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USING RADIO FREQUENCY CURRENT TRANSFORMERS INSTEAD OF THE ROGOWSKI COILS IN HIGH VOLTAGE ROTATING EQUIPMENT

T.K. Nurubeyli[1,2,3*], Z.K. Nurubayli[1], I.M. Ismayilov[1***], G.N. Mammadova[4****], A.R. Muslumzade[1*****]**
[1] Azerbaijan State Oil and Industry University,
Azadliq Avenue, 20, Baku, AZ-1010, Azerbaijan,
e-mail: iismayilov@cbmes.com; znurubayli@cbmes.com; amuslumzada@cbmes.com.
[2] Institute of Physics of the Ministry of Science and Education of Republic of Azerbaijan,
H. Javid Avenue, 131, Baku, AZ-1073, Azerbaijan, e-mail: t.nurubeyli@physics.science.az.
[3] Khazar University, Mahsati Str. 41, Baku, AZ 1096, Azerbaijan.
[4] Nakhichevan State University,
Nakhichevan, AZ-7012, Azerbaijan, e-mail: gulsenmemmedova@ndu.edu.az.

This paper presents a comparative study of the use of Radio Frequency Current Transformers (RFCT) and Rogowski Coils (RC) for partial discharge (PD) monitoring in high-voltage rotating equipment. The relevance of work lies in the need to enhance the accuracy and reliability of equipment diagnostics while maintaining its operational status during measurements. The authors focus on the technical aspects of both methods, analyzing sensitivity, accuracy and resistance to interference, ease of installation, and operational simplicity. The study demonstrates that RFCTs offer significant advantages, including from high sensitivity to low-amplitude signals, resilience to radio interference, and a wide frequency bandwidth. These features make RFCTs particularly effective for use in environments with intense external interference, such as radar signals at industrial sites. Moreover, RFCTs feature a design that simplifies installation and operation, reducing setup time and increasing cost-effectiveness. The analysis confirms the superior accuracy of RFCTs under real operating conditions, ensuring high-quality PD signal detection against noise, a capability difficult to achieve with RCs without additional filtering. The study highlights the potential of RFCTs for use in modern high-voltage equipment monitoring systems, offering a practical and economically efficient solution that improves power system reliability and helps prevent critical failures. References 16, figures 10, tables 2.
Keywords: Partial discharge, Radio Frequency Current Transformers (RFCT), Rogowski Coils (RC), high-voltage equipment monitoring.

Introduction. Presently, all advanced nations in the field of industry are relying on efficient power generation, transmission, and distribution systems functioning. The whole power system is equipped with the best infrastructural components and equipment that can be deemed reliable if effective maintenance techniques are employed for condition monitoring of its critical components. It's well known that the reliability of complex rotating HV equipment is crucial and requires additional attention to operating conditions. To monitor the efficiency and safety of rotating equipment several diagnostic methods are applied, mostly intrusive methods that require taking it out of operation.

Effective real-time monitoring of equipment status during operation (online monitoring) is a cornerstone of modern preventive maintenance strategies. One of the most widely used and efficient methods for achieving this is partial discharge (PD) monitoring, which enables the early detection of potential failures and minimizes downtime risks. By offering a non-intrusive approach, PD monitoring ensures equipment reliability without interrupting operational processes.

The precision of PD detection depends heavily on the effectiveness and accuracy of the sensing equipment used. Currently, there is a broad spectrum of PD sensing technologies available, including High Voltage Coupling Capacitors, Rogowski Coils (RC), Transient Earth Voltage (TEV) detectors, Acoustic sensors, Radio Frequency (RF) sensors, and Radio Frequency Current Transformers (RFCT). Among these,

ORCID: [*]https://orcid.org/0000-0001-9696-2199; [**] https://orcid.org/0009-0000-4318-4602; [***]https://orcid.org/0009-0003-8470-1794; [****] https://orcid.org/0009-0008-0106-7975; [*****] https://orcid.org/0009-0008-9308-5125

the High-Frequency Current Transformer (HFCT) – often referred to interchangeably as RFCT – has gained recognition as one of the most versatile and reliable sensors for PD detection, particularly due to its sensitivity and ability to operate in harsh environments.

