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# A Review of Analysis of Partial Discharge Measurements using Coupling Capacitor in Rotating Machine

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**Abstract:** Partial discharge (PD) is a critical phenomenon in electrical systems, particularly in high-voltage (HV) equipment like transformers, cables, switchgear, and rotating machines. In rotating machines such as generators and motors, PD is a significant concern as it leads to insulation degradation, potentially resulting in catastrophic failure. Effective and reliable diagnostic techniques are essential for detecting and analyzing PD to ensure the operational safety and longevity of such equipment. Various PD detection methods have been developed, including coupling capacitor (CC), high-frequency current transformer (HFCT), and ultra-high frequency (UHF) techniques, each offering unique advantages in assessing the condition of HV electrical systems. Among these, coupling capacitors have gained significant attention due to their ability to improve the accuracy, sensitivity, and efficiency of PD detection in rotating machines. This study focuses on the advancements in coupling capacitor-based techniques and their critical role in enhancing PD diagnostics for monitoring and maintaining high-voltage rotating machinery.

**Keywords:** Partial Discharge; Coupling Capacitor (CC); Rotating Machine; Ultra-High Frequency (UHF); Phase Resolve Partial Discharge (PRPD).

## 1 Introduction

THE Insulation degradation stands out as one of the most critical faults observed in rotating electrical machines. Partial discharge (PD) is one type of insulation degradation that occurs in rotating machines. The significance of PD measurement has grown dramatically, and it is now regarded as one of the most effective ways for determining the health of electrical equipment, as stated in Article [1]. Increasing PD measurement can detect PD activity during the early stages. This is because insulation breakdown can happen gradually and continually, even during normal operation [2]. Hence, the PD activity needs to be treated during the early stages.

Currently, PD monitoring is a commonly used approach in electrical equipment operations for measuring the quality of electrical insulation and detecting early signs of damage before a breakdown occurs [2], [3]. It can be used for analyzing the PD that happens in insulating material in high-voltage equipment such as rotating electrical machines, switchgear, transformers, and cables. This discharge can cause slow insulation damage and accelerated ageing in the primary insulation, which can lead to full insulation breakdown if not properly handled at an early stage [2]. As a result, PD detection is a critical tool for detecting insulation health in high-voltage electrical equipment.

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## 2 Partial Discharge Theory

### 2.1 Partial Discharge Signal

According to IEC 60270, a PD is a localized electrical discharge that may or may not occur near a conductor, partially bridging the insulation between the conductors [4]. PD is characterized by brief bursts of current or voltage. The pulses are greatly affected by the voltage applied, the dielectric material used, and the surrounding conditions [5]. As stated in [6], PD refers to an electrical discharge or pulse that occurs on the surface of an insulation system or within a void. Fig. 1 illustrates a discharge that may occur within or outside the insulation.

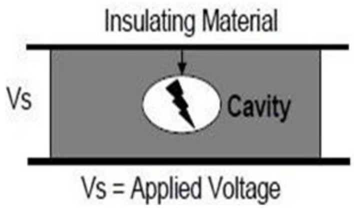


**Fig. 1** Discharge occurring in an insulating material [7]

Localized electric stress, which is an electrical breakdown in the insulation that does not fully bridge the electrodes [8], causes PD. Many materials, such as solid, liquid, and gaseous, are employed as insulation in HV electrical power systems to prevent early breakdown of the equipment. This insulating material's dielectric strength, also known as the breakdown strength, refers to the electric field intensity threshold at which an inter-electrode breakdown occurs in a homogenous outside field. The insulation does not instantly break down in response to PD [9]. These faults have varying electric field strengths, some of which may be greater than the average. PD occurs when the electric field intensity at these faults exceeds the insulation material's tolerance [9].

Thus, the insulation state of electrical equipment is important in ensuring the normal operation of electrical equipment. Insulation problems in electric power equipment can be induced by a variety of reasons throughout the manufacturing, transportation, and operation processes [10]. The electric field strength is not uniform at these defects and may be greater than the average electric field strength. PD occurs when the electric field intensity at these defects exceeds the insulation material's ability to endure [11].

