UDC 621.315.6 DOI https://doi.org/10.32782/1995-0519.2022.2.3

# REVIEW OF PARTIAL DISCHARGE ENVIRONMENTAL ASPECTS AND ACTIVITY AT ALTERNATING AND DIRECT CURRENT VOLTAGES

**Yevgeniy Trotsenko**
PhD, Associate Professor,
Department of Theoretical Electrical Engineering National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», 37, Prospect Peremohy, Kyiv-56, Ukraine, 03056, e-mail: trotsenko2014@gmail.com
**ORCID: 0000-0001-9379-0061**

**Artem Nesterko**
PhD, Associate Professor,
Department of Power System Automation National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Prospect Peremohy, 37, Kyiv-56, Ukraine, 03056, e-mail: watefir@gmail.com
**ORCID: 0000-0001-7488-4214**

**Yuliya Peretyatko**
PhD, Associate Professor
Department of Power System Automation National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Prospect Peremohy, 37, Kyiv-56, Ukraine, 03056, e-mail: peretyatko.julia@gmail.com
**ORCID: 0000-0003-1397-8078**

**Mandar Madhukar Dixit**
Assistant Professor
Department of Electrical Engineering Vishwaniketan Institute of Management Entrepreneurship and Engineering Technology Survey No. 52, Kumbhivali, Tal, Khalapur, Maharashtra, 410202, India e-mail: mandardixit78@gmail.com
**ORCID: 0000-0003-1959-7815**

**Purpose.** The global development of high-voltage direct current transmission has led to a growing interest in partial discharge measurement and analysis at direct current voltage. Partial discharge measurements in dry and moistened insulation under alternating and direct current voltages were performed. **Methodology.** Technique of electrical detection of partial discharges was applied. Measuring system when coupling device is connected in series with the test object was used. **Results.** The impact of partial discharges, mainly corona discharge, on the environment was reviewed. The effect of insulation wetting on the characteristics of partial discharges at various voltage waveforms was studied. Under a direct current voltage conditions, a removal of absorbed moisture as influencing factor leads to the almost complete elimination of partial discharges and a decrease in their amplitude by more than 90% compared to moistened sample. **Originality**. Modified measuring system allows partial discharge measurement at various voltage waveforms. Partial discharge measurements at alternating and direct current voltages were carried out under the same conditions, including the same magnitude of applied voltage and moisture content in the insulation. The applied voltage varied from 7.3 kV to 9.0 kV. The moisture content in the insulation varied from 2.0% to 12.0%. The main attention is paid to the effect of voltage ripples on the characteristics of partial discharges. **Practical value**. The data obtained contribute to the study of the partial discharges phenomenon when the insulation is exposed to non-standard waveforms of applied voltage. **Conclusions**. Phase-resolved partial discharge analysis can be used for a ripple voltage waveform too. The required phase angle assignment to a single partial discharge event becomes possible due to the ripple peaks being present in the rectified voltage oscillogram. Future efforts for this research should be focused on specific questions regarding application of three-capacitance model for simulation of partial discharges under ripple voltage conditions and study of environmental aspects. References 19, figures 7.

**Key words:** partial discharge, moisture content, voltage ripple, environmental aspect.

PROBLEM STATEMENT. By definition, partial discharge is a localized electrical discharge that bridges only a portion of the insulation separating two electrodes or conductive materials [1]. Partial discharges can occur both in the immediate vicinity of the conductor, and far from it, for example, in gas filled cavities that are not adjacent to conductors. Partial discharges occur whenever there is a stressed area due to some kind of insulation defects inside it, like cavities mentioned above or if there are defects outside it, like protrusions on insulation covering. When a partial discharge occurs in a gas filled cavity inside the insulation material, this is due to the fact that the electrical strength of gas bubbles is lower than the electrical strength of a liquid or solid dielectric, and the electric field strength in a gas bubble at alternating current (AC) voltage is higher than in a liquid or solid dielectric.

Partial discharges can occur in electrical insulation both at operating voltage and overvoltage. It is partial discharges that are the main cause of electrical aging of many types of insulation. The aging of insulation impregnated with liquid dielectric materials mainly manifested in the destruction and change in the physical and chemical characteristics of the impregnating material. A change in the characteristics of the impregnating composition is occurred with gas evolution, an increase in conductivity, and an increase in the dielectric loss tangent. Further, the destruction of solid insulation occurs: electrical insulating cardboard, electrical capacitor insulation paper or synthetic materials. These processes, with intensive development, end with an electrical breakdown of the insulation.