This paper will provide a detailed comparative analysis of two prominent PD detection methods: those utilizing RFCT and those based on Rogowski Coils. While both approaches are commonly employed in industrial applications, there are significant differences in their performance characteristics, application scope, and practical limitations. By conducting a comparative study, this work highlights the advantages and disadvantages of these two methods, offering insights into their suitability for various scenarios.

Compared to existing studies [1–4], this research takes a comprehensive approach by addressing not only the technical specifications but also the practical aspects, such as ease of installation, operational robustness, and cost-effectiveness. Furthermore, it emphasizes the critical role of the RFCT's high sensitivity and frequency response, which often make it the preferred choice in environments requiring precise fault localization and high-frequency signal analysis.

The primary objective of this study is to demonstrate how the RFCT surpasses conventional sensors like the Rogowski Coil in specific applications, particularly in high-frequency partial discharge detection. By doing so, the study underscores the contribution of this research in enhancing the understanding of PD monitoring systems and supporting the development of more efficient and reliable condition-monitoring solutions [5–7].

Subject of investigations.

A. Operating Principles of Rogowski Coil.

For use with high voltage equipment, based on some critical parameters of a sensor such as cost, bandwidth, sensitivity, saturation, linearity, operating temperature, footprints, integrability, flexibility, isolation and material technology, RC has been considered as a favorite tool for PD current sensing purposes [8]. Rogowski based current probes can be used for current measurements ranging from few milliamperes to several thousand amperes and frequency from few hertz to several MHz, depending upon the application and design of the RC [9]. A typical Rogowski coil consists of toroidal form windings, encircling the current path [10, 11] (Fig. 1).

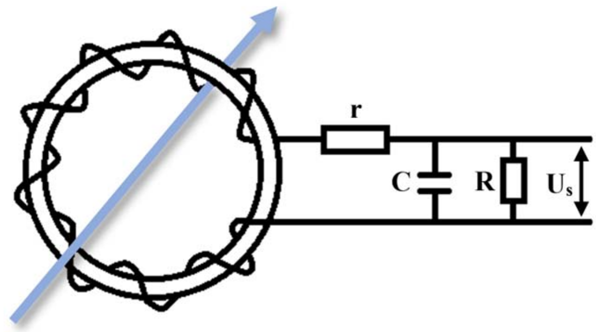

Fig. 1. Rogowski Coil with RC integrator

Based on Faraday's law of induction or simply the law of electromagnetism, the conductive material placed in a moving magnetic field will accumulate an electrical motion force (EMF). Considering this, the RC are used to measure currents through conductors without galvanic contact. The main advantage of RC is the fact that the core is air, so they never saturate, and the upper cut-off current can be higher than the designed values. The RC are ideal candidates to measure high amplitude pulsed currents. However, the main disadvantage of this measurement technique is the fact that the RC requires additional signal integration involving parallel connected capacitance and resistance. Moreover, RC has a reduced accuracy at low current amplitudes and high sensitivity to external disturbance [12, 13].

B. Operating Principles of RFCT.

In the setup shown in Fig. 2, the HFCT is placed around the grounding cables of each phase ($L1$, $L2$, $L3$) to monitor partial discharge (PD) currents. The primary conductors, represented by the grounding cables, pass through the toroidal ferrite cores of the HFCT. The secondary winding, wrapped around the ferrite Ni-Zn core, generates a signal proportional to the high-frequency components of the current. Sampling resistors are connected to the output terminals of the HFCT to convert the induced current signals into measurable voltage signals, enabling accurate detection and analysis of the PD activity. This configuration ensures effective PD monitoring while maintaining electrical insulation and minimizing signal interference.

RFCT offer several benefits in various applications particularly in electrical equipment monitoring including high sensitivity and accuracy that was supplied by special ferrite core located inside of RFCT. Despite that, the main disadvantage of this method is the high sensitivity for external disturbance as well as RC.

Results and discussion. The study compared two methods of measuring partial discharges (PD) in high-voltage rotating equipment using a Radio Frequency Current Transformer (RFCT) and Rogowski Coil (RC). The results showed that both methods have their advantages and limitations, but RFCT showed better results in terms of accuracy, sensitivity, and immunity to external interference [14–16].