### 2.2 Characteristics of Partial Discharge

The shape of a PD signal pattern can reveal valuable information about the insulation's condition. Thus, the detection of PD involves identifying the presence of localized PD in HV windings that are spatially distributed. The travelling wave method is commonly employed to determine the position of PD, especially for cables. The PD pulse splits into two segments and proceeds in both directions towards the terminals. There are various methods to utilize this effect for PD localization, depending on different factors like accessibility and measurement equipment. Once the PD pulse is generated (t = 0 s), the split pieces need to travel through the cable before they can be detected by measurement equipment like an oscilloscope. The time difference between the two travel times ($\Delta t$ = t1-t2) is used to accurately determine the location of the PD source. The equation as shown in Eq. 1.

$$\Delta l = v \frac{\Delta t}{2} \tag{1}$$

Additionally, the characteristic involves ageing processes, which cause the greatest damage and are associated with the fastest rate of degradation, specifically in terms of PD. Identifying the specific defect responsible for the occurrence of PD is another crucial concern, as it is directly associated with the severity of PD and its impact on the rate of aging. The level of harmfulness for machine reliability of typical PD source topologies for rotating machines using Type II insulating systems. Type II insulation, including inorganic micrometric particles, will likely survive PD, but only if the particles are placed in small-magnitude voids (micro voids). As a result, internal PD caused by micro voids is rather harmless, whereas internal PD caused by delamination or de-bonding is far more dangerous to insulating dependability. Machines with organic Type I insulation are unable to endure internal PD at all due to surface discharges, which can cause damage at a slower ageing rate. Thus, internal discharges will be extremely hazardous (high), surface discharges will be somewhat harmful (moderate), and corona discharges will be insignificant (low) [12].

**Table 1.** Type of insulating material

| Types | Insulating material |
|---|---|
| Type I | Organic material |
| Type II | Inorganic micrometric particles |

The rising voltage stress in VFD motor insulation leads to PD in LV motors. Due to the composition of LV stator insulation, it is prone to PD, which accelerates the degradation of the stator winding insulation and greatly shortens its lifespan. As stated in [13], pulse width modulation (PWM) at switching frequencies in the kHz range can place extra electrical and thermal demands on the motor. The voltage impulses with rapid rise time cause voltage overshoot at the motor terminals and an uneven voltage distribution, resulting in increased stress on the terminal end turns. When short rise time impulses, long cables, high temperatures, and a high DC link voltage are present, it increases the electrical stress on the turn, phase, and ground wall insulation in the terminal end insulation [14].

### 2.3 Type of Partial Discharge in Rotating Machine

A PD can be classified into three categories, such as internal discharge, slot discharge, and corona discharges [4]. Figure 2 shows the types of PD that occurred. It often happens with an insignificant defect, resulting in many minimally repeated discharges. Over time, this PD spreads and develops, eventually leading to complete insulation breakdown and equipment malfunction [4]. According to [7], [15], there is a specific place to identify where PD usually occurs, such as slot discharges that occur between the inner wall stator slot and the surface of the coil, while corona occurs at the sharp edges when the dielectric strength of a conductor is beyond a specific threshold. As for internal discharge, there are voids that take place within solid and liquid dielectrics.

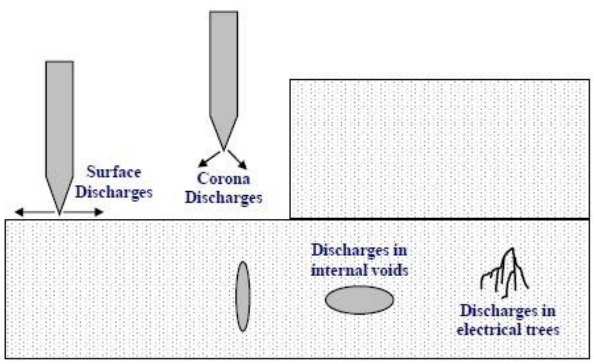


**Fig. 2** Type of partial discharge [7]

Slot discharges occur when there is a significant potential difference between the coil surface and the grounded iron core, which ionizes the air gap. Slot discharges can occur between the inner wall of a stator slot and the surface of a coil or bar inside a rotating machine. According to [7], these discharges can be caused by loose coils in the slot or a poorly constructed semi-conducting covering. When the machine is running, the current flowing through the stator winding creates a magnetic force on the stator coils. When the stator coils are not securely in place within the slot, vibrations can occur while the machine is running. These vibrations can cause damage to the semi-conducting layer, resulting in the coil's surface becoming exposed and disconnected. If things go wrong, the insulation might get damaged. These worn-down areas may lead to slot discharges. Thus, slot discharge indicates a potential issue with the coils in the slot.

