Communication in Physical Sciences, 2026, 13(1): 163-173

Identification of Internal, Corona, and Surface Discharges in Electrical Insulation Through their Characteristics: A Case Study in Norfolk

Emmanuel Acquah

Received: 18 October 2025/Accepted: 23 January 2026 /Published: 30 January 2026
https://dx.doi.org/10.4314/cps.v13i1.13

Abstract: *This study presents a case investigation of partial discharge behavior in high-voltage insulation systems within the Norfolk electrical distribution network, emphasizing defect classification using statistical descriptors. Internal, surface, and corona discharge indicate the discharges upon application of high-voltage stress. Partial discharges (PD), including internal, surface, and corona discharges, occur in electrical insulation systems subjected to high-voltage stress and are critical indicators of insulation degradation. In this work, an integrated hardware–software system was developed to acquire partial discharge signals and automatically identify the corresponding defect type. A MATLAB-based Hardware and software system will be used to achieve this goal. Corona, internal, and surface discharge analysis of electrical insulation helps us to know the integrity of the electrical system. The following parameters, such as charge magnitude and phase angle, will be investigated and interpreted. In this work, we are keen on identifying and knowing the characteristics of partial, internal, and surface discharge by resolving it in charge magnitude and phase domain using skewness and kurtosis to distinguish them. To carry out this identification process, a technique for acquiring Partial Discharge with high sensitivity was developed. The results demonstrate that internal, surface, and corona discharges can be reliably distinguished using statistical parameters such as skewness and kurtosis in the charge–phase domain.*

Keywords: *High voltage stress, Partial Discharge, Corona Discharge, Surface discharge and internal discharge, Skewness, Kurtosis*

Emmanuel Acquah
Electronics Engineering Department, Norfolk State University, Norfolk, Virginia, United States
Email: e.acquah122756@spartans.nsu.edu
https://orcid.org/0009-0005-0848-5924

1. 0 Introduction

Partial discharge (PD) characteristics provide essential information regarding the type and severity of defects present in electrical insulation systems. PD activity serves as an early warning indicator of insulation degradation and impending failure. Accurate identification of PD types is therefore fundamental for condition monitoring and reliability assessment of high-voltage equipment.

A partial discharge (PD) is an electrical discharge that only partially bridges the insulation between conductors. PD is a phenomenon that may or may not occur adjacent to a conductor. Partial discharges are classified as internal, surface and corona. Internal discharges, which are caused by gaseous inclusions, or particles, e.g. metal, or glass and cellulose fibers, in solid, liquid, or impregnated insulation. Gaseous inclusions may arise during manufacture, or develop during approval tests, or in service, as a consequence of overload, or overvoltage conditions. Surface discharges, which occur in gases or liquids, from the edges of conductors onto the surface of insulation, where it is not covered by the conductor. (Zouaghi *et al*., 2023)

Corona, which occurs in gases, around conductors which are remote from solid insulation

Partial Discharges act on an insulation system by causing progressive deterioration and ultimately leading to failure of the insulation. Because of this, it is crucial to detect when and where they occur. Over the years, PD tests have become crucial for insulation quality assessment, equipment integrity verification and diagnostics, which are used to find information regarding defects of samples like cables, bushings, capacitors etc.

Three classes of partial discharge are popular (as demonstrated in Fig. 1), including internal discharge, surface discharge, and corona discharge. While Internal discharge occurs within voids or inclusions enclosed in a solid or liquid insulation (and results from manufacturing defects or material ageing in most cases), Surface discharge develops along the interface existing between insulation and air, because of contamination, moisture, or surface irregularities (Zhang *et al*., 2022; Zou *et al*., 2024).

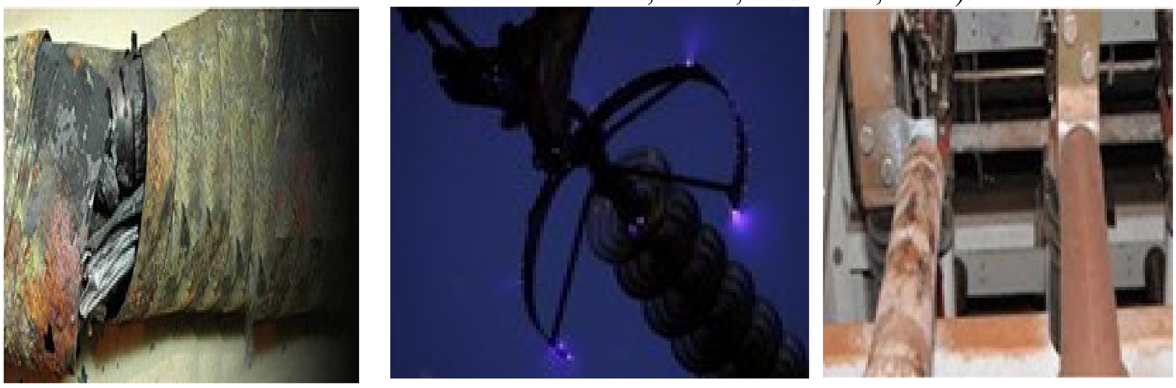

Fig. 1 Diagram of Types of Partial Discharge (a) Internal charge in cable (b) Corona Discharge in overhead line (c) Surface Discharge on Busbars

