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The Influence of a Multilayer Paper-Oil Insulation of Power Transformers on the Measurement Results of Partial Discharges Measured by the Acoustic Emission Method

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The paper presents the measurement results of the acoustic emission (AE) generated by partial discharges (PDs) in a system with multilayer electroinsulation partitions. A short review of electroinsulation materials that can be found in a transformer insulation system was carried out and their influence on the AE signals registered was evaluated. The estimation of their influence was made by using the frequency and time-frequency analyses.

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Introduction

Proper evaluation of the damage degree of paper-oil insulation of high-voltage power appliances by the AE method is connected with accurate recognition of the factors that can affect the registered AE signals coming from PDs. One of such factors can prove to be multilayer stiff barriers used as permanent transformer insulation. The aim of the research work carried out, the results of which are presented in this paper, is determining the influence of multilayer systems of permanent transformer insulation on the AE signal parameters in the frequency domain.

The winding insulation in transformers of high power is most often made of a cable paper of a big number of layers. The thickness of the insulation wound on the wires of a winding depends on the transformer nominal voltage, winding voltage, the values of test voltage at an impulse test and it should also take into account the possibility of mechanical insulation damage at winding and during a regular transformer operation. In some transformers, where strong dynamic reactions of windings that occur during operation can cause mechanical damage to insulation, an additional layer of wire-insulation is used. Such a system, apart from electroinsulation oil soaked with oil, also contains a layer of polyethylenoteraphthal foil of a trade name ‘estrofol’. Estrofol has been widely used due to its high mechanical endurance, which is much bigger than that of electroinsulation paper. A layer of estrofol is wound directly on the wire, and then consecutive layers of paper are overlaid. A small number of estrofol layers increases significantly mechanical resistivity of a winding insulation and therefore it also increases its electrical resistance. Special distance or radial inserts are often placed between the particular layers of a winding, which are most often made of transformerboard. If transpositions are used in places where wires are subjects to mechanical bends or soldering, the wire insulation is additionally strengthened with a pressboard plate [5,7].

For tests, the results of which are presented below, the most often used insulation barriers were applied: estrofol, cable paper, pressboard, transformerboard. The material samples under study were made available by ENERGOSERWIS, Inc. – Power Enterprise in Lubliniec.

I. Characteristics of the measurement path

A model set-up of two flat electrodes, between which cellulose insulation was placed, was used for generation of partial discharges of the surface type (SPDs). The choice of surface partial discharges was purposeful as it is the most common form of partial discharges occurring in insulation systems of transformers, power capacitors, bushing insulators, cable heads, and current and voltage measuring transformers [2,3].

The modeling spark-gap was immersed in a transformer tub filled with electroinsulation oil and supplied with high alternating voltage of the power frequency and rms current of 15.6 kV.

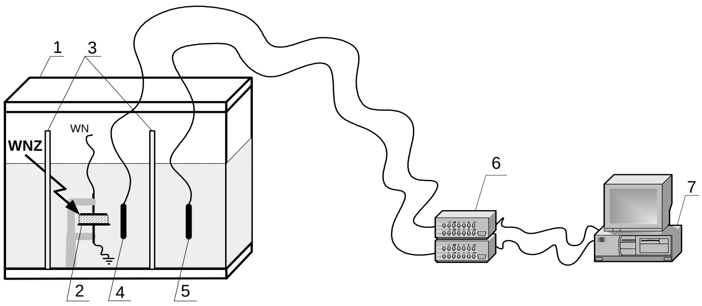


Fig. 1. Diagram of the set-up for the measurement and analysis of the AE signals generated by SPDs.
1 – transformer tub filled with electroinsulation oil, 2 – spark-gap modeling SPDs, 3 – multilayer permanent insulation, 4 – hydrophone in the place of SPD generation, 5 – hydrophone away from the place of SPD generation, 6 – measuring amplifiers and filters, 7 – computer equipped with a CH 3160 measuring card.