Unfortunately, due to manufacturing flaws, there may be instances where the semiconducting coating exceeds the allowed surface resistance in certain areas. The ideal surface resistance range for the semiconducting coating is 100–10,000 per square meter. These events are known as electrical slot discharges. Although the degradation rate of insulation caused by electrical slot discharge is gradual, utilities are expressing concern about the increased rate of ozone production during discharge activity. As a result, PD measurement and slot discharge activity identification are critical in diagnosing the insulation of HV rotating machines [16]. Fig. 3 shows where the slot discharge is located.

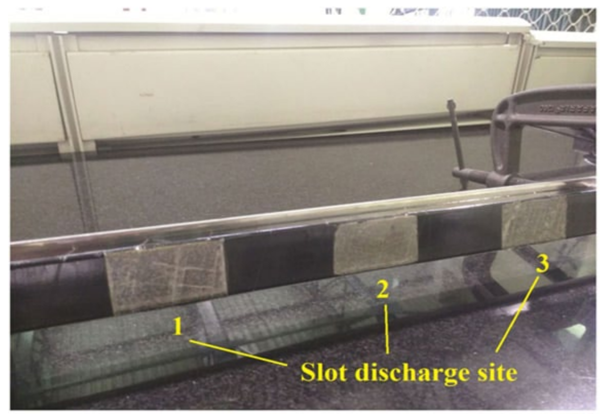


**Fig. 3** Slot discharge site [17]

The next type of PD is corona in high-voltage rotating machines (HVRM), which is a common and potentially inevitable phenomenon. Corona can manifest in a variety of ways, have varying causes and severity, and pose potential hazards to the reliable operation of machines. Corona in HVRM may arise due to the deterioration of outer corona protection (OCP) in various sections of the winding. The OCP, as a critical component of the insulation system, plays a vital role in maintaining the integrity of the electrical system by acting as a field-grading element between the grounded stator core and the main insulation of the coils [18]. Corona can still occur, even if there is OCP erosion or inadequate clearances in the system.

There may be erosion in the OCP due to potential issues with the ground wall insulation near the OCP. If there are micro-voids in the ground-wall insulation near the OCP, any partial discharge occurring within these voids can cause the insulation binder to degrade. Consequently, this degradation spreads to the binder in the OCP, eventually seeping through and becoming visible externally. As the internal voids affected by PD expand and reach the surface, corona is formed, leading to erosion, and bleaching of the OCP, as mentioned in article [17]. Fig. 4 displays the bleaching sign on windings.


**Fig. 4** Bleaching sign on windings [19]

Corona in the end winding is caused by insufficient clearances. This is a common occurrence in air-cooled windings, where the ground-wall insulation may experience significant electrical stresses due to inadequate clearance. Corona causes marks on the windings inside the cell and at the end. Corona is a common occurrence in HVRM. Insufficient ground wall insulation near the OCP can lead to OCP erosion from the interior [17]. Fig. 5 shows the corona occurring at the end twists, where two bars from different phases are next to each other. Fig. 6 shows that corona stains frequently appear at the first bend from the core, known as the "coil crossover".