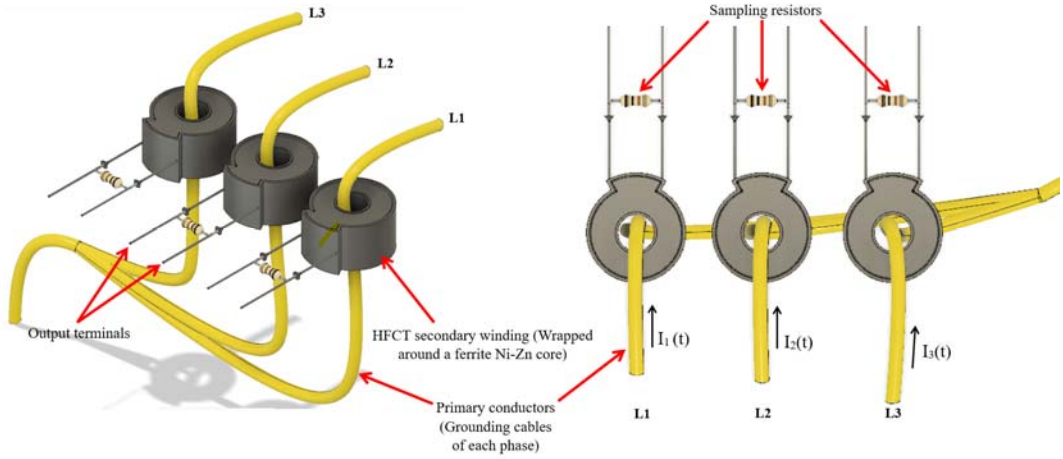

Fig. 2. Schematical connection for HFCT connected to 3 phase grounding system of the generator [5].

To conduct the analysis, more than 100 pieces of equipment were examined, including high-voltage motors and generators, which traditionally used Rogowski Coils for PD monitoring. It was noted that the measured results often had significant deviations, which was due to the influence of external radar equipment used in power plants. These interferences significantly reduced the accuracy of PD assessment and increased the uncertainty in data interpretation. To solve this problem, the RFCT method was chosen, which minimized the influence of external interference and ensured higher accuracy and stability of measurements.

After the RFCT calibration, PD measurements were performed on the equipment. The results showed that RFCT has significantly higher accuracy in identifying low-amplitude PD signals, and the influence of external radio interference was minimal. This significantly improved the quality of diagnostics and increased confidence in identifying potential faults.

Comparison of RFCT and RC data.

Table 1 shows the measurement data using RFCT. The peak amplitude of PD on channel A was 249.12 mV, while the noise level did not exceed 33.41 mV, indicating the high sensitivity and accuracy of this method. Figures 3–6 demonstrate a clear separation of PD signals from noise on different channels, confirming the high efficiency of RFCT for partial discharge monitoring in real operating conditions.

Table 1. Measurement data using RFCT (HVPD Longshot 0-200 MHz, seria. S. N.: LCRY3506N05817)

Test Equipment Channels (Phases)	RFCT Measurement data	
	Peak amplitude, mV	Average amplitude, mV
A	249.12	90.72
B	182.44	72.41
C	67.31	46.64
Noise	33.41	29.33

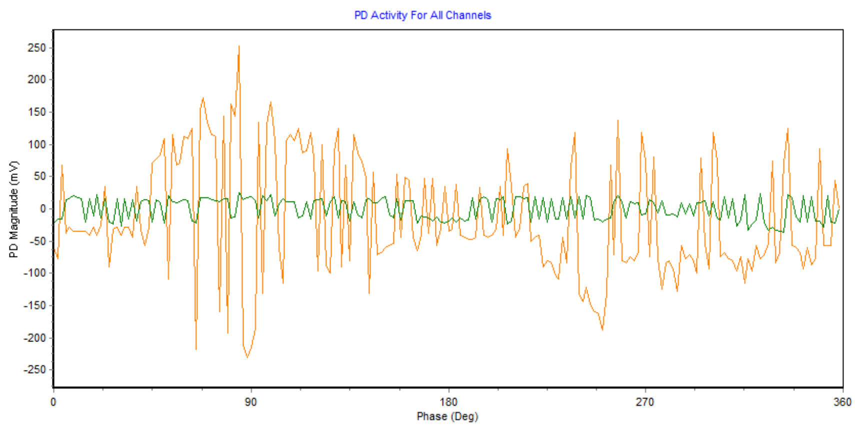

Fig. 3. PD magnitude captured by RFCT compared to external noise (green scale) on Channel A

