale values of I (i, j), respectively.

The fractal dimensions of I (i, j) and I (i, j) are FD , (2 FD 3), with normalized values f , = FD , - 2.

The (p+q)-order origin moment of image region R is:

m__pq = Σ__(x,y R) x^p y^q f(x, y)

Treating the discrete function f(x, y) as a grayscale image, the 0th-order moment serves as the denominator for normalizing the 1st-order moment, yielding the vertical coordinate of the grayscale centroid:

f = m / m

The (p+q)-order central moment of digital image region R is:

__pq = Σ__(x,y R) (x - x̄)^p (y - ȳ)^q f(x, y)

Central moments reflect how image grayscale distributes relative to its centroid. The second-order central moments and exhibit significant physical properties, reflecting the principal axis direction of PD images:

f = / (+)

3.2 N-P Features

N-P features reflect PD frequency bands without considering discharge intensity. Extraction involves accumulating and normalizing 3D discharge data to better reflect PD patterns for model identification. Accumulating each j-coordinate value in the prpd array yields the N-P spectrum:

NP[k] = Σ__j prpd[j][k]

where m is the normalized discharge intensity value. Discharge concentration represents the ratio of discharge pulses within a statistical phase domain:

f = Σ__(k=0)^(n/2-1) NP[k] / Σ__(k=0)^(n-1) NP[k]

For convenience, the discharge phase is divided into 100 equal intervals.

3.3 Q-P Features

Q-P spectra data, derived from the prpd array, focus on discharge intensity rather than frequency. Each element of the Q-P array represents the maximum value at each phase coordinate:

QP[k] = max__j(prpd[j][k])

Based on the Q-P array, features such as positive half-cycle discharge intensity kurtosis and skewness can be statistically obtained.

3.4 Pattern Recognition

This paper employs Pearson correlation coefficient method for PD signal pattern recognition. Pearson correlation essentially calculates the correlation between PD spectrum feature vectors and sample library features. The correlation coefficient is expressed as:

_X,Y = E[(X - E[X])(Y - E[Y])] / (_X _Y)

where X represents the feature vector of the PD signal to be identified, and Y represents the feature vector in the sample library. When the standard deviations of both variables are non-zero, correlation strength increases as the absolute value approaches 1 and weakens as it approaches 0.

---

4 Partial Discharge Signal Acquisition and Simulation

To verify the recognition rate, a GIS discharge model experimental apparatus was constructed, as shown in [Figure 3: see original paper]. Using this apparatus, different types of PD samples were collected and displayed in [Figure 4: see original paper] through [Figure 7: see original paper], with discharge sample features extracted and saved to the device database.

The samples reveal that: tip discharge concentrates near the negative peak of voltage phase (high-voltage tip) with high intensity; particle discharge shows irregular timing and intervals without obvious polarity effects, distributing across the entire power frequency cycle; gap discharge appears in two clusters within quadrants I and III with relatively uniform amplitude; suspension discharge exhibits large, concentrated amplitudes with occasional small signals above and below.

To verify cases where the discharge phase and synchronization signal are inconsistent, the experimental apparatus synchronization signal was aligned with phase A power supply while using phase C for voltage boosting. Collected raw data underwent Pearson correlation calculation with standard spectrum features from the sample library using Matlab simulation. Results demonstrate that PD types can still be identified through correlation coefficients even when synchronization and discharge phases mismatch during data acquisition, as shown in [Figure 8: see original paper].

---

5 System Application

The proposed PD monitoring system primarily consists of sensors, data acquisition units, data processing units, and communication modules [Figure 9: see original paper]. UHF antennas installed on equipment detect PD signals generated by internal defects or faults in high-voltage switchgear. The high-speed acquisition card module employs band-pass filtering, low-noise amplification, envelope detection, AD sampling, and digital denoising [11]. Processed digital signals are sent to the data analysis module for feature extraction, pattern recognition, and early warning processing, with results uploaded to the substation network via DL/T 860 protocol [12-13].