Corona discharge is popular in gaseous media around conductors that are subjected to high electric field stress, especially in regions remote from solid insulation (Dumkhana, 2025; Jang *et al*., 2023)

Early foundational work by Kind & König (1968) investigated the effect of partial discharges within voids on the AC breakdown performance of epoxy resin insulation, establishing the detrimental role of void-induced PD activity on dielectric strength. Contin *et* al. (2000) advanced PD source recognition through Weibull statistical processing of pulse height distributions, demonstrating the applicability of probabilistic models for defect identification. Further investigations by Cavallini *et al*. (2003) evaluated the effectiveness of diagnostic methods for identifying PD phenomena in solid insulation systems using advanced inference techniques. Subsequently, Cavallini *et al*. (2005) proposed a robust and flexible identification methodology suitable for condition-based maintenance of electrical apparatus.

More recent studies have expanded PD source recognition techniques. Martínez-Tarifa *et al*. (2013) employed clustering of spectral power ratios for PD source separation using phase-resolved (PR) maps. Rodrigo Mor *et al*. (2018) developed a unique test platform for electrical detection of multiple PD sources, contributing to improved experimental understanding of PD phenomena.

Additional influential contributions include diagnostic applications in HVDC systems (Cavallini et al., 2011), reproducible defect generation for controlled PD monitoring (Álvarez et al., 2018), and studies on calibration factors affecting UHF PD detectors (Liu et al., 2020). Collectively, these works demonstrate the evolution of PD measurement, statistical analysis, source recognition, and diagnostic methodologies for high-voltage insulation systems.

Although significant advancements have been made in PD detection and classification using statistical modeling, clustering techniques, spectral analysis, and UHF methods, many existing approaches require complex instrumentation, extensive computational resources, or specialized calibration procedures. Furthermore, limited studies have explored the effectiveness of simple higher-order statistical parameters such as skewness and kurtosis for real-time discrimination of PD types within integrated acquisition platforms. This study aims to develop and validate a MATLAB-based hardware–software system capable of high-sensitivity acquisition and classification of internal, surface, and corona discharges using statistical descriptors in the charge–phase domain.

The significance of this work lies in providing a simplified, cost-effective, and computationally efficient diagnostic tool for insulation condition monitoring. The proposed approach enhances defect recognition accuracy and offers practical applicability for high-voltage systems, particularly within regional electrical infrastructure such as the Norfolk distribution network.

2.0 Methods

2.1 *Experimental/simulation techniques adopted*

Partial discharge (PD) signals were generated using a field-programmable gate array (FPGA), and the identification system was implemented as an integrated hardware–software platform. The hardware subsystem consisted of an Agilent function generator, a PD pulse generator, and a National Instruments (NI) 5154 high-speed digitizer. The NI 5154 digitizer, equipped with a high-speed analog-to-digital converter (ADC), was used to capture transient PD signals and store digitized waveform data for subsequent processing. LabVIEW-based data acquisition and MATLAB/Simulink algorithms were employed for signal processing and PD classification. The detection parameters included pulse height, skewness, kurtosis, number of peaks, and the rise and fall times of the PD pulses.

The configuration and data flow of the integrated hardware-software platform, comprising the function generator, PD pulse generator, and the NI 5154 high-speed digitizer for signal acquisition and processing, are illustrated in the block diagram shown in Fig.2. Identifying the types of different partial discharges will also help us seek appropriate preventive measures or control measures in our electrical systems. The generated PD signals were fed into two channels of the digitizer and sampled at 50 mega-samples per second (MSa/s) to ensure accurate capture of fast transient discharge events The sampled PD signals were transmitted to a computer for visualization and analysis. A time–frequency (TF) map algorithm was implemented to separate noise components from genuine PD signals. For test objects designed to generate internal discharges, characteristic "rabbit-ear" phase-resolved patterns were observed. Surface discharge test objects produced asymmetrical phase distributions, while corona discharge exhibited irregular phase-resolved patterns. Internal discharges were observed to incept before voltage zero-crossing, whereas surface discharges typically initiated after zero-crossing. Moreover, in the case of internal discharges, PD markedly incepted before zero-crossing, while in surface discharges, PD started after zero-crossing. For corona discharge, irregular pattern shapes are identified (Aguadze, *et al*., 2022). The sequential logical process for acquiring partial discharge pulses, measuring statistical descriptors such as skewness and kurtosis, and executing the subsequent classification into internal, surface, and corona categories is detailed in the procedural flowchart shown in Fig. 3. This study adopted a mixed-method approach, combining qualitative descriptive observations with quantitative traffic performance analysis. The qualitative component was used to describe the role and behavior of Supeltas in guiding traffic, while the quantitative component assessed measurable impacts on traffic flow, speed, and congestion.