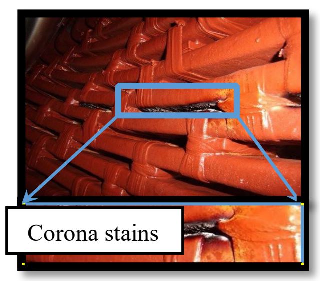


**Fig. 5** Corona stains at interface along the end turns [19]


**Fig. 6** Corona at interface at the first crossover [19]

Finally, internal discharge is the most common discharge that occurs in rotating machines. Internal discharges occur in the stator winding's electrical insulation when the cavities experience electrical stress beyond their dielectric strength. According to D.S. Patel et al., internal discharge is most found in cavities or spaces in liquid or solid dielectrics [6]. The discharge is caused by the formation of internal voids and delamination in the conductor insulation or by delamination between the conductor insulation and the main insulation. Insulation degradation due to internal PD is often delayed by several years or decades in typical stator insulation systems that use epoxy-glued mica tapes [20].

Based on Fig. 7, there are two types of internal discharge that happen inside the stator winding: internal voids occur when internal cavities of the insulating material, such as roughly spherical bubbles, are created during the manufacturing process. Other than that, voids may occur due to impurities in the insulation material or mechanical stresses. Internal delamination has an ellipsoidal geometric shape and can be induced during the production process by incomplete curing (resin hardening failure) or mechanical or thermal stress during operation.

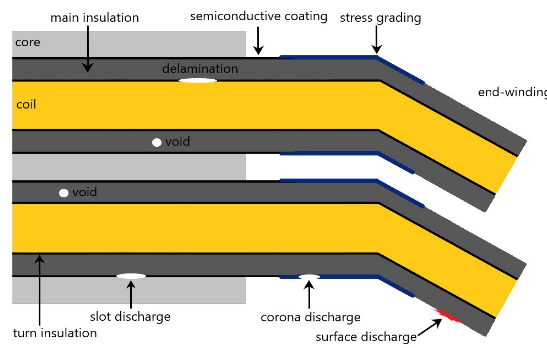


**Fig. 7** Type of discharge [21]

## 3 Partial Discharge in Rotating Machine

### 3.1 Corona Armor Tape in Stator coils

The Corona armor tape (CAT) used in the stator coils of a rotating machine can experience breakdown if there are holes or delamination in the main insulation of the stator coils. As a result, the material has a remarkably high resistivity. The CAT is a low-resistance tape that consists of a substrate coated with binding glue. Carbon black particles are added to the tape, and it is positioned between the main insulation layer and the stator core.

The CAT's primary function is to reduce any potential differential between the stator core and the outer surface of the main insulating layer to prevent PD in the slots. The degradation of the CAT, which is preceded by PD in the void and delamination in the main insulation, may pose challenges as the operating electric field in the main insulation increases [19]. Ozone can break down the CAT because it oxidizes the binding resin and takes away the resin that keeps the conductive carbon black particles on the substrate. Fig. 8 displays the stator coil insulation system of a formed-wound rotating machine.

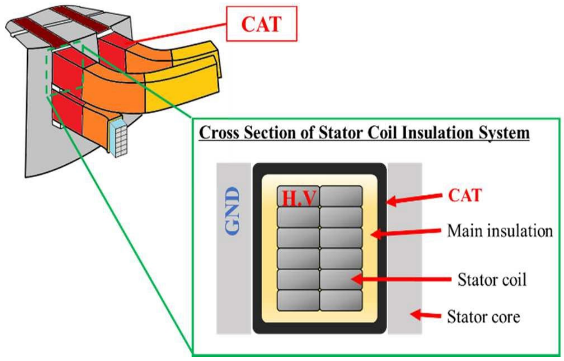


**Fig. 8** Stator coil insulation system of a formed-wound rotating machine [22]

### 3.2 Stator Slots

The stator slot in a rotating machine is most prone to experiencing a forced outage. These surface discharges occur at the interface between the solid and air in the stator slot gaps or at the slot exit. Surface discharges can result in more severe insulation corrosion, accelerate ageing processes, and ultimately lead to premature machine failure. A conductive or semi-conductive protective layer can provide a certain level of protection for solid insulation against these discharges. Special tapes are used to protect the coils at the slot exit region, ensuring that the electrical field is properly managed and surface discharge is avoided.

There are several PD quantities that can provide insight into the condition of insulation life in the stator slot during insulation deterioration [23]. Inadequate field elimination at the stator slot ends can lead to insulation failures that are difficult to control. Surface discharges may manifest at various locations, such as coil ends, stator body slots, or the slots themselves. Fig. 9 displays an illustration depicting various signal propagation paths in the end-winding region of a rotating machine HV-winding [21].