When classifying partial discharges, several types of them are distinguished [2]. Main types of partial discharges are a) internal partial discharge; b) surface discharge; c) corona discharge. Additionally, discharge patterns of the following insulation defects are also classified as partial discharges: d) treeing discharge; e) floating electrode discharge; f) contact discharge [2-4]. Since different insulation defects present different hazards, it is important to distinguish between variety of partial discharge types. Irreversible insulation damage can be avoided if partial discharge is detected before it causes significant damage.

Partial discharges have some relation to the problem of ecology. Partial discharges generate an electric current pulse, acoustic noise and wideband radio-frequency interference [5] that can be used for non-intrusive partial discharge measurement. This impulsive noise in electrical substations caused by partial discharges is a source of interference for wireless communication systems [6, 7]. The impulsive noise is mostly caused by partial discharges occurring inside high-voltage equipment or outside it on the insulation surface. Energy transmission over long distances with a help of overhead power lines has both well-known and lesser-known environmental impacts. The first includes the influence of electric and magnetic fields on the environment [8, 9]. The latter include the influence of partial discharges, and above all of the corona discharge and the effects associated with it. For example, noise caused by corona discharge may influence whether wild animals pass under overhead power lines [10]. Recent studies show that some animals detect ultraviolet light emitted from the corona discharge on overhead power line conductors, which is led to physiological adaptations and functional constraints [11].

Partial discharges may arise at both AC and direct current (DC) voltages. The global rise of high-voltage direct current (HVDC) technology nowadays has led to a growing interest in partial discharge measurement and analysis at DC voltage [12, 13]. Another important point in studying partial discharge behavior at DC voltage is further circuit simulation and development of appropriate model. For many years now, the well-known three-capacitance model [14, 15] has been used for simulation of partial discharges at AC voltage. An important question is whether the three-capacitance model is suitable for modeling partial discharges at a ripple voltage. Whether the three-capacitance model is applicable to ripple voltage can only be determined by comparing the results of experiment and simulation.

The authors undertook studies of partial discharges in a high-voltage laboratory at comparable magnitudes of AC and DC voltages. The obtained data permit to summarize the information about common and distinctive properties of partial discharge behavior at AC and DC voltages.

The aim of this article is to continue the research started in [16-18] and to overview the similarities and differences between partial discharges at AC and DC voltages.

MATERIAL AND RESULTS. All the results below in this article were obtained in experimental installation for electrical detection of partial discharges. Circuit diagram of experimental installation is shown in Fig. 1. The principle of operation of this high-voltage installation was previously described in previous publications [16-18], so it is not described here.

In Fig. 1: $U\sim$ is AC input voltage; $U=$ is DC voltage input; $Z_{mi}$ is input impedance of measuring system; *CC* is connecting cable; $C_a$ is test object (sample of insulation with defects); $C_k$ is coupling capacitor; *CD* is coupling device having signal amplifier; *MI* is measuring instrument (commonly it is an oscilloscope); *Z* is filter (commonly it is a high-pass filter).

Measuring system allows partial discharge measurement both at AC and DC voltages.

In order to identify the insulation defect type, the phase-resolved partial discharge patterns are used. Thus, phase-resolved pattern is main representation form at AC voltage. Phase-resolved pattern representation cannot be applied for pure DC voltage, because it does not allow a phase value be assigned to the partial discharge event [19]. As a common representation form, suitable for both AC and DC voltage, a time-resolved partial discharge pattern was used in this work.

Partial discharge pulses in dry insulation under pure AC voltage are shown in Fig. 2.

The maximum amplitude of partial discharge pulses in Fig. 2 is 2.914 V. Here and in all the illustrations below, the partial discharges are shown in red color, and the voltage applied is shown in blue color. According to Fig. 2, under pure AC voltage conditions, partial discharges may occur at different voltage polarity, mainly on the rising or falling slopes of the sinusoidal wave cycle. Partial discharges occur until the sinusoidal voltage of the power source passes through the maximum value. After this happens, partial discharges will occur in the next half cycle of the applied voltage. An increase in the amplitude of the applied voltage leads to a rise in the number of partial discharges and an increase in the amplitude of the pulses (refer to Fig. 3).