3.1. Study Location and Period

The case study was conducted at the U-turn on Jl. Soekarno Hatta, Pekanbaru City, in front of Jasmine Residence, a corridor characterized by mixed residential and commercial activity. Observations were carried out over two consecutive weeks in August 2024. Supeltas were present on August 12, 13, 17, and 18.

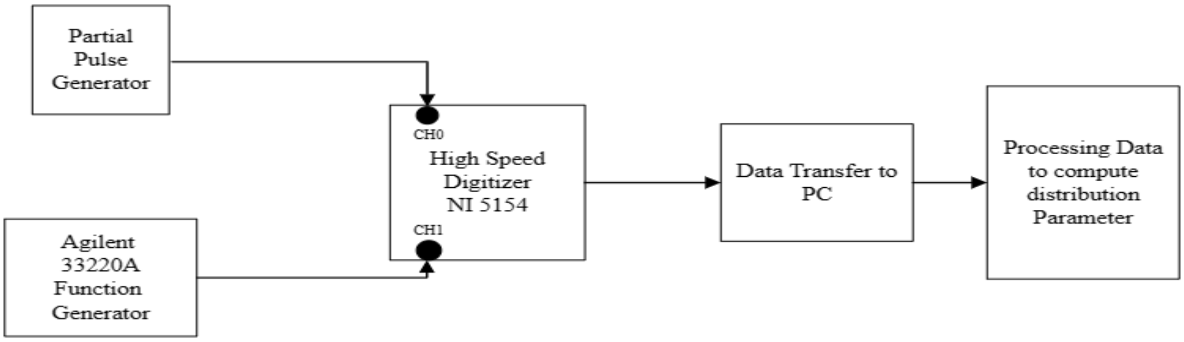

Fig. 2: Block Diagram of Hardware System Setup

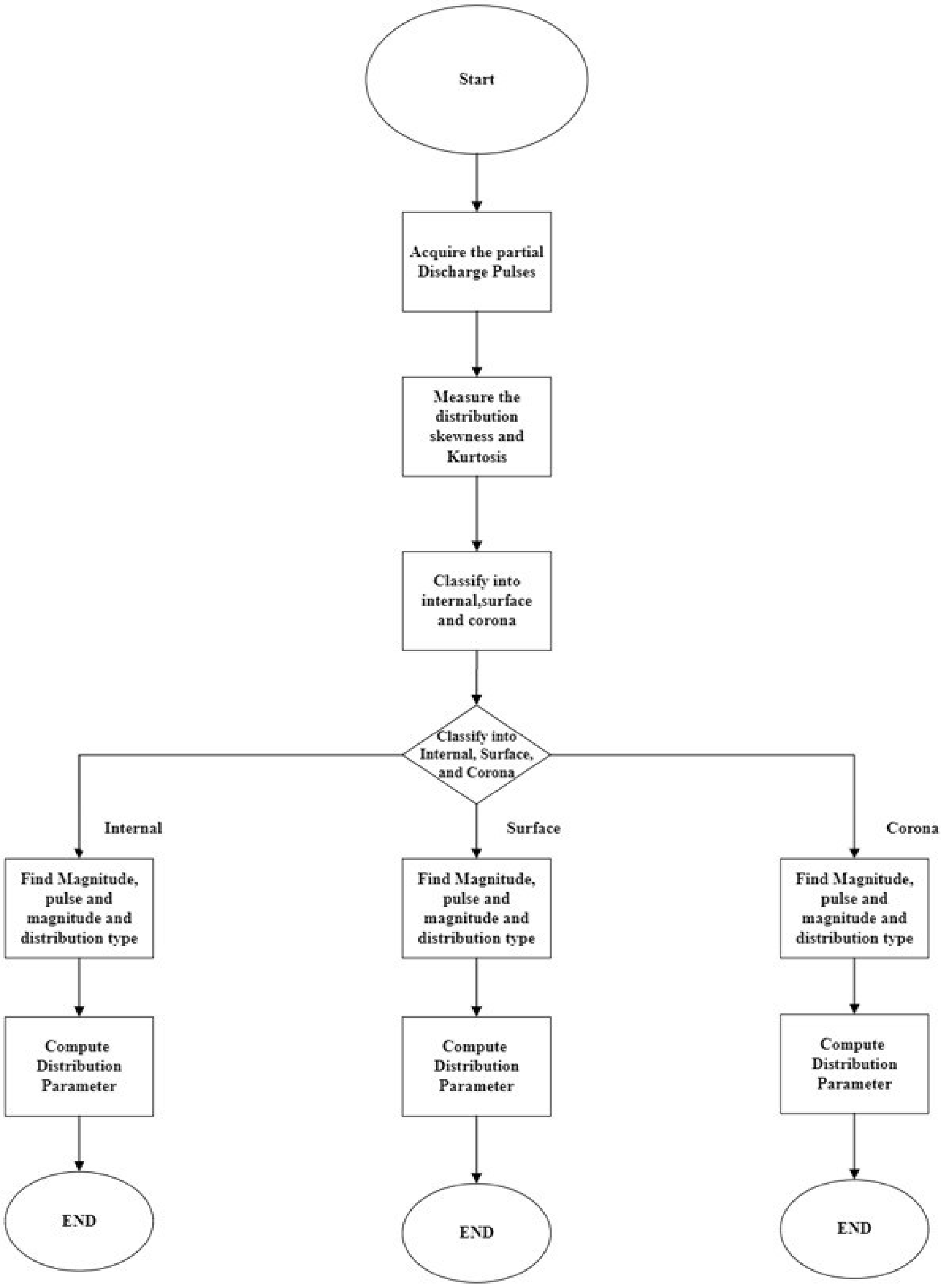

Fig. 3 :Logic Flow Chart for identifying the Partial Discharge

3.2. Data Collection

For PD source identification, a variety of patterns can be used. Identification of the defect type from the observed PD pattern may be achieved if these differences can be expressed in terms of statistical metrics. It is crucial to understand the relationship between discharge patterns and the type of defect since every flaw has a unique degradation mechanism.

Therefore, advancements in internal discharge recognition and their relationship to the type of fault are becoming more and more crucial for quality control in insulating systems. Statistical techniques have been used in studies to identify the sources of partial discharge.

Utilizing statistical parameters including skewness and kurtosis for (-q) and (-n) and mean, standard deviation, variance, skewness, and kurtosis for (n-q), we investigated a variety of internal and exterior discharges, including vacuum, surface, and corona.

Phase angle, charge magnitude, and pulse count are crucial factors in PD characterization. This parameter makes up PD distribution patterns. The statistical parameters for phase-resolved patterns (n-q) are obtained.

From the generator, the following data must be processed: q, n, and voltage V. Phase-resolved patterns are produced from this data. By their phase angle with respect to a sine wave frequency of 50 (5) Hz, PD pulses are categorised. The voltage cycle is therefore split into phase windows that correspond to the phase angle axis (0 to 360). Each phase window's statistical distribution of individual PD events can be calculated if measurements are performed over a number of voltage cycles. The observed PD patterns are represented in two dimensions throughout the entire phase angle axis by the mean values of these statistical distributions.

