Partial Discharges Characteristics Analysis in Power Transmission Lines Artificial Defects

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Abstract. The paper describes the research on partial discharges (PD) characteristics in various types of power transmission lines insulation defects. Thirteen types of insulation defects were considered. PD measurements were performed using the AC high voltage source and commercial PD registration device. Phase-resolved partial discharge (PRPD) patterns, average apparent charge, and PD intensity were obtained for each defect type. The research results showed that most overhead lines insulators defects had relatively high PD intensity with small average apparent charge. Several insulators’ defects showed a low average charge and intensity, but insulators’ bodies in these cases were cut and could be destructed by mechanical loads. Power cable samples showed relatively high intensity and average charge in case of the cable termination defect. However, the needle grounding electrode defect showed considerable average charge and intensity. The obtained results will be useful for the defect type recognition tools development and PRPD patterns base extension.

1. Introduction
The reliable operation of electric power systems is one of the most important tasks of the modern electrical power industry. Despite a significant number of known electrical equipment diagnostic methods, the existing test complex is not effective enough. Besides, power grid companies try to reduce their operating costs. One of the directions, in this case, is to reduce the number of technological disturbances. Therefore, the creation of new and the development of existing methods and tools of high-voltage insulation diagnostics is an urgent task.

Partial discharge (PD) electrical equipment diagnostics is a promising tool. It becomes more widespread in the electric power industry. Partial discharges are usually registered based on occurring physical processes [1]:

- Current pulses of partial discharges. Registration of electric signals of the PD is performed using sensors that provide inductive or capacitive coupling with the measurement object [2,3];
- Acoustic signals [4,5];
- Disturbances in the electromagnetic field [6];
- Changes in the chemical composition of insulating material (e. g. transformer oil) [7].
The partial discharge diagnostics method is widely applicable. It is applied to diagnose transformers [8,9], power cables [10,11], overhead lines insulators [12], rotating machines [13], gas-insulated switchgears [14], circuit breakers [15] etc. There are systems and devices for periodic measurements of partial discharges and their characteristics monitoring during equipment operation. The major advantage of this diagnostic tool is the ability to predict insulation breakdowns based on measured partial discharges characteristics. Note that PD characteristics monitoring can significantly increase the effectiveness of the method due to reliable detection of the defect presence before a breakdown occurs. A known fact is a decrease of partial discharges intensity after its increase and before the insulation breakdown [16]. Partial discharges characteristics measurement by portable devices during this period can show the absence of defects.

Another research direction in this field is partial discharges recognition. PD signals must be separated from the noise and detected as dangerous or not. Noise filtration can be achieved by hardware and software methods. The hardware method example is using the bridge PD registration circuit [1]. Software methods are using neural networks [17,18], wavelet transform [19]. Besides, the cases of multiple defect presence are also studied [20,21].

However, despite the widespread use of the method, research in the field of increasing the PD registration efficiency is still ongoing. For the simplification, insulation defects with partial discharges are artificially recreated in laboratory conditions [22]. At the same time, the phase-resolved partial discharge (PRPD) patterns and their characteristics can significantly differ in various types of defects. It can be explained by the different distribution of the electric field intensity and defects shape in electrical equipment.

2. Problem statement
This work is devoted to the study of PD characteristics in various types of insulation defects in 10 kV overhead and cable power transmission lines. The research results will be useful in further works on recognition of the insulation defect type based on PRPD patterns in combination with other PD characteristics. To achieve the goal the following tasks have to be solved:

- Insulation samples preparation for cable and overhead power lines with artificial defects of various types;
- PD characteristics record in each insulation sample;
- The experimental research results analysis.

3. Theory

3.1. Experimental samples preparation
The paper considers overhead and cable power transmission lines. Therefore, it is required to create artificial defects in both types of insulation. Insulating materials in overhead lines are the air between the wires and insulators of various materials (ceramics, glass, porcelain, polymers, etc.). Discharges in the air in most cases are not harmful to insulation in general. Due to the air natural circulation, a defect rarely develops until a sustained breakdown. Even in case of the air sufficient ionization and an arc occurrence between the phase conductors, the insulation is restored in a short time and can be further operated. This fact is confirmed by the statistics of successful automatic reclosures on overhead power lines.

Therefore, the main insulating element requiring attention in overhead power transmission lines are insulators. Their defects are a destruction of the insulator body and its contamination and moisture. The insulator’s polluting can cause the appearance of surface discharges significant amount with consequent complete overlap. Insulator’s body destruction can be different. For example, cracks can occur in insulators due to mechanical stresses. Electrical treeing can occur inside insulators and lead to the destruction of the insulating material. However, electrical treeing usually occurs in polymer insulators.
due to their relatively lower dielectric constant and, consequently, the higher electric field strength in defects.

In power cables, insulation defects are usually the poor-quality termination and jointing. Besides, cable insulation defects are inhomogeneities of the insulation layer located in the field of high-voltage or grounding electrode or inside the insulation layer. Not all these defect types can be considered under laboratory conditions. A cable termination defect and insulating layer needle form defect in the field of the grounding electrode can be emulated. A defect in the field of the high-voltage electrode and the thickness of the insulation can be researched only if a defect is made at the factory.