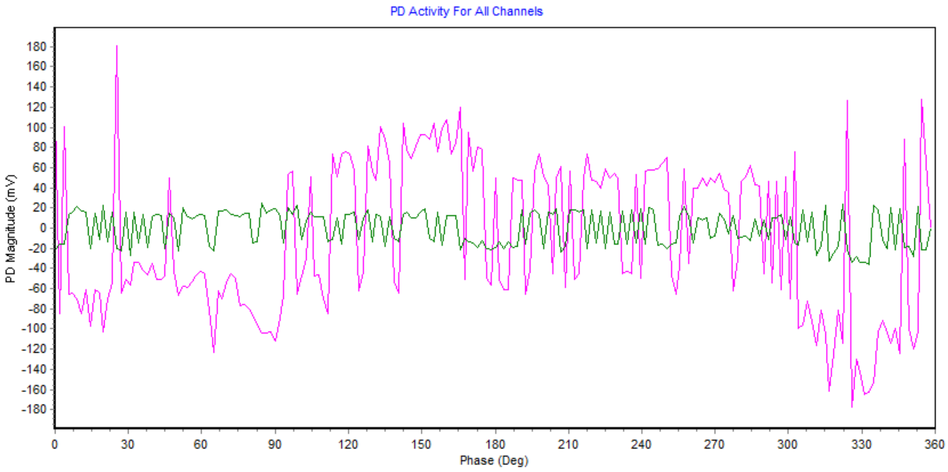

Fig. 4. PD magnitude captured by RFCT compared to external noise (green scale) on Channel B

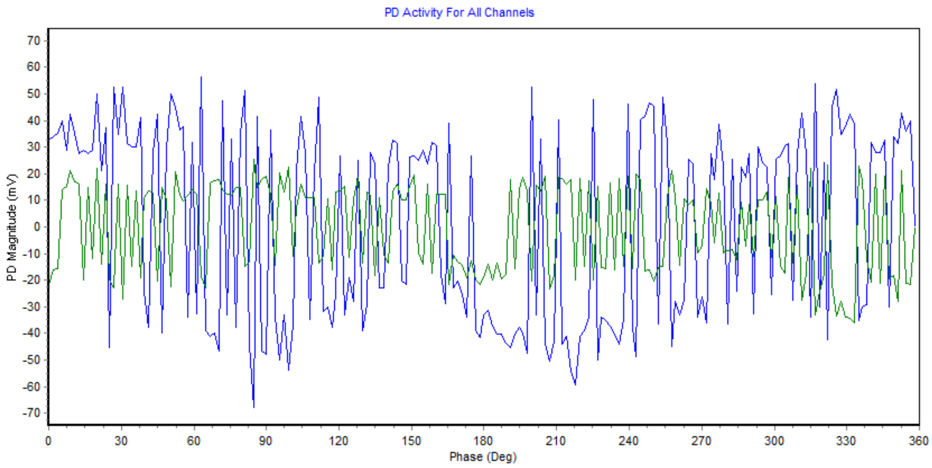

Fig. 5. PD magnitude captured by RFCT compared to external noise (green scale) on Channel C