The maximum amplitude of partial discharge pulses in Fig. 3 is 3.314 V. Partial discharges still occur mainly on the rising or falling slopes of the sinusoidal voltage cycle. With an increase in the amplitude of the applied voltage by 22.2%, the maximum amplitude of partial discharge pulses increased by 13.7%. Moisture content in the insulation sample (insulation pressboard) in above two cases is about 2.0%. An increased moisture content in the insulation sample leads to an increase in the amount of partial discharge pulses and an increase in their maximum magnitude (refer to Fig. 4).

The maximum amplitude of partial discharge pulses in Fig. 4 is 3.086 V. This is 5.9% more than for the dry sample (refer to Fig. 2). Moisture content in latter insulation sample is about 12.0%.

When a DC voltage is applied, the behavior of partial discharges is changed. With the application of ripple voltage, partial discharge pulses tend to cluster around the ripple peaks, where the applied voltage having complicated waveform

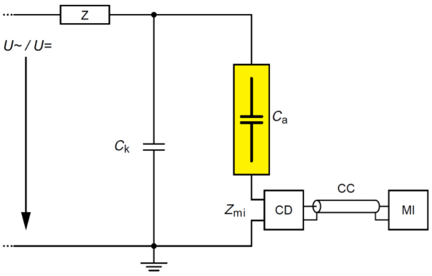
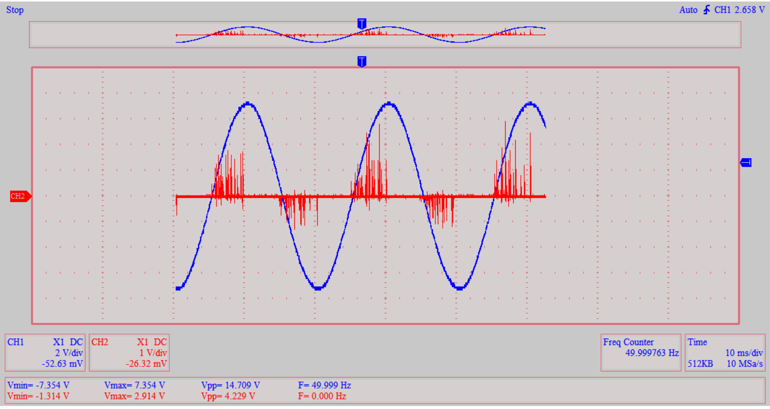


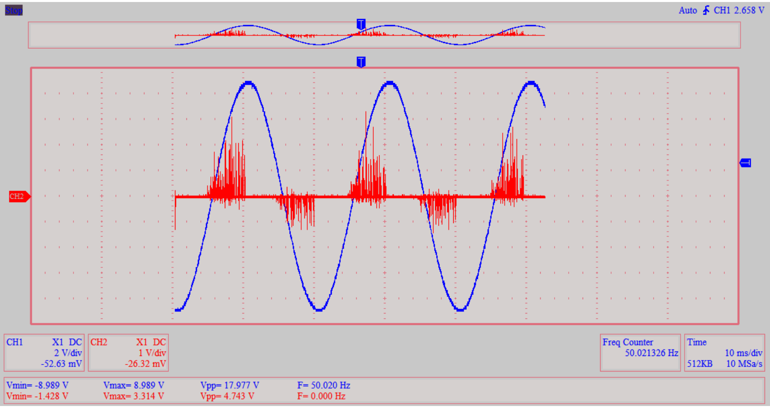
Figure 1 – Circuit diagram of measuring system when coupling device is connected in series with the test object



```
CH1        X1  DC    CH2        X1  DC                Freq Counter          Time
             2 V/div              1 V/div                  49.999763 Hz                10 ms/div
          -52.63 mV            -26.32 mV                                    512KB     10 MSa/s

Vmin= -7.354 V     Vmax= 7.354 V     Vpp= 14.709 V     F= 49.999 Hz
Vmin= -1.314 V     Vmax= 2.914 V     Vpp= 4.229 V      F= 0.000 Hz
```

Figure 2 – Time-resolved pattern of partial discharges in dry insulation at 7.3 kV AC voltage

