Optical and Acoustical Methods in Science and Technology 2013

Identification of Deformation Processes within Power Oil Transformers Using Maps of ADC Descriptors in Selected Frequency Bands

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The paper presents identification results of deformation processes within power oil transformers where — according to dissolved gas analysis investigation results — partial discharges took place. The original method worked out for analysis of acoustic emission signals recorded within tested transformer and particularly maps of ADC descriptors have been applied. Analysis has been carried out within chosen frequency bands in order to distinguish signals coming from different sources (among other things partial discharges, Barkhausen's effect, circulation of the oil, and outer acoustic sources). One source of partial discharges has been identified within the tested transformer as a result of analysis of acoustic emission signals.

DOI: 10.12693/APhysPolA.124.525

PACS: 43.40.Le, 52.80.−s, 43.60.−c, 43.58.Ta, 77.22.Jp, 84.70.+p

1. Introduction

Insulation systems decide on safe operation of power equipment. Phenomena which decide in turn on reliability of insulation systems within high voltage power equipment are partial discharges (PD). They initiate aging processes, causing degradation of insulating materials which aftermath are short-circuits and expensive supply disconnections. In order to estimate how is the state of insulation and — by extension — how is remaining time of correct operation of a power transformer the following activities are important: detection and estimation of PD.

Owing to electrical nature of partial discharges, the foreground role in the range of PD investigations is played by electric methods. However, in recent years acoustic emission (AE) method, as an important supplement of measuring methods applied in diagnosis of insulation systems, becomes more and more significant in diagnostic tests of oil power transformers. AE method — first of all — enables us to locate PD sources, and give a unique possibility to observe deformation processes. It is very useful to analyze different partial discharges. Undoubted advantage of AE method is possibility to apply it during normal operation of power transformers. Thus application of AE method enables us to detect partial discharges within power transformers on the basis of diagnostic on-line measurements, without necessity to de-energize of tested objects.

However, such a method has also its limitations. Recorded signals differ from AE signals generated within PD sources because elastic waves, generated by these sources, change during the propagation in a medium as well as during detection and processing of recorded signal. AE elastic waves during propagation in the real medium are subjected to absorption as well as to reflection, refraction, and dispersion. That decreases amplitude of the wave (damping) and changes a pass band of a signal along its propagation path [1, 2]. Besides, AE signals coming from partial discharges are accompanied by other acoustic phenomena appearing in the tested object [1]. In particular, there are inner acoustic interferences, and among other things: Barkhausen's acoustic effect, magnetostriction phenomena, noises connected with oil circulation, and other noises of the medium. For the sake of acoustic nature of these phenomena, they should be identified in detail. Literature reports point at the following frequency bands characteristic for these phenomena: Barkhausen's acoustic effect — from 10 to 65 kHz [3], magnetostriction phenomena — up to 10 kHz [4], noise connected with circulation of the oil and other noises of the medium — about 50 kHz [5]. Effects of these limitations are, proposed in the literature, frequency bands useful for observation of partial discharges within power transformers by means of AE method: 70–180 kHz [3, 6], 100–200 kHz [5], 110–200 kHz [7, 8] and above 500 kHz [9, 10].

In order to analyze properties of AE signals connected with identification of deformation processes within the tested power oil transformer the original method elaborated to analyze AE signals has been applied [11, 12]. Analysis of AE recorded signals has been carried out within chosen frequency bands in order to distinguish signals coming from different sources.

The purpose of the present work was analysis of signals recorded by means of AE method at chosen measuring points on the transformer tank within different frequency bands and fulfillment on this basis identification of deformation processes as well as location of PD sources.

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2. Object and methodology of investigations

The tested object, presented in the paper, was the power oil transformer with power of 25 MVA and rated voltage of 110 kV. Results of the same last testing of the oil coming from the tested transformer, made by means of chromatograph dissolved gas analysis (DGA), proved an increased level of hydrogen and other gases, which pointed out existence of partial discharges within this transformer.

In order to record AE signals within the tested transformer the original measuring system, named as EA DEMA-COMP, was applied [1, 13–16]. AE signals are recorded on selected but accessible to measurements points of lateral surfaces of the tested transformer. Generated AE signals are received by measuring sensors WD type, made by Physical Acoustic Corporation. These points constitute a measuring network on lateral walls of the transformer tank (Fig. 1). Coordinates of measuring network are described in Sect. 3. Signals are recorded several times at each measuring point. During of each signal is 2 s (100 periods of the supply voltage). Measurements have been carried out on-line at the power substation during operation of the transformer.