a) b) c)

Fig. 2. Elements of the measurement path
hydrophone Brüel&Kjaer type 8103 b) measuring amplifier AE Signal Conditioner equipped with a band-pass filter
c) Acquitec CH3160 card

The AE signals generated by SPDs were measured with two hydrophones type 8103 by the Brüel&Kjaer in such a way that one of the transducers received the AE signals in the generation place of SPDs, and the other received a signal after passing through electroinsulation layers (Fig. 1). The hydrophones used are characteristic of a flat transfer characteristics in the band from 0.1 Hz to 180 kHz, and their sensitivity is equal to 48.3 μV/Pa [4]. The AE signals measured were amplified in two independent measuring amplifiers AE SIGNAL CONDITIONER by the firm AE SYSTEM. The amplification of the amplifiers is 34 dB in the band (0.1 – 1.5) MHz. An active high-pass filter of the cut-off frequency of 16 kHz and a low-pass filter of the cut-off frequency of 900 kHz [6] were attached to the amplifier. A computer equipped with a four-channel measuring card type CH 3160 by the firm Acquitec was used for registration of the AE signals measured. The measuring card used is of a 12-bit resolution and enables a simultaneous sampling and registration of the four channels with the speed of 10 MS/s. During the measurements the sampling frequency of 2.56 MHz was adopted and 51,200 samples were registered. It made it possible to record runs of the length of 20 ms (supplying voltage period) [1].

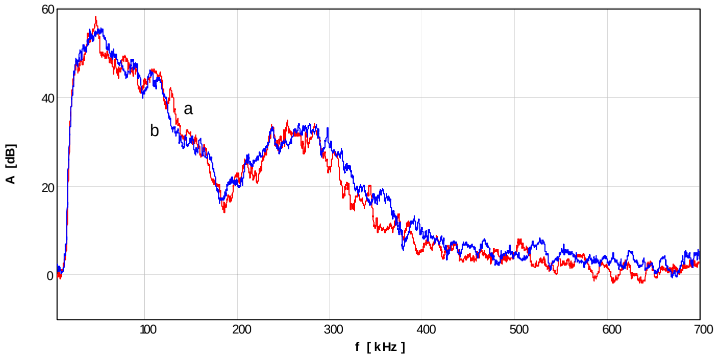
II. Results of the frequency and time-frequency analyses carried out

The AE signals generated by SPDs were measured with the hydrophones placed on both sides of the multilayer electroinsulation partition. The AE signals registered were subject to the frequency analysis – determining amplitude spectra (Fig. 3) and to the time-frequency analysis – drawing two-dimensional spectrograms of the spectrum density of energy (Fig. 4) and three-dimensional spectrograms of the spectrum density of energy (Fig. 5). For the characteristics of the amplitude spectrum noise signals were eliminated as result of digital filtration. The diagrams presented below (Fig. 3) show amplitude spectra coming from the hydrophone placed before the partition, and for comparison, spectra from the hydrophone placed behind the partition.

In the further analysis of the AE signals in the frequency domain the values of the selected descriptors that characterize them were calculated.

Table 1. Collective listing of the descriptor values of the AE signals calculated for the amplitude spectrum

1)



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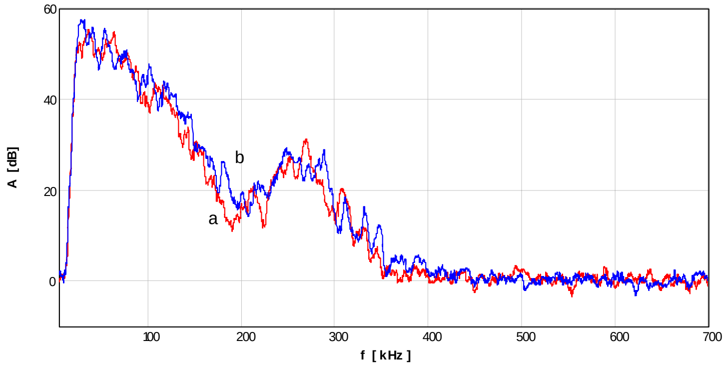