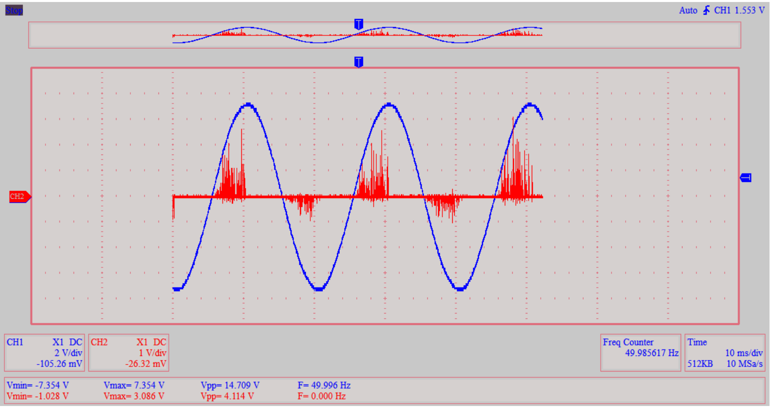


Auto CH1 2.658 V

CH1 X1 DC 2 V/div -52.63 mV
CH2 X1 DC 1 V/div -26.32 mV
Freq Counter 50.021326 Hz
Time 10 ms/div 512KB 10 MSa/s

Vmin= -8.989 V Vmax= 8.989 V Vpp= 17.977 V F= 50.020 Hz
Vmin= -1.428 V Vmax= 3.314 V Vpp= 4.743 V F= 0.000 Hz

Figure 3 – Time-resolved pattern of partial discharges in dry insulation at 9.0 kV AC voltage



Auto CH1 1.553 V

CH1 X1 DC 2 V/div -105.26 mV
CH2 X1 DC 1 V/div -26.32 mV
Freq Counter 49.985617 Hz
Time 10 ms/div 512KB 10 MSa/s

Vmin= -7.354 V Vmax= 7.354 V Vpp= 14.709 V F= 49.996 Hz
Vmin= -1.028 V Vmax= 3.086 V Vpp= 4.114 V F= 0.000 Hz

Figure 4 – Time-resolved pattern of partial discharges in moistened insulation at 7.3 kV AC voltage

is at a maximum. This is shown in Fig. 5, where a non-ideal DC voltage waveform is applied to the insulation.

When exposed to DC voltage, the activity of partial discharges depends on the ripple component, that is, on how much the actual voltage differs from the ideal DC voltage. A non-ideal DC voltage waveform can be considered as a composite of an ideal DC component with an AC voltage overlaid, resulting in ripple voltage.

Actually, ripple is undesirable in HVDC systems, and the smaller the ripple, the better smoothing action of AC filters in HVDC systems. In this paper, ripples are deliberately introduced to study their effect on the characteristics of partial discharges. Ripple component can be described by peak-to-peak ripple voltage.

Magnitude of the applied ripple voltage in Fig. 5 is the same as the AC voltage in Fig. 4. A half wave rectifier circuit that uses only one diode for the transformation was used in this research. Peak-to-peak ripple voltage in Fig. 5 is 2.0 kV. The maximum amplitude of partial discharge pulses is 3.372 V. This is 9.3% more than in the case of an AC voltage of the same magnitude. No partial discharges on the falling slopes of the rectified sinusoidal voltage were observed. Moisture ingress plays a decisive role in the behavior of partial discharges under DC and ripple voltage. This can be shown by removing moisture as an influencing factor in Fig. 6.

Compared to the insulation sample in Fig. 5, in the insulation sample in Fig. 6 moisture content reduced from 12.0% to 2.0%. Magnitude and ripple component are the same in both cases. The nearly complete removal of absorbed moisture as influencing factor leads to the almost complete elimination of partial discharges and a decrease in their amplitude by 91.5%: from 3.372 V in Fig. 5 to 0.285 V in Fig. 6. Thus, to obtain a reliable statistical data, a DC or ripple voltage must be applied to the insulation for a longer time than under AC voltage conditions.

A further increasing the applied rectified voltage and ripple component causes a rising of partial discharge intensity (Fig. 7).