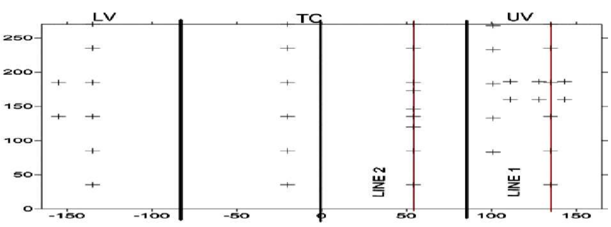

Fig. 1. Positions of measuring points at lateral walls of the tested transformer.

The proposed methodology concerning investigations of AE signals within power oil transformers include recording and analysis of AE signals after filtration within different frequency bands. The basic characteristics, amplitude distributions of AE signals and AE descriptors with acronym ADC are calculated in the frame of this analysis.

The way how this descriptor was defined is presented in [1, 16]. Descriptors consider physical features of investigated phenomenon, connected with propagation and thickness of interconnected layer (logarithmic scale of values in amplitude distributions). Descriptors are not based on values measured immediately and — owing to elimination of principle limits of acoustic measuring methods — describe recorded AE signals and assign them the so-called degree of advance of AE signal. The degree of advance of AE signal is connected with the degree of advance of deformation process. Descriptors take negative values — greater values of descriptor (more flat fragment of a curve) means a higher (more advanced) degree of AE signal.

Afterwards, using kriging method and obtained descriptors, the maps of such descriptors on lateral walls of the tested transformer are determined. On the grounds of these maps, by means of the method of advance degree of signals, PD sources can be localized. Investigations proved that analysis of AE signals carried out within chosen frequency bands enables to identification of deformation processes within tested transformers.

3. Maps of descriptors in chosen frequency bands

Analysis of recorded AE signals has been carried out after filtration within whole range of analyzed frequency (20–200 kHz) as well as within less bands of frequency, among other things within bands of 20–60 kHz and 100–200 kHz. Such a choice of frequency bands enables to distinguish signals coming from different sources — partial discharges, Barkhausen's acoustic effect, oil circulation, and outer acoustic noises.

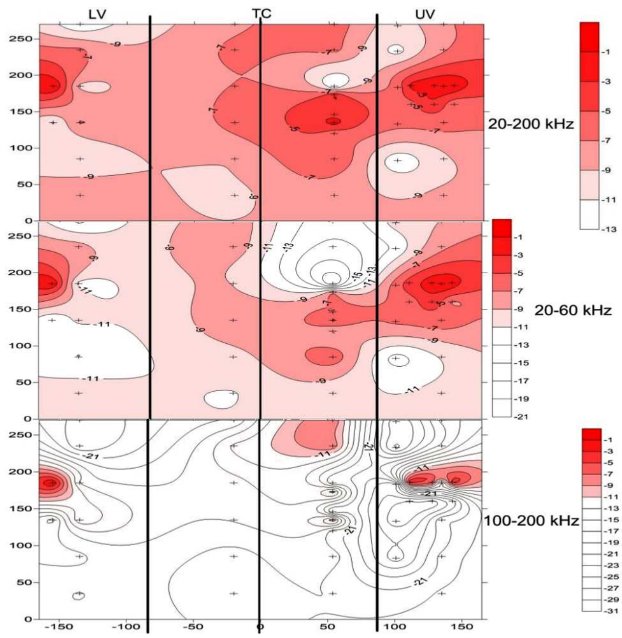

Fig. 2. Maps of ADC descriptor on lateral walls of the transformer tank within chosen frequency bands. Tank dimensions (X; Y) in cm: X — running position along the transformer tank, 0 — the center of the tap changer, positive X values — part of the tank from the side of the upper voltage, negative X values — part of the tank from the side of the lower voltage, Y — running height on the transformer tank, + — measuring points.

Elaborated maps of ADC descriptors for chosen frequency bands used in the tested transformer are presented in Fig. 2. XY plane on these maps is a developed lateral plane of the tank. Coordinates of points on this plane, given in cm, are determined in the following way: values of Y coordinates are calculated from the bottom of the tank, the value of X coordinate is equal to zero for the center of the tap changer, values of X coordinates increase in direction of the side of the upper voltage (UV), values of X coordinates decrease in direction of the side of the low voltage (LV); extreme values of X coordinates describe points opposite to ones which describe the center of the tap changer.