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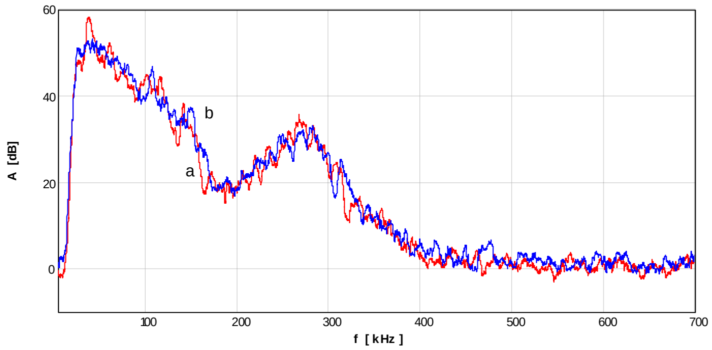

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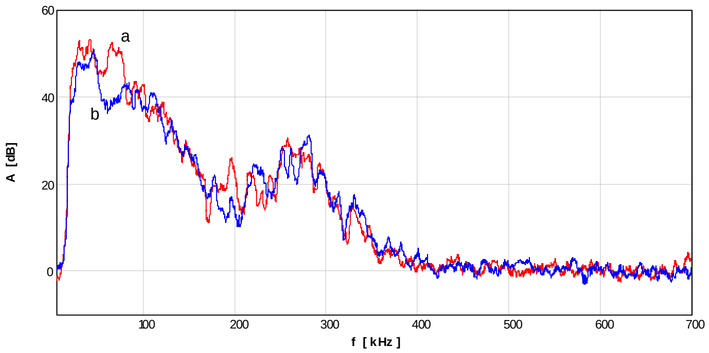

Fig. 3. Amplitude spectra of the AE signals from SPDs before the partition (a) and behind the partition (b). 1) estrofol – cable paper, 2) pressboard – transformerboard, 3) estrofol – cable paper – pressboard, 4) estrofol – cable paper – pressboard – transformerboard