Figure 5 – Time-resolved pattern of partial discharges in moistened insulation at 7.3 kV DC ripple voltage

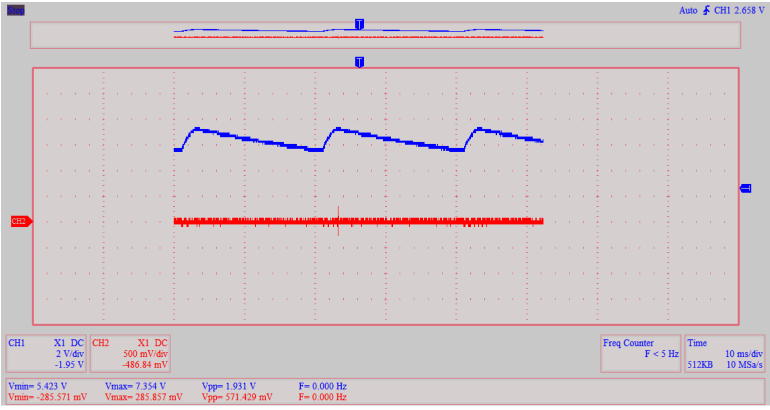


Figure 6 – Time-resolved pattern of partial discharges in dry insulation at 7.3 kV DC ripple voltage

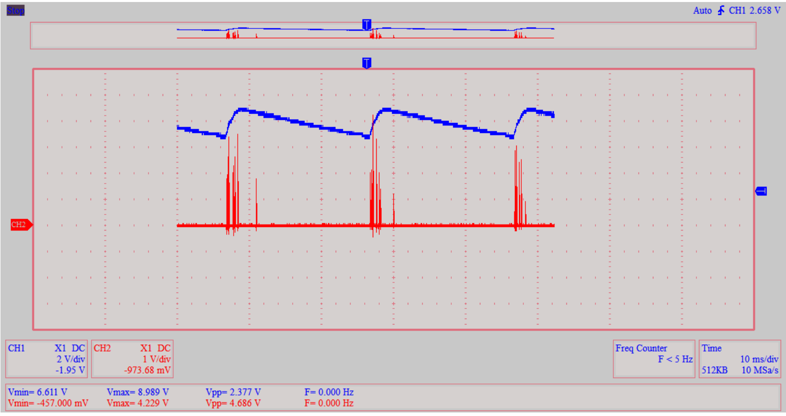


Figure 7 – Time-resolved pattern of partial discharges in moistened insulation at 9.0 kV DC ripple voltage

Peak-to-peak ripple voltage in Fig. 7 was increased to 2.4 kV. The maximum amplitude of partial discharge pulses rose to 4.229 V. With the same moisture content (12.0%), but an increase in the amplitude of the applied rectified voltage by 22.2%, the amplitude of the partial discharge pulses increased by 25.4% (refer to Fig. 5 and Fig. 7). This time case rare partial discharges on the falling slopes of the rectified sinusoidal voltage were observed. The majority of partial discharges still appear on the rising slopes of the sinusoidal voltage cycle and they are concentrated around the peaks of rectified sinusoidal voltage waveform.

CONCLUSIONS. This article examines the partial discharge behavior at AC and DC voltages. The partial discharge pulses have the same polarity as the applied voltage, for example for positive half-cycle of pure AC voltage and positive rectified AC voltage current pulses are the same polarity. In case of a DC voltage, the moisture absorbed by the insulation has a greater influence on the partial discharge intensity than the ripple component. Under a DC voltage conditions, drying the insulation and removal of absorbed moisture as influencing factor leads to the almost complete elimination of partial discharges and a decrease in their amplitude by 91.5% compared to moistened sample.

Contrary to a pure DC voltage, phase-resolved partial discharge analysis can be used for a ripple voltage waveform. The required phase angle assignment to a single partial discharge event becomes possible due to the ripple peaks being present in the rectified voltage plot, which indicate where the start and end of the sinusoidal voltage cycle is.

Future work for this research should be focused on specific questions regarding application of three-capacitance model for simulation of partial discharges under ripple voltage conditions and study of environmental aspects.

## REFERENCES

1. International standard IEC 60270:2000, “High-voltage test techniques – Partial discharge measurements”. Third edition, pp. 1-99. ISBN 2-8318-5507-1.

2. Gulski, E. (1995), “Digital analysis of partial discharges”, *IEEE Transactions on dielectrics and electrical insulation*, Vol. 2, No. 5, pp. 822-837. doi: 10.1109/94.469977.

3. Higinbotham, W. G. (2020), “Partial discharge secrets, tips, and tricks”, *NETA World. The International Electrical Testing Association Journal*, Fall 2020, pp. 2-7.