The hardware architecture matches existing PD monitoring devices, including sensors installed on three-phase cylindrical GIS equipment, peripheral circuits generating power frequency synchronization signals, and PD processing units. The data processing module performs amplitude normalization, discharge count calculation, PRPD/N-P/Q-P spectrum generation, feature vector extraction, and discharge type identification. Laboratory testing of 100 discharge type groups yielded the recognition rates shown in .

A high-voltage switchgear company in Xiamen applied this recognition algorithm in their 110kV intelligent GIS during grid connection testing, passing certification at Xi' an High Voltage Apparatus Research Institute. Tests on a 110kV three-phase cylindrical GIS with an internal tip discharge model successfully captured discharges matching the tip discharge sample pattern [Figure 10: see original paper].

---

6 Conclusion

In high-voltage switchgear PD monitoring, particularly for three-phase cylindrical GIS at voltage levels above 110kV, pattern recognition of PD signals has remained a challenging engineering problem. This paper proposes a recognition method for three-phase cylindrical GIS based on power frequency synchronization signals that maintains existing system architecture while applying phase correction factors to raw sampling data. By extracting features from different spectra and outputting the type with maximum Pearson correlation coefficient, the method achieves effective pattern recognition. This approach is applicable not only to three-phase cylindrical GIS but also to three-phase separated GIS through targeted phase correction based on sensor installation positions. Practical engineering applications demonstrate that this method offers flexibility, simplicity, and high recognition rates, effectively improving PD type identification accuracy.

References

[1] Lu Guanghui, Yong Mingchao, Wang Xingang, et al. A synchronous reference correction method based on SV sampling in partial discharge monitoring[J]. Electrical Measurement & Instrumentation, 2016, 17: 118-123.

[2] Qi Bo, Li Chengrong, Geng Bibo, et al. Severity diagnosis and assessment of the partial discharge provoked by high-voltage electrode defect on GIS insulator surface[J]. High Voltage Engineering, 2011, 37(7): 1719-1727.

[3] Shang Haikun. Research on feature extraction and pattern recognition methods for partial discharge signals in power transformers[D]. Beijing: North China Electric Power University, 2014.

[4] Xia Yunyong, Xu Tao, Xu Jian. UHF-based online monitoring system for GIS partial discharge[J]. East China Electric Power, 2014, 42(8): 1729-1732.

[5] Zhang Tianchen, Hu Yue, Li Qing, et al. Combined ultrasonic and electrical detection system for GIS partial discharge based on virtual instrument[J]. High Voltage Apparatus, 2012, 48(11): 43-49.

[6] Chen Yu, Cheng Yonghong, Xu Xiaowei, et al. Development of 100 MHz intelligent unit for partial discharge on-line monitoring[J]. High Voltage Engineering, 2008, 34(11): 2368-2373.

[7] Li Xin, Li Chengrong, Ding Lijian, et al. Identification of PD patterns in gas insulated switchgear(GIS)based on UHF signals[J]. High Voltage Engineering, 2003, 29(11): 26-30.

[8] Zhou Sha, Jing Liang. Pattern recognition of partial discharge based on moment features and probabilistic neural network[J]. Power System Protection and Control, 2016, 44(3): 98-102.

[9] Yuan Jinsha, Shang Haikun, Wang Yu, et al. Pattern recognition for partial discharge based on correlation coefficient matrix and probabilistic neural networks[J]. Power System Protection and Control, 2013, 41(13): 110-115.

[10] Tan Xiangyu, Huang Ran, Liu Hongwen, et al. Analysis of phase synchronization influence on partial discharge PRPD spectrum[C]. Proceedings of the 2012 CSEE Annual Conference, 2012: 1-5.

[11] Yang Jianguo, Liu Zhenwei. Strong high-voltage electrical equipment partial discharge on-line monitoring technology research[J]. Guide of Sci-tech Magazine, 2011(30): 199-251.

[12] Wang Caixiong, Tang Zhiguo, Chang Wenzhi, et al. A method for multi-source partial discharge signals separation[J]. Proceedings of the CSEE, 2013, 33(13): 212-219.

[13] Guo Xiaoxia, Wu Guangning, Zhou Kai, et al. Phase distribution characteristic of partial discharge under square pulse voltage[J]. High Voltage Apparatus, 2008, 44(6): 505-508.