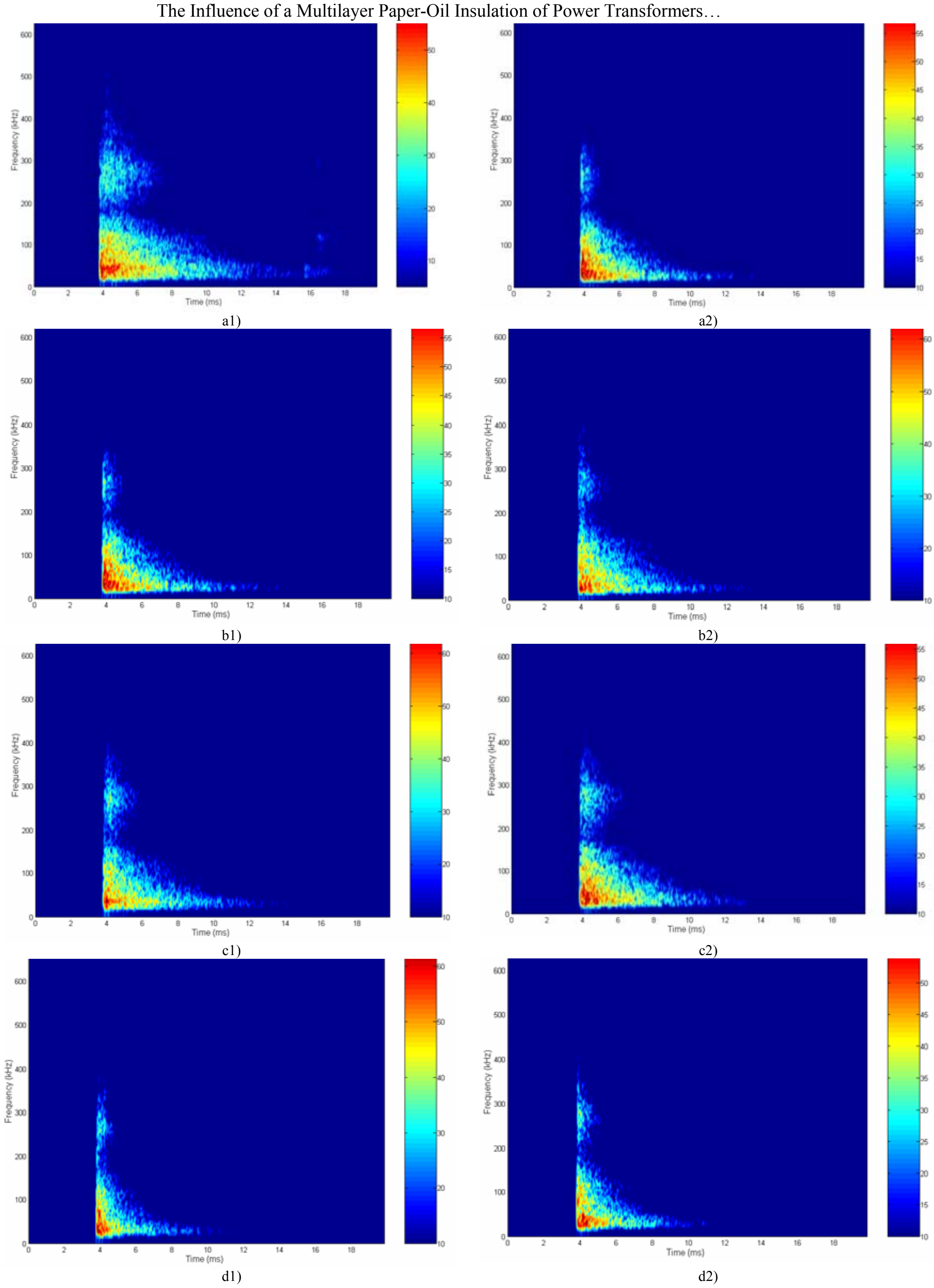

Fig. 4. Two-dimensional spectrograms of the spectrum density of energy of the AE signals from SPDs before the partition (a1, b1, c1, d1) and behind the partition (a2, b2, c2, d2):
a1, a2) estrofol – cable paper, b1, b2) pressboard – tramsformerboard, c1, c2) estrofol – cable paper – pressboard, d1, d2) estrofol – cable paper – pressboard – transformerboard