4. Morette, N., Heredia, L. C., Ditchi, T., Mor, A. R., & Oussar, Y. (2020). Partial discharges and noise classification under HVDC using unsupervised and semi-supervised learning. *International Journal of Electrical Power & Energy Systems*, 121, 106129. doi: 10.1016/j.ijepes.2020.106129.

5. Portugues, I. E., Moore, P. J., Glover, I. A., Johnstone, C., McKosky, R. H., Goff, M. B., van der Zel, L. (2008), “RF-based partial discharge early warning system for air-insulated substations”, *IEEE Transactions on Power Delivery*, vol. 24, no. 1, pp. 20-29, doi: 10.1109/TPWRD.2008.2005464.

6. Sacuto, F., Labeau, F., Agba, B. L. (2014), "Wide band time-correlated model for wireless communications under impulsive noise within power substation", IEEE Transactions on Wireless Communications, Vol. 13, No. 3, pp. 1449-1461, doi: 10.1109/TWC.2014.011714.130685.

7. Madi, G., Sacuto, F., Vrigneau, B., Agba, B. L., Pousset, Y., Vauzelle, R., & Gagnon, F. (2011), “Impacts of impulsive noise from partial discharges on wireless systems performance: application to MIMO precoders”, *EURASIP Journal on Wireless Communications and Networking*, Vol. 1 (186), pp. 1-12, doi:10.1186/1687-1499-2011-186.

8. Abdallah, A. S. (1999), “Electric fields from transmission lines nearby populated areas in Egypt: theory versus experiment”, *1999 Eleventh international symposium on high voltage engineering*, Vol. 2, pp. 119-122, doi: 10.1049/cp:19990610.

9. Javadi, H., Mobarhani, A., Ameli, A. (2010), “Electric field evaluation of 400kV overhead transmission lines on the earth surface”, *5th IET International conference on system safety 2010*, pp. 1-5, doi: 10.1049/cp.2010.0841.

10. Reimers, E., Flydal, K., Stenseth, R. (2000). “High voltage transmission lines and their effect on reindeer: A research programme in progress”. *Polar Research*, Vol. 19, No. 1, pp. 75-82.

11. Tyler, N. J., Stokkan, K. A., Hogg, C. R., Nellemann, C., Vistnes, A. I. (2016), “Cryptic impact: Visual detection of corona light and avoidance of power lines by reindeer”, *Wildlife Society Bulletin*, Vol. 40, No. 1, pp. 50-58, doi: 10.1002/wsb.620.

12. Fard, M. A., Farrag, M. E., McMeekin, S. G., Reid, A. J. (2017), “Partial discharge behavior under operational and anomalous conditions in HVDC systems”, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 24, no. 3, pp. 1494-1502, 2017, doi: 10.1109/TDEI.2017.006469.

13. Guo, R., Wang, K., Xu, Z., Li, J., Sun, J. Cheng, H. (2016), “Partial discharge characteristics and classification in oil-paper insulation under DC voltage”, *2016 IEEE International Conference on High Voltage Engineering and Application (ICHVE)*, pp. 1-4, 2016, doi: 10.1109/ICHVE.2016.7800629.

14. Trotsenko, Y., Brzhezitsky, V., Protsenko, O., Mykhailenko, V. (2019), “Application of three-capacitance models for simulation of partial discharges in solid dielectric containing several cavities”, *2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering (UKRCON), Lviv, Ukraine*, pp. 279-282. doi: 10.1109/UKRCON.2019.8879931.

15. Illias, H. A., Chen, G., Lewin, P. L. (2017), “Comparison between three-capacitance, analytical-based and finite element analysis partial discharge models in condition monitoring”, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 24, no. 1, pp. 99-109, doi: 10.1109/TDEI.2016.005971.

16. Trotsenko, Y., Protsenko, O., Nesterko, A., Chyzhevskyi, V., Mykhailenko V. (2021), “Calibration of experimental installation for measuring partial discharges in low capacitance insulation samples”, *Transactions of Kremenchuk Mykhailo Ostrohradskyi National University*, Issue 5(130), pp. 97-102. doi: 10.30929/1995-0519.2021.5.97-102.

17. Trotsenko, Y., Peretyatko, J., Protsenko, O., Dixit, M. M. (2022), “Effect of vacuum drying the insulation pressboard on partial discharge characteristics under ripple voltage conditions”, *Technology Audit and Production Reserves*, Vol. 2, No. 1(64), pp. 28-33, doi:10.15587/2706-5448.2022.256564.