Thus, the following types of power transmission lines insulation defects were prepared and investigated in the paper:

- Artificial transverse crack (cut) of the porcelain insulator in the field of the high-voltage electrode;
- Artificial diagonal crack (cut) of the porcelain insulator;
- Artificial transverse crack (cut) of the polymer insulator in the region of the high-voltage electrode;
- Artificial diagonal crack (cut) of the polymer insulator;
- Emulation of a needle high-voltage (HV) electrode in a polymer insulator;
- Artificial porcelain insulators contamination with aluminum powder and moistening;
- Artificial porcelain insulators contamination with carbon black and moistening;
- Artificial porcelain insulators contamination with dust and moistening;
- Termination defect of the power single-core 10 kV shielded cable with XLPE-insulation;
- Needle grounding electrode embedded in the insulation layer of a 10 kV shielded single-core cable with XLPE-insulation.

3.2. Experimental setup

All the listed samples of power transmission lines insulation were tested with AC voltage above the operating. A dielectric test apparatus with up to 50 kV was used as a voltage source. The insulation samples were connected with a large distance between electrodes to minimize discharges in the air. During the experiments, partial discharge characteristics were measured using a commercial PD tester. An inductive sensor was used in measurements - a high-frequency current transformer (HFCT) is installed on a grounding conductor.

During the experiments, PD characteristics were measured in a wide range of voltages. As a result, it was determined that the characteristics of partial discharges are indicative enough at a voltage of 20 kV for insulators of overhead power lines and 15 kV for power cables. The higher test voltage for insulators is explained by a large margin of electrical strength compared to power cables. The thickness of the insulating gap inside the insulator body is 2-3 times greater than in the cable. Besides, porcelain has the dielectric constant much higher than polymers, which might increase the reliability of power supply when using insulators of this type.

4. Experimental data and their analysis

4.1. PRPD patterns

The obtained results of PD measurements in the insulation samples with artificial defects are shown in figure 1.
a) Porcelain insulator with transverse cut

b) Porcelain insulator with diagonal cut

c) Polymer insulator with transverse cut
d) Polymer insulator with diagonal cut

e) Polymer insulator with needle HV electrode

f) Aluminium powder contaminated insulator

g) Aluminium powder contaminated and moistened insulator

h) Carbon black contaminated insulator
Carbon black contaminated and moistened insulator

Dust contaminated insulator

Dust contaminated and moistened insulator

Cable termination defect

Cable needle grounding electrode defect

**Figure 1.** PRPD patterns for insulation samples

Besides, PD intensity and average apparent charge were obtained for each insulation sample. Their measurement results are shown in figure 2

**Figure 2.** Partial discharges average apparent charge and intensity in insulation samples
5. Discussion
The experimental results unexpectedly showed significantly dissimilar PRPD patterns, apparent charge, and intensity. Porcelain insulator’s transverse cut was done in the field of high voltage electrode and it has similar peaks of partial discharges in PRPD patterns with polymer insulator high voltage electrode defect. However, the insulation sample (a) has higher PD intensity and average apparent charge than polymer insulator with needle high voltage electrode defect (e). Probably, this difference is connected with insulating material type in the field of the defect. Sample (a) has a contact with the air in the field of the defect and sample (e) has mostly insulator’s material. Polymer insulators with transverse (c) and diagonal (d) cut showed similar to needle HV electrode defect (e) PRPD pattern. However, PD peak in the field of positive voltage half-wave is more concentrated and expressed. Porcelain insulator with diagonal cut (b) showed the least PD intensity and average apparent charge. This fact is probably connected with the insulator material and design. The porcelain insulator has the largest dielectric constant and insulating gap thickness. Therefore, significant discharges were not registered. Contaminated insulators showed similar PRPD patterns. Partial discharges are mostly positive both in positive and negative half-waves. All contaminated insulator samples showed relatively low average apparent charge and high PD intensity. Besides, the insulator sample’s moistening caused the average apparent charge reduction in every insulator sample. Carbon black contaminated insulators showed PD intensity 25% increase after moistening. However, the other contaminated insulators did not show a considerable change in these conditions. The cable termination defect (l) showed considerable PD intensity and average apparent charge comparable with the sample (a). PRPD pattern has the expressed form of negative discharges half-wave. Discharges in a positive half-wave are distributed between 0 and 150°. The cable grounding electrode needle defect (m) has expressed a triangular shape form both in a positive and negative half-wave with displaced to the half-wave start maximum.

6. Conclusion
Thirteen power transmission lines insulation defect types were researched in this paper. PD measurements were performed using the HCFT sensor of the commercial device and AC 50 Hz voltage source. However, the device’s software could detect the defect type only in cable insulation defect samples. Insulators' defects were detected as defects with the possible danger of breakdown but defect types were not recognized. Therefore, PD defect detection tools have to be improved. The obtained research results will be useful for the development of PD defect recognition tools and the defects PRPD patterns base extension.

7. References

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