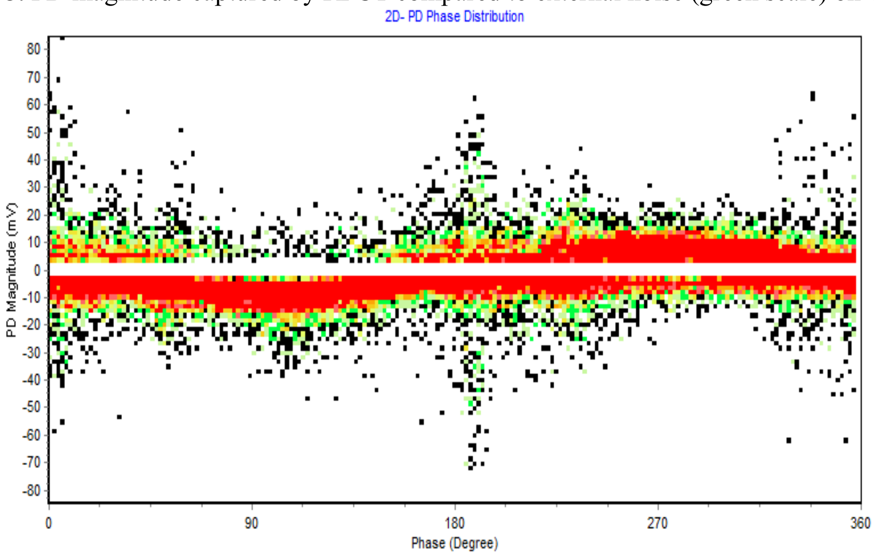

Fig. 6. Phase Resolved Partial Discharge (PRPD) magnitude captured by RFCT

In addition, the phase-resolved partial discharge (PRPD) analysis performed using RFCT in Figure 6 shows clear and stable signature of PD signals, which enables clear and accurate determination of the source and nature of the discharge. The PRPD results captured using RC (Figure 10) show a significant amount of noise, which makes the data difficult to interpret and makes this method less effective for diagnosis.

For RC, the data are shown in Table 2. The peak amplitude of PD on channel A was 92.60 mV, while the noise level on this channel was significantly higher, reaching 253.17 mV. These results are illustrated in Figures 6–8, where it is evident that the noise significantly dominates the PD signals, which reduces the accuracy of interpretation.

Table 2. Measurement data using RC (HVPD Longshot 0-200 MHz, Seria. S. N.: LCRY3506N05817)

Test Equipment Channels (Phases)	**RFCT Measurement data**	
	Peak amplitude, mV	**Average amplitude, mV**
A	92.60	43.51
B	65.96	40.98
C	44.13	34.74
Noise	253.17	96.32

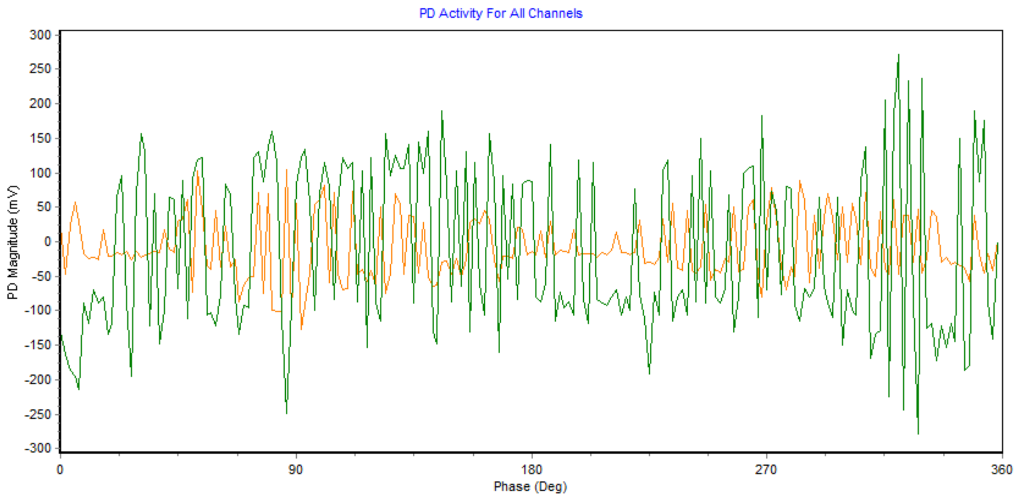

Fig. 7. PD magnitude captured by RC compared to external noise (green scale) on Channel A