18. Trotsenko, Y., Protsenko, O., Mykhailenko, V., Burian, S. (2020), “Effect of direct voltage ripples on partial discharge activity in solid dielectric”, *2020 IEEE Problems of Automated Electrodrive. Theory and Practice (PAEP), Kremenchuk, Ukraine*, pp. 1-5, doi: 10.1109/PAEP49887.2020.9240799.

19. Romano, P., Imburgia, A., Rizzo, G., Ala, G., Candela, R. (2021), “A new approach to partial discharge detection under DC voltage: Application to different materials”, *IEEE Electrical Insulation Magazine*, Vol. 37, No. 2, pp. 18-32, doi: 10.1109/MEI.2021.9352713.

# ОГЛЯД ЕКОЛОГІЧНИХ АСПЕКТІВ ЧАСТКОВИХ РОЗРЯДІВ ТА АКТИВНОСТІ ПРИ НАПРУЗІ ЗМІННОГО ТА ПОСТІЙНОГО СТРУМУ

**Євгеній Троценко**
кандидат технічних наук, доцент
кафедра теоретичної електротехніки Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», проспект Перемоги, 37, м. Київ-56, Україна, 03056, e-mail: trotsenko2014@gmail.com
**ORCID: 0000-0001-9379-0061**

**Нестерко Артем**
кандидат технічних наук, доцент
кафедра автоматизації енергосистем Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського» проспект Перемоги, 37, м. Київ-56, Україна, 03056, e-mail: watefir@gmail.com
**ORCID: 0000-0001-7488-4214**

**Юлія Перетятко**
кандидат технічних наук, доцент
кафедра автоматизації енергосистем Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського» проспект Перемоги, 37, м. Київ-56, Україна, 03056, e-mail: peretyatko.julia@gmail.com
**ORCID: 0000-0003-1397-8078**

**Мандар Мадхукар Діксіт**
доцент
кафедра електротехніки Інститут управління підприємництвом та інженерних технологій Вішванікетана Survey No. 52, Kumbhivali, Tal, Khalapur, Maharashtra, 410202, India e-mail: mandardixit78@gmail.com
**ORCID: 0000-0003-1959-7815**

Глобальний розвиток високовольтних передач постійного струму призвів до зростаючого інтересу до вимірювання та аналізу часткових розрядів при напрузі постійного струму. Проведено вимірювання часткових розрядів у сухій та зволоженій ізоляції під напругою змінного та постійного струму. Застосовано методику електричного вимірювання часткових розрядів. Використано вимірювальну систему, в якій з’єднувальний пристрій увімкнено послідовно з досліджуваним об’єктом. Проведено огляд впливів часткових розрядів, переважно коронного розряду, на довкілля. Проведено дослідження впливу зволоження ізоляції на характеристики часткових розрядів за різних форм напруги. В умовах напруги постійного струму усунення поглиненої вологи, як фактора впливу призводить до практично повного усунення часткових розрядів та зменшення їхньої амплітуди більш ніж на 90% порівняно із зволоженим зразком. Модифікована вимірювальна система дозволяє вимірювати частковий розряд при різних формах напруги. Вимірювання часткових розрядів при напрузі змінного та постійного струму проводилися в однакових умовах, зокрема при однаковій величині прикладеної напруги та вологомісткості в ізоляції. Прикладена напруга змінювалась від 7.3 кВ до 9.0 кВ. Вологомісткість в ізоляції змінювалася від 2.0% до 12.0%.

Основну увагу приділено впливу пульсацій напруги на характеристики часткових розрядів. Отримані дані роблять внесок у дослідження явища часткових розрядів при впливі на ізоляцію нестандартних форм прикладеної напруги. Аналіз часткових розрядів з фазовим розділенням також можна використовувати для пульсуючої напруги. Потрібний зв'язок фазового кута з окремим частковим розрядом стає можливим завдяки наявності піків пульсацій на осцилограмі випрямленої напруги. Подальші зусилля за тематикою цього дослідження повинні бути зосереджені на конкретних питаннях щодо застосування трьохємнісної схеми заміщення для моделювання часткових розрядів в умовах пульсацій напруги та вивчення екологічних аспектів.

**Ключові слова**: частковий розряд, вологомісткість, пульсації напруги, екологічний аспект.

*Стаття надійшла 13.05.2022*