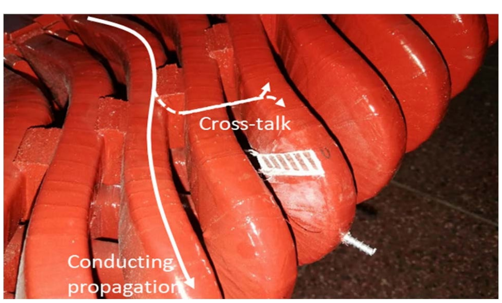


**Fig. 9** Illustration of different signal propagation paths in the end-winding region of rotating machine HV-winding [21]

### 3.3 Stator Winding

A hydrogen generator's stator winding insulating system may experience partial discharge (PD) in voids. This is caused by the organic material's chemical bonds in the insulation, leading to ruptures and the repeated bombardment of electrons and ions on the void surface. As a result, electric treeing, or electric tracing, occurs. Power distribution in hydrogen generator Stator windings typically indicate aging rather than degradation. Coatings on the surface of the coils in hydrogen generators rated at 6 kV and above are used to reduce the PD. These coatings offer semi-conductive and voltage-grading properties, just as an electrical engineer would expect.

Generating hydrogen Coatings are commonly applied to the surface of stator windings rated at 6 kV and above. These coatings are intended to prevent PD on HV wires. These coatings are commonly applied in the form of tape or paint to individual bars and coils during the manufacturing process. Commonly, the deterioration of semi-conductive coatings can be traced back to inadequate manufacturing procedures. Fig. 10 displays the semi-conductive coating of the motor.

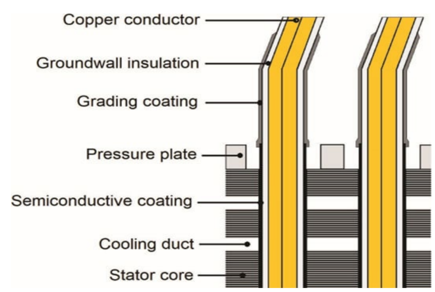


**Fig. 10** Semi-conductive coating [22]

## 4 Partial Discharge Detection Method

PD is detected using a variety of sensors in many different types of HV equipment. The selection of a sensor is influenced by criteria such as suitableness, cost, and application type. For preventive maintenance, monitoring and detecting PD in rotating machines is critical.

### 4.1 Coupling Capacitor

The CC is a sensor that is used to separate PD from the monitored conductor. This sensor is suitable for both online and offline measurements on a rotating machine. They consist of an HV capacitor and an impedance measurement device. The frequency range of the sensor is determined by the combination of the capacitor and the measuring impedance. All CC models include quadrupoles integrated into the base, along with over-voltage protection to ensure the safety of both the instrument and the user.

The CC plays a crucial role in the PD measuring circuit. It detects the PD pulse and transmits it as a voltage signal to a preamplifier for additional processing. It is designed to ensure that only relevant PD data is processed by blocking DC signals and allowing AC signals to pass through. Furthermore, CC are strategically placed for optimal sensitivity near the winding in a wide range of applications, such as transformers, switchgear, generators, and motors.

As mentioned in [27], the various types of high-voltage CC used for diagnosing PD are described. Thanks to advancements in production methods, modern applications frequently use epoxy-mica-insulated capacitors. Neutral Capacitor Coupling (NCC) maintains a high level of reliability, even surpassing that of Neutral RFCT Coupling (NCT), while also offering increased sensitivity. The detection frequency range in NCC closely matches that in NCT. Interpreting PD signals and evaluating insulation conditions can be quite challenging due to a low signal-to-noise ratio (SNR) that can be difficult to overcome. Prior to the development of the PD analyzer, there was the HV Terminal Capacitor Coupling (HVCC), which was an offline test method.