Darkest colors in the map indicate places with greater values of the descriptor, and — in the same — places with greater degree of advance of AE signal, recorded at a measuring point.

These maps point that — owing to analysis of AE signals in different frequency bands and to application of defined descriptors — identification and location of various acoustic sources is possible.

The map of ADC descriptor, obtained in result of analysis of AE signals within the band of 20–200 kHz, describes both AE signals coming from PD and other acoustic noises. Signals coming from outer acoustic noises dominate within the band of 20–60 kHz. The maps of ADC descriptor within the band of 100–200 kHz describe signals coming from partial discharges. There are no components coming from inner acoustic noises within this band.

4. Identification of deformation processes

The purpose of subsequent analysis of AE signals was determination of values of ADC descriptor at chosen measuring points situated in two measuring lines (line 1 and line 2 marked in Fig. 1) within frequency bands of 20–40, 40–60, 60–80, 80–100 kHz, and within the band of 100–200 kHz.

Values of ADC descriptors for AE signals recorded at measuring points 1–6 in a measuring line 1 during analysis of the signal within chosen frequency bands have been presented in Fig. 3. Analysis of the diagram contained ADC descriptor, calculated within the band of 100–200 kHz, identifies the PD source situated near the measuring point 4. Identical location of PD source was received from diagrams of ADC descriptor calculated within the bands of 60–80 kHz and 40–60 kHz. Detail analysis concerning width of the pick round maximum gives similar values for frequency bands of 100–200 kHz and 60–80 kHz, as well as greater value within the band of 40-60 kHz. It shows that the signal within this frequency band contains — besides of components coming from PD sources — components coming from other acoustic phenomena. Values of ADC descriptors prove considerable advance degree of the signal coming from PD source, situated near the measuring point 4.

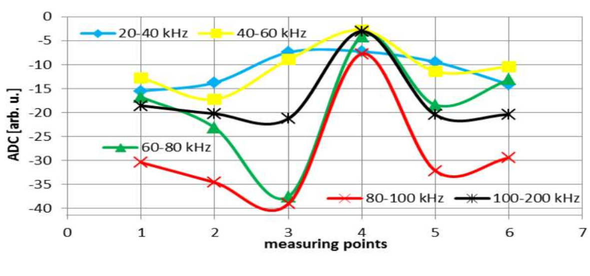

Fig. 3. Diagram of ADC descriptor values within chosen frequency bands from succeeding measuring points at line 1 (numeration of measuring points from the bottom of the line).

Basic characteristics of AE signal recorded at the measuring point 4 for frequency band of 100-200 kHz is pre-

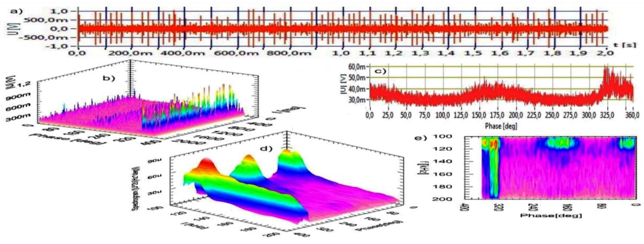

Fig. 4. Introductory description of the AE signal recorded at selected measuring point of the transformer (measuring line 1, measuring point 4): (a) impulse, (b) phase–time characteristic, (c) averaging phase characteristic, (d), (e) averaging STFT spectrograms, ADC = −3.06 (file T1G02(2).BIN, band of 20–100 kHz).

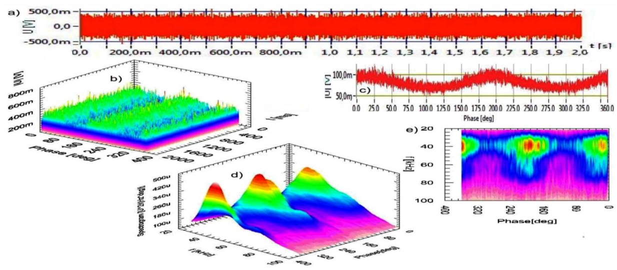

Fig. 5. Introductory description of the AE signal recorded at selected measuring point of the transformer (measuring line 1, measuring point 2): (a) impulse, (b) phase–time characteristic, (c) averaging phase characteristic, (d), (e) averaging STFT spectrograms, ADC = −9.70 (file T1B02(2).BIN, band of 100–200 kHz).

sented in Fig. 4. These characteristics show the following properties of the signal: it appears regularly twice during each period of the supply voltage and its bands of phases where the signal appears are very narrow (Fig. 4b); the signal has dominant frequency band of 100-120 kHz and big amplitudes.