The amount of the PD charge ("q") and the number of pulses ("n") as a function of the phase angle ("" mean pulse height distribution) are represented by a two-dimensional (2D) distribution. The average PD charge magnitude in each window, as a function of phase angle, is given by H_{qn} (φ). The number of PD pulses in each window as a function of phase angle is represented by the pulse count distribution

H_n (φ).Four new distributions one for the positive half of the voltage cycle, H_{qn}^{+} (φ) and H_n^{+} (φ), and one for the negative half of the voltage cycle, H_{qn}^{-}(φ) and H_n^{-}(φ) are produced when these two values are further separated into two independent distributions of the negative and positive half cycles. The normal distribution can be used to explain PD numbers for a single fault. The moments of the normal distribution, skewness and kurtosis, have been used to describe the distribution profiles of H_{qn}^{+}(φ) and H_n^{+}(φ).

$$Skewness\ (S_k) = \frac{\sum_{i=1}^{N}(x_i - \mu)^3 f(x_i)}{\sigma^3 \sum_{i=1}^{N} f(x_i)} \quad (1)$$

$$Kurtosis\ (K_u) = \frac{\sum_{i=1}^{N}(x_i - \mu)^4 f(x_i)}{\sigma^4 \sum_{i=1}^{N} f(x_i)} \quad (2)$$

where, f(x) = PD charge magnitude q, μ = average mean value of q, σ = variance of q

Skewness and kurtosis are known with respect to a reference normal distribution. Skewness is a measurement of the distortion of symmetrical distribution or asymmetry in a data set. The distribution is said to be symmetric, Sk = 0. The distribution is said to be asymmetric to the left, Sk>0. Distribution is said to be asymmetric to the right, Sk<0.

Kurtosis is a measure of the "tailedness" of the probability distribution of a real-valued random variable. If Kurtosis (Ku=0), then the distribution has the same sharpness as a normal distribution. If Kurtosis (Ku>0), then the distribution is sharper than normal. If Kurtosis (Ku<0), then the distribution is flatter.