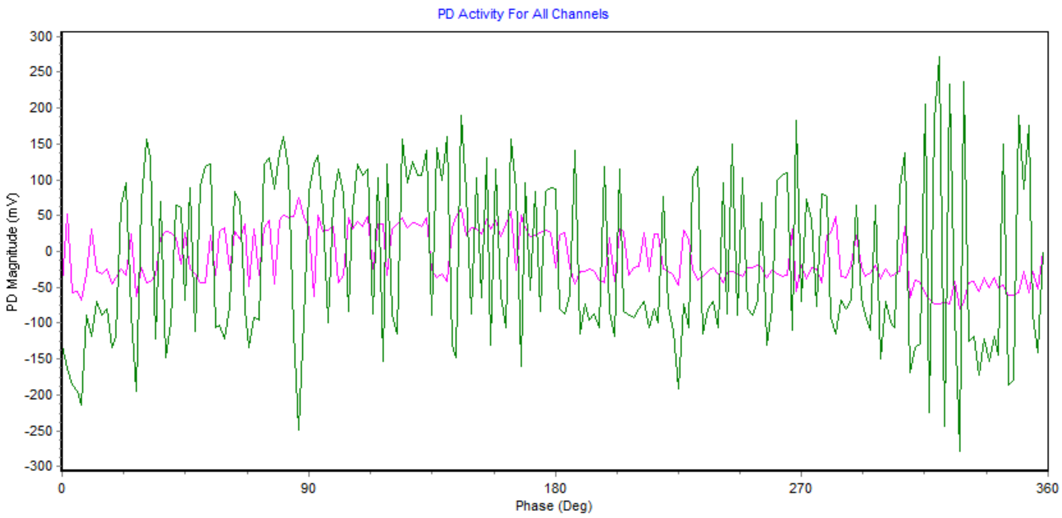

Fig. 8. PD magnitude captured by RC compared to external noise (green scale) on Channel B

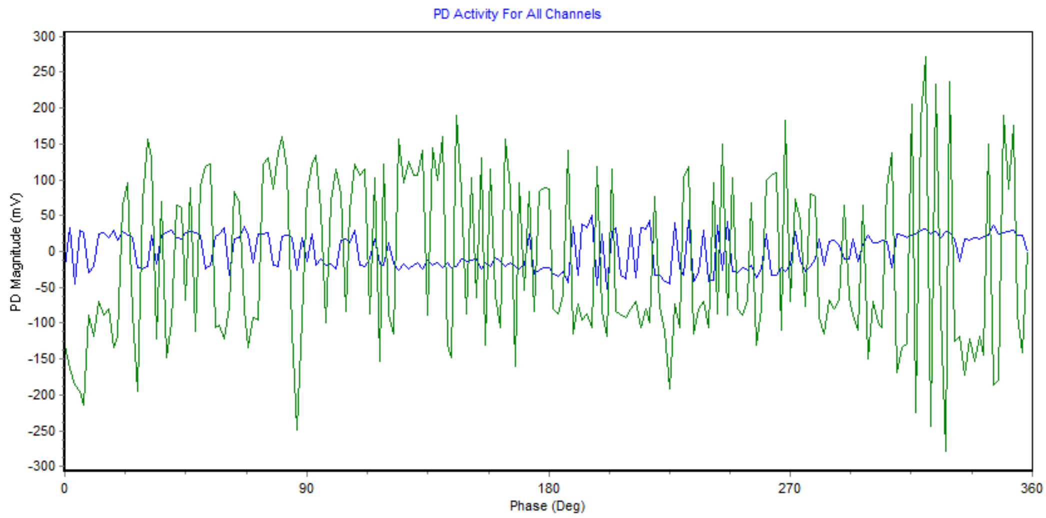

Fig. 9. PD magnitude captured by RC compared to external noise (green scale) on Channel C

Discussion of Advantages and Limitations. Sensitivity and Accuracy: RFCT has higher sensitivity and accuracy in measuring PD, especially in conditions where the discharges have low amplitude. This is especially important for early diagnosis and prevention of faults in high-voltage equipment.

Stability and Minimization of Interference: Unlike RC, RFCT is less susceptible to external interference such as radar signals, which makes it a more stable and reliable tool for monitoring in real-world operating conditions. This also reduces the need for additional filtering and data adjustments, which is often required when using RC.