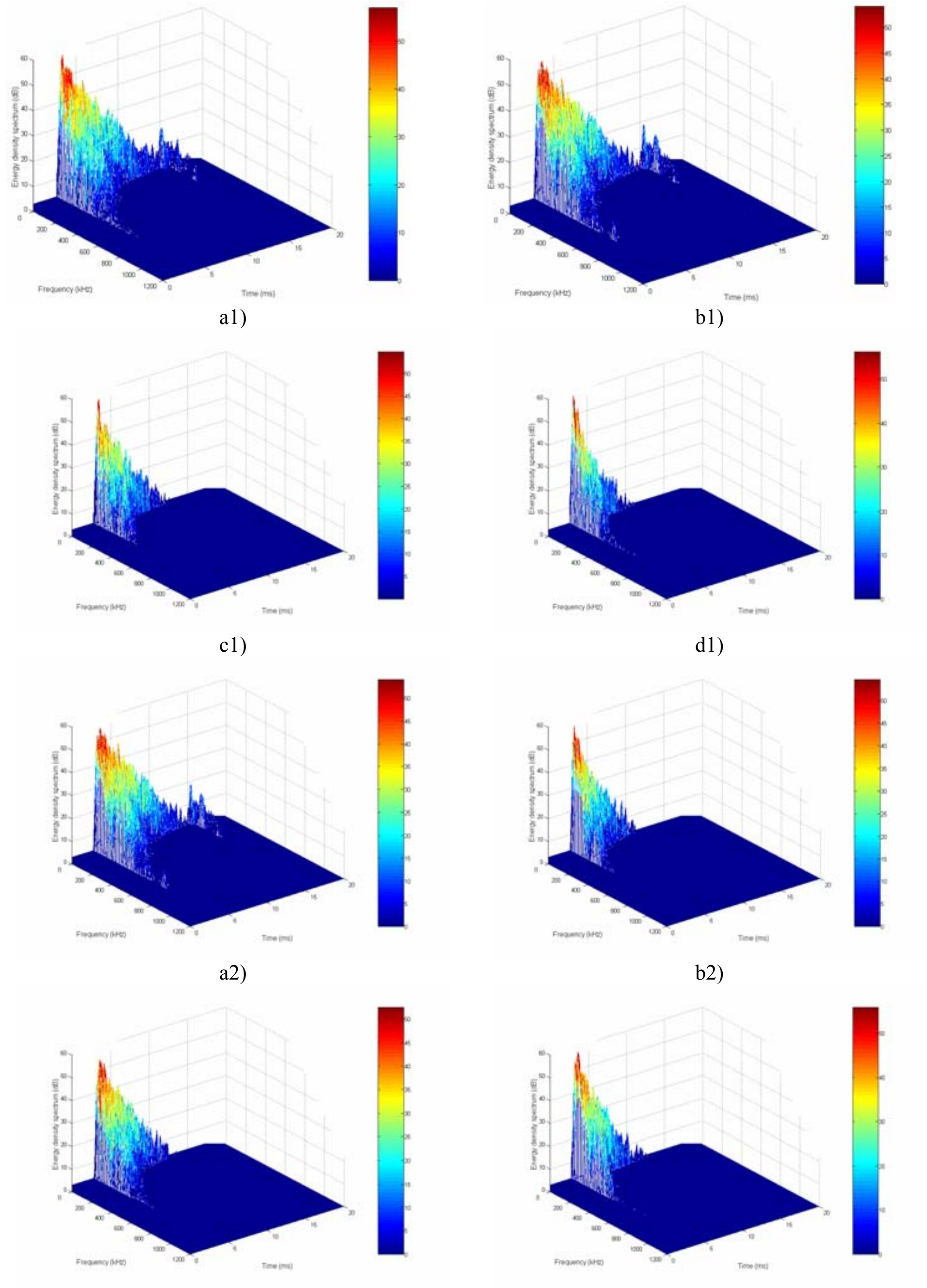

Fig. 5. Three-dimensional spectrograms of the spectrum density of energy of the AE signals from SPDs before the partition (a1, b1, c1, d1) and behind the partition (a2, b2, c2, d2):

a1, a2) estrofol – cable paper, b1, b2) pressboard – tramsformerboard, c1, c2) estrofol – cable paper – pressboard, d1, d2) estrofol – cable paper – pressboard – transformerboard

Table 2. Collective listing of the descriptor values of the AE signals calculated for the spectrum density of energy

Summing-up

Carrying out the frequency and time-frequency analyses it was concluded that the type of the multilayer insulation partition does not have influence on the parameters of the AE signals generated by SPDs in the frequency domain. This has been proved by the drawn characteristics of the amplitude spectrum of a signal (Fig. 3), the run of which has been averaged. The spectrum coming from the hydrophone placed before the insulation partition (a) overlaps, to a large extent, the spectrum coming from the hydrophone placed behind the partition (b). A similar conclusion can be drawn comparing the spectrograms of the spectrum density of energy, comparing both two-dimensional (Fig. 4) and three-dimensional (Fig. 5) spectrograms. The range of dominant frequencies is identical and it is contained in the band from about 20 kHz to 400 kHz and does not depend on the place of measurement of the AE signals (before or behind the partition) or the type of the permanent insulation. A characteristic ‘saddle’ in the range from 180 kHz to 250 kHz results from the transfer characteristics of the transducers used. The next proof confirming the above-stated conclusion are the determined frequency descriptor values of the AE signals (Table 1, 2). The descriptor values are relatively constant, both before and behind the partition.