3.4. Data Analysis

Comparisons were made between conditions with and without Supeltas. Results were summarized in tables and graphs for interpretation. Observations relied on manual measurements, which may introduce timing errors. Weather conditions and driver behavior variations across days may also influence results. Nevertheless, triangulating data across multiple days and time periods strengthens validity.

3.0 Results and Discussion

3.1. The bi-modal distribution of the partial discharges

Unknown PD patterns were identified by comparing their statistical characteristics with established reference patterns for internal (void), surface, and corona discharges. The comparison was performed using higher-order statistical parameters derived from phase-resolved PD distributions.

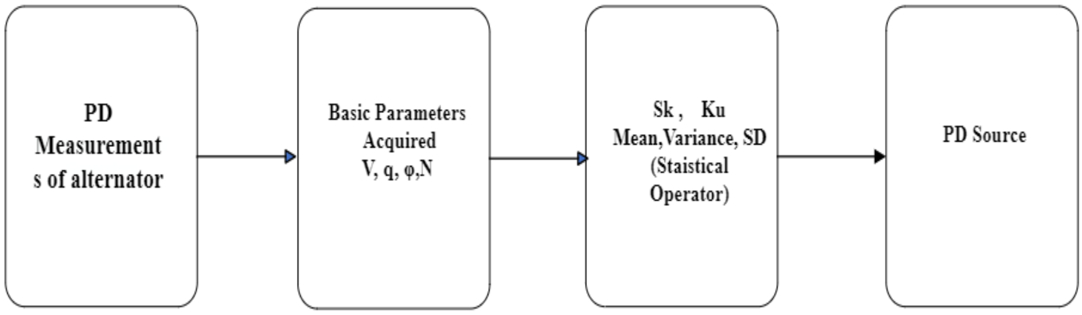

Fig. 4: Block diagram of discharge analysis for (n-q)

Evaluation was performed using the phase-resolved (-q) and (-n) distributions, which represent the charge magnitude and pulse count patterns, respectively. Three known PD patterns (internal/void, surface, and corona) and three unknown patterns (Data1, Data2, and Data3) were analyzed using the (-q) phase-resolved distributions. The phase angle versus charge magnitude (φ–q) plots for void, surface, and corona discharges are presented in Fig. 5 to 8 The phase vs. charge q plot for void, surface, and corona discharges, respectively, is shown in these graphs.

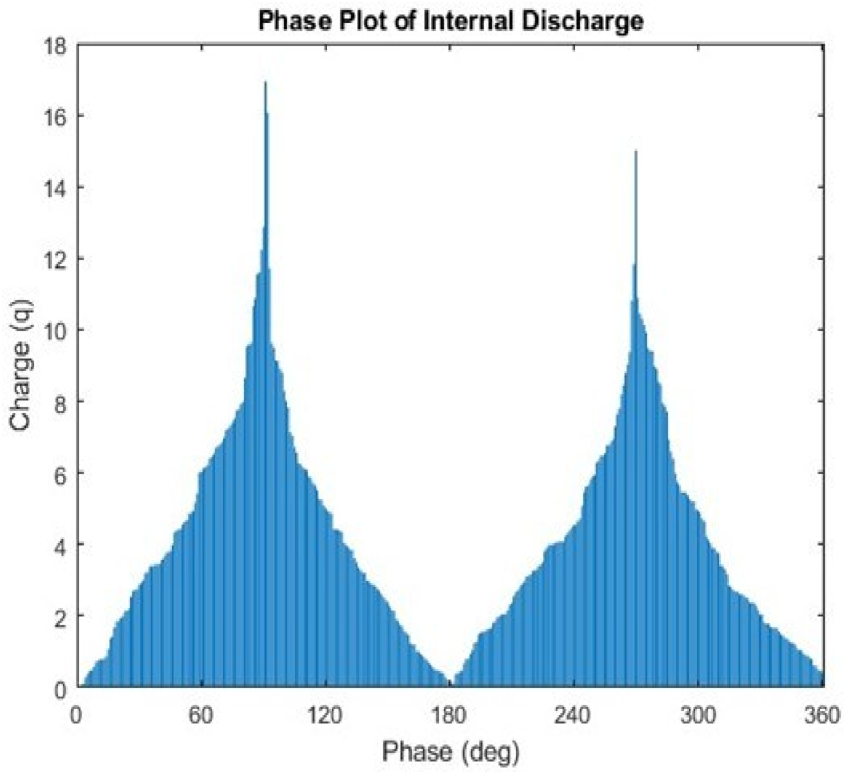

Fig. 5: Phase plot of void discharge(φ-q)