Speed and efficiency: The RFCT method allows for much faster data collection and interpretation, which is important for operational monitoring and rapid response to possible emergencies. With RC, more time and effort are required to filter and process the data to obtain similar results.

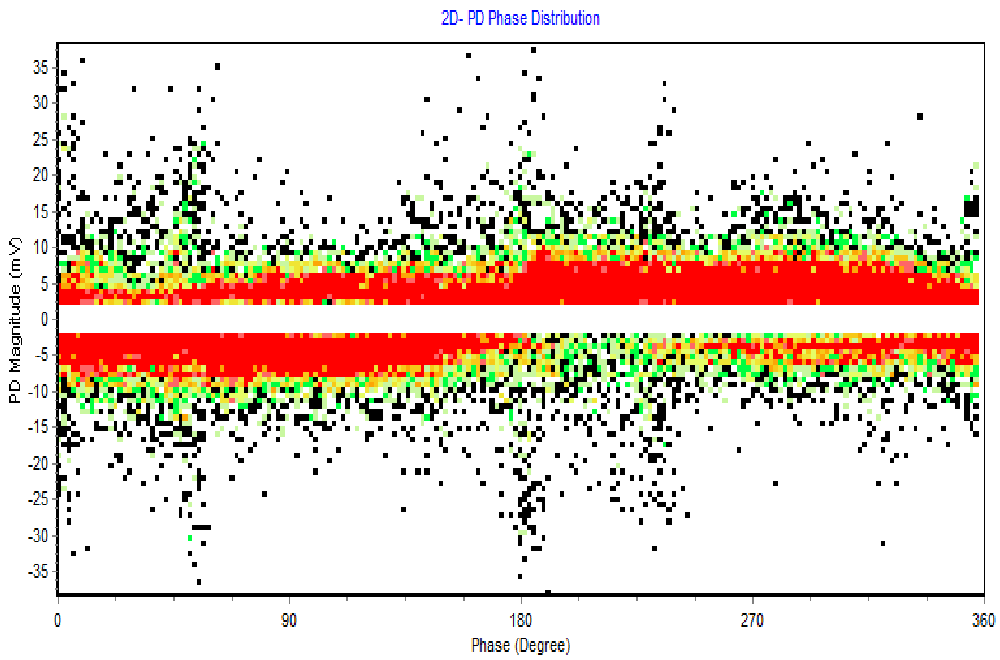

Fig. 10. Phase Resolved Partial Discharge (PRPD) magnitude captured by RC

The novelty of this work lies in the comparison of two popular methods for measuring partial discharges – RFCT and RC – under real industrial equipment conditions. This study not only confirms the advantages of RFCT in accuracy and sensitivity but also emphasizes its advantage in immunity to external interference, which is one of the main problems when using RC. The inclusion of phase-resolved partial discharge

(PRPD) analysis in the study significantly expands the diagnostic capabilities and allows for a more accurate interpretation of data obtained using RFCT. This makes this method preferable for use in high-voltage equipment, where the accuracy and reliability of monitoring are critical.

Based on the results presented in Tables 1 and 2, additional quantitative characteristics were calculated to evaluate the measurement accuracy of RFCT and RC. The average peak amplitude of signals measured using RFCT was 166.29 mV, which is more than twice the corresponding value for RC (67.56 mV).

The noise level with RFCT was significantly lower, 30.69 mV, compared to 253.17 mV for RC. This demonstrates the high sensitivity of RFCT and its ability to isolate partial discharge (PD) signals from background noise.

Particularly noteworthy is the signal-to-noise ratio: for RFCT, it is 5.32, which is more than 20 times higher than that of RC (0.27). These data confirm that RFCT offers high accuracy, stability, and minimal susceptibility to external radio-frequency interference, making it the preferred choice for partial discharge monitoring in high-voltage equipment.

Conclusions.

The research conducted demonstrates that Radio Frequency Current Transformers (RFCT) have significant potential to replace Rogowski Coils (RC) with partial discharge (PD) monitoring systems for high-voltage equipment. This method offers advantages in both measurement accuracy and resistance to external interference.

