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The detection and classification of partial discharges in power transformer using the acoustic method

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ABSTRACT

Partial discharges are the main causes of degradation of the insulation system in power transformers. Their permanent monitoring is therefore of fundamental importance, in the way that it ensures a better assessment of the level of electrical insulation. Several types of partial discharges are present in power transformers depending on the components of the electric field to which the insulation is subjected. Many on-line methods are used to the continuous measurement of partial discharges, including the acoustic method which doing both measurement of electrical parameters and localization of the sources of partial discharges. This article deals with both recognition and classification of partial discharges by analysis of acoustic signals. The goal is to reproduce various types of partial discharges present in the transformers (surface, internal, and corona discharges) by several structures of electrodes in a prototype transformer filled with insulating oil. The generation of partial discharges is done using an experimental setup consisting of a controlled 220V/50kV HV transformer connected to a prototype of transformer containing an electrode system. The experimental procedure are carried out according to the protocol of the IEC 61270 standard. The measurement of the acoustic signals on the tank is carried out using a conventional broadband sensor from the company ACOUSTIC EMISSION (GI150). Both signal analysis obtained in the frequency domain using the time-frequency response and high-resolution frequency analysis (MUSIC) makes it possible to clearly distinguish the type of discharge produced.

Keywords: partial discharge, acoustic method, power transformer, classification

1. INTRODUCTION

Power transformers play an essential role in the transmission of electrical energy over long distances and in the distribution[1], by transforming the voltage and current values to values that make transport from the production centers to the centers of use technically and economically affordable.The internal structure of the transformer consists on the one hand of the conductive elements ensuring the circulation of the current and the magnetic flux and on the other hand of the insulators which play the role of electrical barrier between the various conductors of different potentials.[2]. These internal elements are subject to intense electrical stress[3], added to that, the presence of certain involuntary defects occurring during manufacture, transport, assembly or maintenance promotes the creation of electrical phenomena harmful to transformers called partial discharges (PD)[4, 5]. Partial discharges are electrical discharges or sparks that occur in an insulating material thereby short-circuiting part of the insulation[3]. The preponderance of these PDs can lead to the failure of the electrical insulation system and lead to the failure of the power transformer if they are not controlled.[6]. Statistical results show that 85% of medium and high voltage network failures are due to power transformers[7]. It is therefore important to control the activity of the partial discharges. These phenomena give rise to several chemical and physical phenomena, so their measurements correspond to a PD measurement method. The ultrasonic acoustic waves which propagate in the transformer are measured by the acoustic method[8, 9].

The measurement of the acoustic signals is done using generally piezoelectric acoustic sensors coupled to the transformer tank using a magnetic medium. The acoustic coupling between the steel tank and the sensor is ensured by a couplant in order to limit the losses due to the interfaces[8]. The acoustic measurement in addition to evaluating the level of partial discharge also allows the localization of the sources of partial discharges thanks to the difference in the times of arrival of the acoustic signals on various sensors installed on the tank[10]. Transformers are subject to several types of PD due to the distribution of the electric field in a region and the nature of the fault present in the transformer, among which we can mention surface discharges, internal discharges and corona. Each of these types can also give rise to several other types. Surface discharges are due to tangential components of the intense electric field on solid insulators, they are generally of high energy and have a highly destructive character of electrical insulators[11-13]. The internal discharges are less energetic than the surface discharges but also remain very dangerous, they are due to the intense electric field or to an excessive accumulation of gas bubbles in the corner filled with oil, or to the axial deformations of the windings[11-13]. Corona discharges occur in insulating oil and are due to strong electric field strength[13].