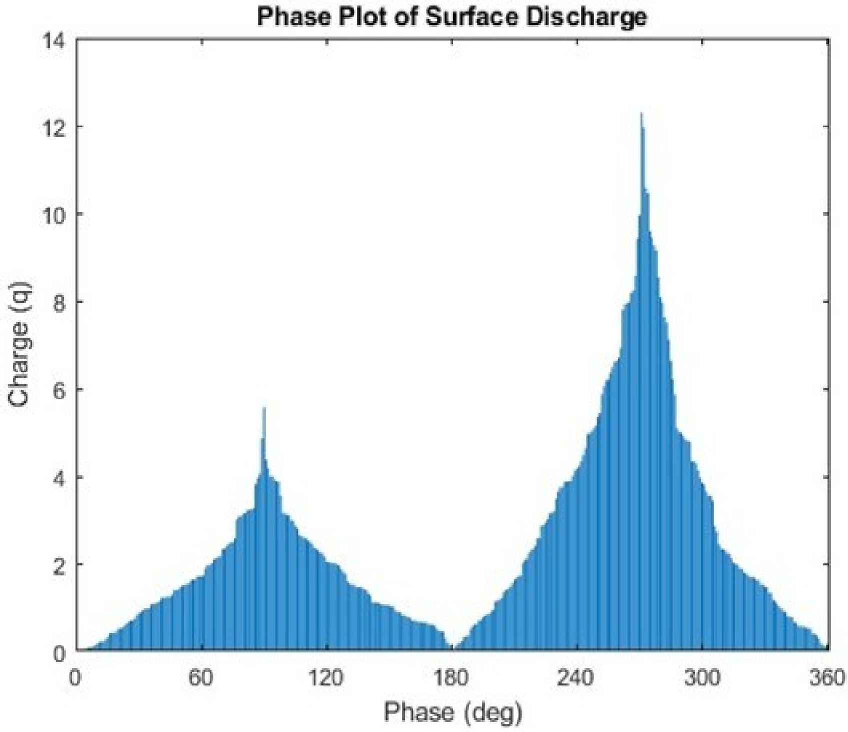

Fig. 6: Phase plot of surface discharge(φ-q)

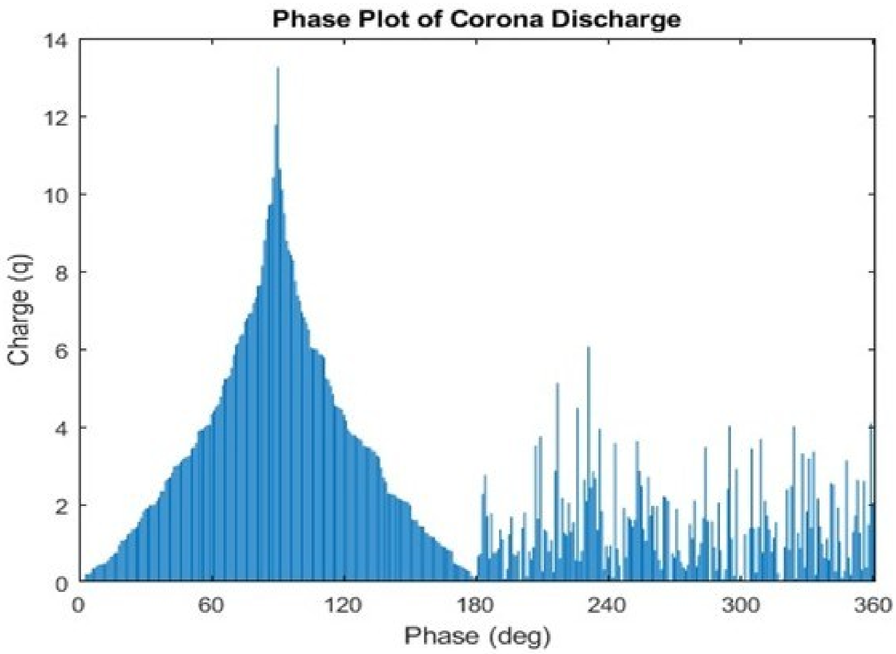

Fig. 8: Phase plot of corona discharge(φ-q)

The average skewness and kurtosis values for the known PD patterns are presented in Table I. The statistical parameters Hqn+ were computed over the phase range 0°–180°, while Hqn− were calculated over 180°–360°, corresponding to the positive and negative half-cycles of the applied voltage.

3.2. Characteristics Of Partial Discharges

3.2.1 significance of identifying the types of discharges

The characteristics of PD signals depend on the defect type, cavity dimensions, electrode geometry, insulation material, applied voltage magnitude, and environmental conditions. The PD mechanism is commonly explained using the ABC capacitive model, where discharge activity initiates when the electric field within a cavity exceeds the inception voltage. Following discharge, the voltage across the cavity drops to the extinction voltage before gradually increasing again, resulting in repetitive discharge events within each AC cycle. The voltage across the cavity between the electrodes reduces to a small voltage (extinction voltage) and the discharge extinguishes at this stage. Voltage across the cavity again starts to increase until it reaches the inception voltage to create the next discharge. This causes continuous and repetitive discharge events during the power cycle. The PD activity emerges during different phase angles of the voltage during positive and negative half cycles. PD events cause very fast movement of charges and give rise to a high-frequency transient current pulse (PD pulse) with pulse duration in the nanosecond to microsecond range.