RFCTs exhibit high sensitivity and precision, enabling the effective detection of low-amplitude PD signals that are difficult to capture using RC. This capability is particularly critical for the early detection of defects, ensuring timely identification of potential equipment failures. Furthermore, in environments with the presence of electromagnetic interference, such as radar equipment at power plants, RFCTs minimize the impact of such disturbances, reducing data uncertainty and increasing diagnostic reliability.

The technical characteristics of RFCTs, including a wide operating frequency range and the ability to clearly distinguish signals from noise, make them a versatile tool for monitoring under various conditions. The ease of installation, facilitated by a split-core design, enables real-time deployment without requiring equipment shutdowns, thereby reducing setup time and associated costs.

The advantages of RFCTs extend beyond technical attributes. Their use enhances the overall reliability of power systems by improving diagnostic accuracy and preventing critical failures. The resilience to external interference and reduced need for additional data filtering make this method both economically viable and practically applicable for a wide range of tasks.

The findings confirm that RFCTs not only improve the accuracy of high-voltage equipment diagnostics but also contribute to the development of more reliable monitoring systems by minimizing downtime risks and enhancing operational safety. Thus, RFCTs have the potential to become the new standard in partial discharge monitoring systems, providing a higher level of control and failure prevention.

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УДК 621.3

ВИКОРИСТАННЯ РАДІОЧАСТОТНИХ ТРАНСФОРМАТОРІВ СТРУМУ ЗАМІСТЬ КОТУШОК РОГОВСЬКОГО У ВИСОКОВОЛЬТНОМУ ОБЕРТОВОМУ ОБЛАДНАННІ

T.K. Nurubeyli[1,2,3], Z.K. Nurubayli[1], I.M. Ismayilov[1], G.N. Mammadova[4], A.R. Muslumzade[1]
[1] Azerbaijan State Oil and Industry University,
Azadliq Avenue, 20, Baku, AZ-1010, Azerbaijan,
e-mail: iismayilov@cbmes.com; znurubayli@cbmes.com; amuslumzada@cbmes.com.
[2] Institute of Physics of the Ministry of Science and Education of Republic of Azerbaijan,
H. Javid Avenue, 131, Baku, AZ-1073, Azerbaijan, e-mail: t.nurubeyli@physics.science.az.
[3] Khazar University, Mahsati Str. 41, Baku, AZ 1096, Azerbaijan.
[4] Nakhichevan State University,
Nakhichevan, AZ-7012, Azerbaijan, e-mail: gulsenmemmedova@ndu.edu.az.

Проведено порівняння використання радіочастотних трансформаторів струму (RFCT) і котушок Роговського (RC) для моніторингу часткових розрядів (PD) у високовольтному обертовому обладнанні. Актуальність роботи полягає у необхідності підвищення точності та надійності діагностики обладнання при збереженні його працездатного стану під час вимірювань. Автори зосереджуються на технічних аспектах обох методів, аналізуючи чутливість, точність і стійкість до завад, простоту встановлення та експлуатації. Отримані результати показують, що RFCT мають значні переваги, зокрема високу чутливість до сигналів низької амплітуди, стійкість до радіоперешкод і широку смугу частот. Ці функції роблять RFCT особливо ефективними для використання в середовищах з інтенсивними зовнішніми завадами такими, як сигнали радарів на промислових об'єктах. Крім того, RFCT мають конструкцію, яка спрощує встановлення та експлуатацію, скорочує час налаштування та підвищує економічну ефективність. Аналіз підтверджує високу точність RFCT в реальних умовах експлуатації, забезпечуючи високоякісне виявлення сигналу PD проти шуму, здатності, якої важко досягти з RC без додаткової фільтрації. Це підкреслює потенціал використання RFCT в сучасних системах моніторингу високовольтного обладнання, пропонуючи практичне та економічно ефективне рішення, яке підвищує надійність енергосистеми та допомагає запобігти критичним збоям. Бібл. 16, рис. 10, табл. 2.

Ключові слова: частковий розряд, радіочастотні трансформатори струму (RFCT), котушки Роговського (RC), моніторинг високовольтного обладнання.

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