This approach required swapping out the bulky CC with a much smaller one, around 80 pF, that was connected to a resistive-detecting impedance. A typical PDA capacitor is a type of epoxy-mica capacitor that has a capacitance of 80 pF. It operates within a frequency range of 40 MHz to 350 MHz, has a high signal-to-noise ratio, and requires a low number of windings. Capacitors with higher capacitance can detect higher PD energy, thus increasing their sensitivity to PD events occurring deep within the stator winding [27].

In addition, PD pulses are highly effective for PD diagnostics using CC. Fig.11 displays the circuits used for diagnosing PD through pulse current diagnostics with the help of CC. The circuit is made up of various components, including an HV source that is free from PD, an HV source impedance (Z), a test insulation (Ca, Cb, and Cc) where PD occurs, a CC (Ck), and an impedance (Zm) that allows current pulses based on PD in the test isolator to pass. Additionally, there is an oscilloscope and an amplifier.

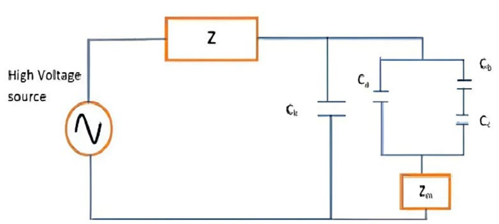


**Fig. 11** The circuit of PD diagnosis with CC [26]

Accurate measurement of PD and CC is of utmost importance. They are responsible for blocking high-voltage power frequency signals and connecting high-frequency PD signals from rotating machines' high-voltage windings to the measuring tools. This allows for effective isolation between the delicate measuring equipment and the high-voltage circuit. With their ability to capture PD signals at high frequencies and minimal attenuation, these capacitors guarantee accurate detection by maintaining low impedance. Working with HFCT to filter and boost PD signals before analysis, CC plays a crucial role in the signal conditioning process. Early identification of insulation flaws in rotating machines relies on the overall sensitivity and precision of PD measurements [28].

There are several types of CC used in PD measurements, each with specific properties suitable for different purposes. For high-frequency applications that require compact size and exceptional performance, ceramic coupling capacitors are an ideal choice. These capacitors are renowned for their consistent capacitance and minimal inductance, making them highly desirable [26]. Commonly used in situations that require reliability under extreme conditions, mica coupling capacitors are highly regarded for their stability, ability to handle high voltages, and minimal loss. These capacitors are commonly found in polypropylene film capacitors, which are known for their durability and resilience. These capacitors offer low dielectric losses, excellent insulation resistance, and impressive temperature stability. Due to their exceptional electrical performance and long lifespan, oil-impregnated paper capacitors are the preferred choice for high-voltage applications and are suitable for use in large rotating equipment like generators and turbines.

### 4.2 High Frequency Current Transformer (HFCT)

HFCT sensors are commonly employed for PD detection and have proven to be highly effective in pinpointing and characterizing PD sources. This sensor, which is commonly referred to as a radio frequency current transformer (RFCT), is comprised of an induction coil with a ferromagnetic core. It is designed to accurately measure transient signals like PD and pulsed noise interference. HFCTs are inductive sensors designed for accurately measuring current signals with high-frequency content [24].

In addition, HFCTs are commonly used for PD detection on power cables and are typically placed at the cable ends near the cable shield ground connection or around the cable core [25]. Due to their exceptional sensitivity, HFCTs are perfectly suited for detecting even the most minute amplitudes of PD. They are well-suited for online monitoring due to the inductive coupling between the sensor and the equipment under test, which provides galvanic isolation. Based on article [25], the highest sensitivity for HFCT is attained when using a measuring bandwidth of 10 MHz. The article [26] states that the HFCT frequency bandwidth ranges from 100 kHz to 25 MHz. Fig displays the HFCT installation's placement at the power cable's end [25].