Internal PDs pose a significant threat to electrical insulation. On the other hand, rather than a threat, the coronavirus is considered a source of disturbances during internal PD measurements. Therefore, it is essential to identify the origin of the measured PDs In order to make an accurate assessment of the ongoing discharge activity.

3.2.2 Internal discharge

Internal discharges typically originate from voids or cavities within solid insulation. These defects may arise from manufacturing imperfections, thermal degradation, mechanical stress, or insulation cracking. In AC systems, internal PD patterns generally exhibit positive skewness for both Hqn+ and Hqn− distributions. The kurtosis values are typically moderately to heavily tailed, indicating clustered discharge activity within specific phase regions.

4.2.3 Corona discharge

Corona is likely to occur on high voltage equipment, especially at a sharp protrusion on a bare conductor energized to a high enough voltage. Because of the sharp edge, the local electrical field is significantly enhanced around the point. Considering corona in air at atmospheric pressure, when the electrical stress surpasses approximately 3 kV/mm, PD occurs. The inception voltage initiating corona discharges depends on the curvature of the point or edge of the conductor and its distance from the grounded electrode. Corona discharge patterns typically exhibit near-zero or slightly positive skewness in the Hqn+ distribution and stronger positive skewness in Hqn−. The kurtosis values often indicate heavy-tailed distributions, reflecting sporadic but high-amplitude discharge pulses.

3.2.4 Surface discharge

Surface discharge patterns generally exhibit strong positive skewness in Hqn+ and negative skewness in Hqn− distributions, reflecting asymmetric discharge activity across half-cycles. The kurtosis values are typically high, indicating sharply peaked phase distributions. When discharge travels along the surface of insulation, this is called surface discharge—or surface tracking. It can be one of the most destructive types of partial discharge. Contamination and weather of the insulator surface are the two most common causes of surface discharge. In medium- and high-voltage equipment, this type of discharge occurs when insulation breaks down, usually due to high humidity or poor maintenance. Moisture intrusion is also a common cause of surface discharge.

The surface discharge showed more positive skewness (Hqn+) and more negative skewness (Hqn-) for skewness, respectively. It is also very heavily tailed and very heavily tailed for Kurtosis Hqn+ and Kurtosis Hqn-, respectively

The comparative analysis demonstrates that skewness and kurtosis parameters derived from phase-resolved PD distributions provide effective discrimination among internal, surface, and corona discharge sources. The unknown patterns (Data1–Data3) were classified by matching their statistical signatures with the reference distributions, confirming the reliability of the proposed identification methodology.

Table 1: Comparative Statistical Parameters (Skewness and Kurtosis) for the Identification of Internal, Surface, and Corona Partial Discharges.

Parameter	Void / internal	Surface	Corona
Skewness Hqn+	Normal positively skewed	More positively skewed	Less positively skewed(Almost 0 Skew)
Skewness Hqn-	Normal positively skewed	More positively skewed (> Hqn +)	More positively skewed (way + and > Hqn+)
Kurtosis Hqn+	Slightly Heavily tailed	Very heavily tailed	Normally heavily tailed
Kurtosis Hqn-	Normally heavily tailed	Heavily tailed	Very heavily tailed

4.0 Conclusions

This study presented the development and evaluation of an integrated hardware–software system for the identification of internal, surface, and corona partial discharges (PD) in high-voltage insulation systems. The primary objective was to investigate whether statistical parameters derived from phase-resolved PD distributions—particularly skewness and kurtosis—could effectively differentiate discharge types.

The results demonstrated that the pulse shape and the corresponding phase-resolved PD distributions provide distinctive statistical signatures for each discharge category. Internal discharges exhibited characteristic skewness and kurtosis trends different from those of corona and surface discharges, confirming that higher-order statistical descriptors can serve as reliable classification features. The bi-modal nature of the phase-resolved charge distributions further enhanced discrimination between discharge types.

In this preliminary stage, randomly generated simulated data were used to represent PD signals to validate the performance of the proposed statistical identification framework. The findings confirm that the developed MATLAB-based analytical system can successfully distinguish between discharge sources based on the statistical characteristics of their underlying distributions.

A key contribution of this work lies in demonstrating that the underlying statistical distribution of PD data contains essential diagnostic information regarding insulation condition. By analyzing parameters such as skewness and kurtosis, it is possible to infer the nature of discharge activity and, consequently, assess the integrity, safety, and expected lifespan of electrical insulation systems.