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Table 1

Collective listing of the descriptor values of the AE signals calculated for the amplitude spectrum

Spectrum density of amplitude						
Kind of stable insulation	**Peak coefficient (inside) [-]**	**Peak coefficient (outside) [-]**	**Shape coefficient (inside) [-]**	**Shape coefficient (outside) [-]**	**Median Frequency (inside) f_{med} [kHz]**	**Median Frequency (outside) f_{med} [kHz]**
Estrofol-Paper	13,14	12,54	3,66	3,44	62,20	67,87
Pressboard-Transformerboard	12,65	13,02	3,81	3,80	56,69	60,17
Estrofol-Paper-Pressboard	13,47	13,87	4,02	3,82	53,47	59,29
Estrofol-Paper-Pressboard-Transformerboard	13,57	13,37	3,98	3,84	55,87	58,99
Average value	13,21	13,20	3,87	3,73	57,06	61,58
Standard deviation	0,42	0,56	0,16	0,18	3,69	4,22
Standard deviation [%]	3,1	4,2	4,3	5,1	6,5	6,7

Table 2

Collective listing of the descriptor values of the AE signals calculated for the spectrum density of energy

Spectrum density of energy						
Kind of stable insulation	**Peak coefficient (inside) [-]**	**Peak coefficient (outside) [-]**	**Shape coefficient (inside) [-]**	**Shape coefficient (outside) [-]**	**Median Frequency (inside) f_{med} [kHz]**	**Median Frequency (outside) f_{med} [kHz]**
Estrofol-Paper	25,62	24,56	6,75	6,25	45,68	46,95
Pressboard-Transformerboard	22,93	23,81	6,99	7,13	41,41	40,25
Estrofol-Paper-Pressboard	24,45	27,29	7,42	7,07	41,22	43,56
Estrofol-Paper-Pressboard-Transformerboard	23,75	24,07	7,78	7,41	34,78	40,41
Average value	24,18	24,93	7,23	6,96	40,77	42,79
Standard deviation	1,14	1,60	0,46	0,50	4,49	3,16
Standard deviation [%]	4,7	6,4	6,4	7,2	11,02	7,4

The measurement results presented in this paper prove that the influence of electroinsulation barriers of a transformer multilayer insulation system on the analysis results of the measured AE pulses from SPDs is insignificant, which is important for a proper evaluation of the condition of paper-oil insulation of high-voltage power appliances.

Constant development of the research work on non-destructive evaluation methods of the condition of insulation systems of high-voltage power appliances makes it indispensable to take into account all factors that can influence the measurement parameters of signals.

The research results presented in this paper prove that the influence of electroinsulation barriers of a transformer multilayer insulation system consisting of estrofol, cable paper, pressboard and transformerboard on the analysis results of the measured AE signals from SPDs (in the frequency domain) is statistically of little significance, which is vital for a proper interpretation of the results obtained.

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Вплив багатошарової паперово-масляної ізоляції силових трансформаторів на результати вимірювань часткових розрядів, методом акустичної емісії

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Стаття представляє результати вимірювання акустичної емісії, яка зумовлена частковими розрядами в системі за допомогою полімолекулярного шару перегородки. Короткі замикання матеріалів в системі ізоляції трансформатора були враховані. Оцінка їх впливу була зроблена при використанні частоти і частотних аналізів часу.

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