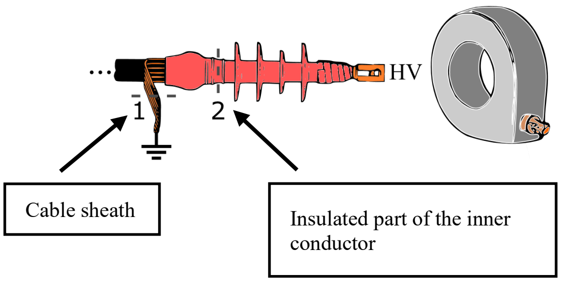


**Fig. 12** The Location of installation HFCT at the end of power cable [25]

### 4.3 Ultra-High Frequency (UHF)

UHF sensors have found extensive applications in various fields, including the identification of defects in physical constructions, the detection of displacement and tilt in wireless radio frequency identification systems, and the measurement of PD in high-voltage engineering. These applications are possible due to the quick rise times of the transient processes associated with these imperfections. These imperfections cause the frequency components in the UHF range to be inducted. Fig. 13 illustrates the significance of a UHF sensor in measuring UHF PD. The initial phase of PD measurement involves capturing electromagnetic signals using these devices for further signal processing [2].

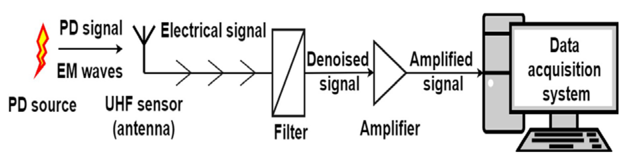


**Fig. 13** A general process of UHF measurement [26]

Insulation monitoring using UHF sensors on the premises offers several advantages. It is immune to external electromagnetic interference, making it more suitable for on-site testing compared to conventional methods. This also applies to insulation monitoring. Impulses can generate electromagnetic waves with frequencies spanning from 300 MHz to 3 GHz. This method uses a UHF sensor with an antenna to detect the electromagnetic waves emitted by the PD source.

## 5 Phase Resolve Partial Discharge Pattern

The PRPD pattern is a widely used tool in electrical engineering for monitoring the condition of power equipment [29]. In the past, systems for classification were developed to automate the process of fault identification. Many of these systems are designed with the assumption that only one source is active. It is common for multiple PD sources to be active at the same time in real-world scenarios. Thus, PRPD patterns can sometimes overlap, making it difficult to easily distinguish them, for example, through visual inspection. Dealing with multiple PD sources within a single PRPD can be quite challenging, as it presents a complex multi-label classification problem [29].

Using coupling capacitors is crucial for detecting partial discharge (PD) events in rotating machines. Various configurations of capacitive sensors, including simple, directional, and differential, can affect noise sensitivity and the detection of PD signals [30]. Commercial systems for PD detection typically use an HFCT or CC as the coupling element, with the CC filtering component designed to prioritize the PD signal while operating at a low frequency. The coupling capacitor selection has a direct impact on the frequency range used for detection, which in turn affects the sensitivity to low-frequency PD events. Manufacturers such as OMICRON use a 2 nF coupling capacitor to detect low-frequency events, employing the technique of de-noising through digital signal processing [31].

The study utilizes the PRPD pattern to analyses PD activity with the assistance of coupling capacitors, as stated in article [32]. With the help of a multispectral analyzer, PD pulses from various sources are detected and organized into three phases. These phases are then used to create vectors, which are further categorized into PRPD patterns based on their phase or source type for detailed analysis. This method enables us to determine the type of PD and the phase in which it occurs, as illustrated in Figures 14, 15, 16, and 17. Understanding the PRPD pattern is crucial for distinguishing between PD sources and noise, enabling the accurate identification of PD events in electrical machines [32].

The study introduces a technique for examining partial discharge (PD) patterns, specifically the PRPD pattern and the two-dimensional (2D) pattern. These patterns illustrate the relationship between pulse repetition rate and amplitude. PD measurements were conducted on a standard machine stator coil with a voltage class of 13.8 kV. This methodology is investigated in a laboratory environment by conducting experiments on stator coils taken from the stator core to simulate artificial faults and analyzing each type of partial discharge. Both a PRPD pattern and a representation of the pulse rate by the PD amplitude were generated for each PD type, enabling analysis of the geometric characteristics of the pulses in the PRPD cycle and the behavior of the 2D pattern [31].

In its half-cycle, the PRPD of slot discharge in Fig. 14 displays an asymmetrical pattern. It mainly consists of positive PD with low pulse amplitudes, and during the negative half-cycle, it exhibits triangular geometric features.