Analysis of AE signal recorded at the measuring point 4 for frequency band of 20–100 kHz shows that within the band of 40–80 kHz there are components both coming from PD and from other acoustic phenomena; phase of occurrence of PD phenomena is contained in the space of a base typical for other acoustic phenomena.

It is worth adding that an effect of described investigations was revision of the power oil transformer which proved that near the measuring point 4 conductors connecting HV leads and tap changer have been situated considerably nearer the transformer tank — discordantly with designed solutions. PD were not recorded after restoration of proper distances in the vicinity of the measuring point 4.

Basic characteristics of AE signal, recorded at the measuring point 2 for frequency band of 20–100 kHz, are presented in Fig. 5. Prevailing weightiness, as seen in Fig. 3, is possessed by components coming from other acoustic phenomena. Properties of the recorded signal are as follows: it appears regularly twice during each period of the supply voltage, it has dominant frequency band of 30–50 kHz, its ADC descriptor is value of −9.70, and bands of phases where the signal appearing at each periods of the supply voltage falls into very wide "corridors" (Fig. 5b). Such wide corridors enable to identify sources of these signals as Barkhausen' noises. There are also components coming from one PD source, recorded at the vicinity of the measuring point 4. It is visible well in Fig. 5e in the form of two areas of phases lying within the band of 50–70 kHz.

ADC descriptor values for AE signals recorded at measuring points 1–9 in the measuring line 2 during signal analysis at chosen frequency bands are presented in Fig. 6. Measuring points 1–9 in the measuring line 2 are situated in the area of the tap changer. Therefore, partial discharges should come from PD and not from magneto-acoustic phenomena.

According to Fig. 6, signals recorded at measuring points 4 and 6 have the greatest advanced level. It is worth to remember that in the case of ADC descriptors the accepted scale is logarithmic one. Values of ADC descriptor below −5 of conventional unities show lack of advanced deformation processes [1]. Basic description of signals recorded at these points proves that partial discharges are sources of these signals. However, values of ADC descriptors are small (ADC = −8.74), therefore recorded AE signals are generated by PD sources with little advanced degree. Such an analysis qualifies for a conclusion that — though basic characteristics for the signal recorded at measuring points do not differ considerably from basic characteristic of PD source located in the line 1 — ADC descriptor values decide on a propriety that advanced PD sources do not appear in the area of the tap changer.

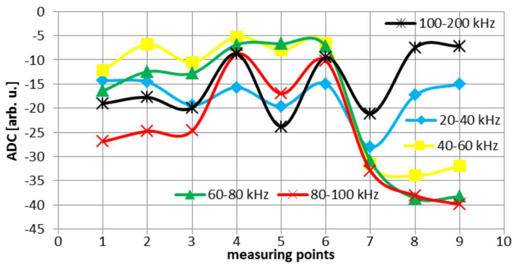

Fig. 6. Diagram of ADC descriptor values within chosen frequency bands from succeeding measuring points at line 2 (numeration of measuring points from the bottom of the line).

5. Recapitulation

The description of acoustic phenomena appearing in power oil transformers was presented.

The original method useful to analyze AE signal properties connecting with identification of deformation processes in power oil transformers was presented. This method contains: — calculation of amplitude distribution of recorded signals and descriptors, — determination of maps of descriptors, — location of PD sources by means of the method of advanced degree of signals, — analysis of properties of AE signals coming from partial discharges.

Repeated application of the original method in selected frequency bands makes it possible to identify the deformation processes.

Investigations made in the band of 20–100 kHz shows that within the band of 40–80 kHz there are components both coming from PD and from other acoustic phenomena. In the band of 100–200 kHz signals coming from partial discharges are dominant (Fig. 4).

Properties of signals coming from PD sources and magneto-acoustic phenomena have been presented.

Analysis of values of ADC descriptors within chosen frequency bands together with results of basic analysis of AE signals recorded at selected measuring points of tested transformer enables us to locate PD source in the vicinity of the measuring point 4 in a measuring line 1. This location was proved during the revision of this transformer.

Analysis of AE signals recorded in the area of the tap changer proved that these signals are generated by PD sources with little advanced degree.

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