Future work will involve the acquisition and evaluation of real PD measurements from practical high-voltage systems to further validate and optimize the proposed methodology under real operating conditions. The integration of genuine field data will strengthen the applicability of the system for condition monitoring and predictive maintenance within power distribution networks.

5.0 References

Álvarez, F., Garnacho, F., Ramírez, A., Arcones, E., García, P., & Vera, C. A. (2018). Generation of reproducible reference insulation defects in experimental test cells for controlled PD monitoring. In *2018 IEEE International Conference on High Voltage Engineering and Application*. IEEE.

Aguadze, M., Manu, D., & Basappa, P. (2022). An integrated hardware–software system to identify the underlying distribution of PD pulse height records. In *2022 IEEE Insulation Evaluation and Design Laboratory*. IEEE. https://doi.org/10.1109/978-1-6654-6795-7

Cavallini, A., Conti, M., Contin, A., & Montanari, G. C. (2003). Advanced PD inference in on-field measurements. II. Identification of defects in solid insulation systems. *IEEE Transactions on Dielectrics and Electrical Insulation,* 10, 4, pp. 599–606.

Cavallini, A., Montanari, G. C., Puletti, F., & Contin, A. (2005). A new methodology for the identification of PD in electrical apparatus: Properties and applications. *IEEE Transactions on Dielectrics and Electrical Insulation,* 12, 2, pp. 203–215.

Cavallini, A., Montanari, G. C., Tozzi, M., & Chen, X. (2011). Diagnostic of HVDC systems using partial discharges. *IEEE Transactions on Dielectrics and Electrical Insulation,* 18, 1, pp. 275–284.

Contin, A., Montanari, G. C., & Ferraro, C. (2000). PD source recognition by Weibull processing of pulse height distributions. *IEEE Transactions on Dielectrics and Electrical Insulation,* 7, 1, pp. 48–58.

Dumkhana, L. (2025). Comparative analysis of corona discharge characteristics in high voltage AC and DC transmission lines. *International Journal of Electrical, Electronics and Renewable Energy (IJEERE),* 5, 2, https://doi.org/10.57152/ijeere.v5i2.2372

Jang, K. H., Seo, S. W., & Kim, D. J. (2023). Electric field analysis on the corona discharge phenomenon according to the variable air space between the ionizer and ground current collector. *Applied System Innovation,* 6, 1, 10, 10. https://doi.org/10.3390/asi6010010

Kind, D., & König, D. (1968). AC breakdown of epoxy resins by partial discharges in voids. *IEEE Transactions on Electrical Insulation, EI-3*(4), 173–178.*

Liu, S., Xiang, J., Cheng, J., Chen, J., Du, L., & Wang, L. (2020). Research on the calibration influence factors of UHF partial discharge detector. In *2020 5th International Conference on Smart Grid and Electrical Automation*. IEEE.

Martínez-Tarifa, J. M., Ardila-Rey, J. A., & Robles, G. (2013). Partial discharge source recognition by means of clustering of spectral power ratios. *Measurement Science and Technology,* 24, 12, pp. 125106, doi10.1088/0957-0233/24/12/125605

Mor, A. R., Castro Heredia, L. C., Harmsen, D. A., & Muñoz, F. A. (2018). A new design of a test platform for testing multiple partial discharge sources. *International Journal of Electrical Power & Energy Systems,* 99, pp. 495–503.

Shafiq, M., Kiitam, I., Taklaja, P., Hussain, A., Kütt, L., & Kauhaniemi, K. (2020). Characterization of corona and internal partial discharge under increasing electrical stress using time domain analysis. In *2020 IEEE Electrical Insulation Conference (EIC)* (pp. 217–220). IEEE. https://doi.org/10.1109 EIC47619.2020.9158701

Zhang, G., Zhang, X., Wang, B., Guo, Y., Gao, G., & Wu, G. (2022). Study on the discharge characteristics along the surface and charge movement characteristics of insulating media in an airflow environment. *Energies, 15*(10), Article 3706. https://doi.org/10.3390/en15103706

Zou, H., Yin, Y., Chen, J., Zhang, S., & Tian, F. (2024). Research on the inner surface discharge of the insulation sheath of electric locomotive cable terminals. *Applied Sciences,* 14, 21, 9681. https://doi.org/10.3390/app14219681

Zouaghi, A., Vollaire, C., & Dalstein, M. (2023, October). Analysis of corona and surface discharge signals from different non-intrusive sensors under HVDC. In *2023 IEEE Industry Applications Society Annual Meeting (IAS)* (pp. 1–5). IEEE. https://doi.org/10.1109/IAS54024.2023.10406887

Declaration

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public

Conflict of Interest

The authors declared no conflict of interest

Ethical Considerations

Not applicable

Competing interest

The authors report no conflict or competing interest

Funding

The authors declared no source of funding

Author Contributions

All components of the work were carried out by the author