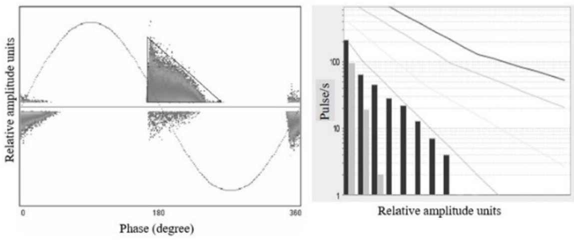


**Fig. 14** PRPD pattern of Slot discharge [31][32]

This type of discharge, known as delamination, occurs when an internal PD occurs between layers of laminations. The balanced PD activity in both half cycles typically suggests the occurrence of delamination discharge. Fig. 15 shows a delamination discharge with an imbalance in the PRPD's half-cycle. Negative PD pulses have higher amplitudes, while the positive half-cycle has a more symmetrical shape.

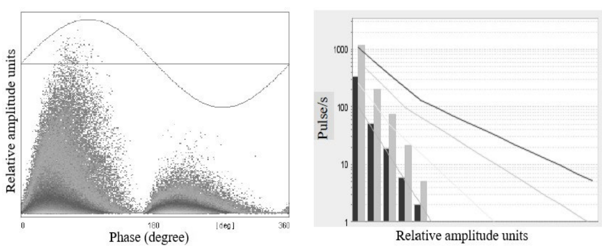


**Fig. 15** PRPD of Delamination discharge [31][32]

The PD pattern exhibits symmetrical half-cycles, characterized by small pulses with smooth geometric properties. Fig. 16 displays the PRPD patterns of internal discharge.

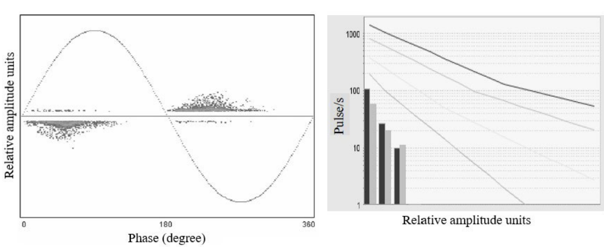


**Fig. 16** PRPD of Internal discharge [31][32]

Surface discharge occurs in an HV insulation system when corrosion processes cause it to appear on the surface of a solid dielectric material. This discharge may hasten the degradation of the insulation surface. In Fig. 17, the PRPD pattern of surface discharge displays asymmetry in its half-cycles, with high amplitudes for negative PD pulses. As seen geometrically, these pulses form vertical clouds that span between angles 30 and 40.

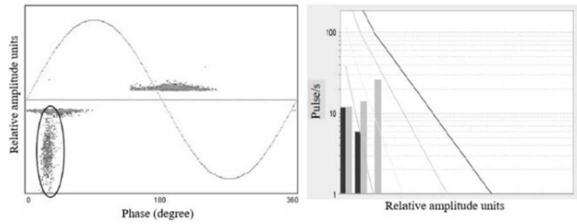


**Fig. 17** PRPD pattern of Surface discharge [31][32]

## 6 Conclusion

In conclusion, the measurement and analysis of partial discharge (PD) in rotating machines are crucial for ensuring the longevity and reliability of high-voltage electrical equipment. Coupling capacitors (CCs) have proven to be an effective tool for detecting PD, offering high sensitivity and the ability to filter out noise, thereby providing accurate diagnostics. The review highlights the importance of early PD detection, as it helps prevent insulation degradation, which could otherwise lead to severe equipment failures. The advancements in CC technology, particularly the integration of epoxy-mica-insulated capacitors, have significantly improved PD detection in a variety of high-voltage applications. In addition, a PRPD pattern study was undertaken to conduct in-depth analysis of PD. Thus, continued research and development in this area are essential for enhancing the maintenance and operational strategies of rotating machines.

### Conflict of Interest

The authors declare no conflict of interest.

### Author Contributions

Ahmad Syukri Abd Rahman solely conceived and conducted the study. The author prepared the manuscript completely and all authors agreed to be accountable for the content of the work.

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### Informed Consent Statement

Not applicable.

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