These different types of discharges produce acoustic waves with particular frequency responses which can also depend on the type of acoustic sensor used, this due to the central frequency and the frequency range (broad band or narrow band)[13]. Many works on the correspondence between the type of partial discharge and the frequency range are carried out in order to identify the type of PD by analysis of the acoustic signals[14-19]. Many circumstances give rise to many types of partial discharges in power transformers, the incessant need to decide on the type of partial discharge on site requires an in-depth study of the parameters of these in the laboratory. The works of[17-20]succeeded in highlighting the characteristic features relating to each type of discharge, thanks to configurations of electrodes for each type. Their work shows similarities and differences related to the same electrode configurations.[15]explains these differences using two acoustic sensors (one broadband and the other narrowband) and several different electrode configurations giving rise to the same type of discharge (surface discharge), it shows the influence of the type sensor in the classification and that the same type of discharge gives rise to several responses, depending on the electrode configuration. Afterwards,[13]in these works of realization of an optimal acoustic sensor, finds the same results when it uses 4 different acoustic sensors (PAC R15D, Olympus V101-RB, PAC WD and PAC D9241A) and obtains different frequency responses. In order to build an adequate database, it is therefore important to carry out studies on a large electrode configuration with one type of sensor. This amounts to developing several structures of electrodes corresponding to several types of partial discharges in order to evaluate the spectral response of the acoustic signals they produce.

This article evaluates the spectral signature of the acoustic signals of several types of PD, materialized by the use of 8 electrode structures. This makes it possible to make a characterization of the different types of PD in the frequency domain and to have a large database linked to the acoustic signals of the PD. This study therefore makes it possible to classify the different types of partial discharges thanks to the spectral response of the acoustic signals obtained by advanced methods in signal processing. The first part of this work presents the material used mainly the experimental bench, this followed by the protocol used. In the third part, the results discussed and finally a conclusion.

2. MATERIALS

2.1. Configuration of electrodes

The creation of different types of partial discharges is obtained thanks to different configurations of the electrode system. Each electrode configuration corresponds to a very precise distribution of electric fields, which gives rise to different types of surface, corona and internal discharge. For this study, 8 configurations of electrodes were carried out as shown in the Figure 1. Configurations (a), (b), (g) and (h) give rise to partial surface discharges[15, 21, 22], the configurations (c) and (d) give rise to the internal discharges[13, 14]and the configurations (e) and (f) in turn give rise to the corona discharges in the oil[17, 18]. The tips of the electrodes are made of tungsten and the flat electrodes of bronze.

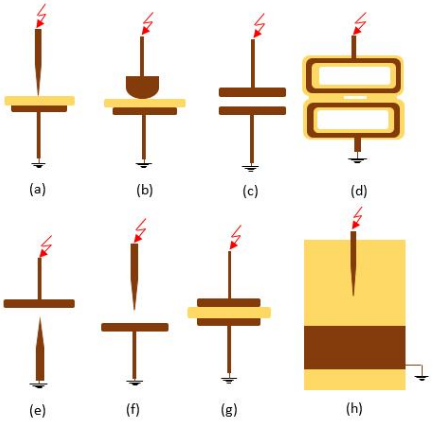

Figure 1: Electrode configuration

In the configuration presented in figure 1.a, the presence of the tip at the high voltage potential intensifies the normal component of the electric field[15], a somewhat similar increase is observed in the configuration presented in figure1.b by replacing the tip with a Rogowski electrode[14]. The one presented in figure1.c consisting of two flat electrodes placed 20 mm from each other subjects the insulating liquid to a constant electric field[18]. The configuration presented in figure 1.d characterizes an internal discharge between winding[15]. The configurations presented in figure1.e and figure 1.f represent the corona discharges in the oil[15]. The configuration presented in figure1.g presents a plane-plane configuration separated by insulator. figure1.h the needle is placed close to the horizontal containing the insulation and located 20 mm from the conductive bar connected to earth and also placed on the insulation. This configuration guarantees a strong tangential component of the electric field at the surface of the insulator and reduces the normal component[21, 23, 24].

2.2. Acoustic signal measurement system

The partial discharge signals produced are measured simultaneously by two methods, the first is the electrical method and the second the acoustic method. The electrical signals are measured using a shunt sensor, consisting of a 50Ω precision resistor connected in series between the ground of the electrode system and the earth. It thus makes it possible to obtain the waveforms of the current produced by the partial discharge. The acoustic sensor is a broadband sensor with a central frequency of 150kHz (GI150) with a 40dB gain preamplifier. It is fixed on the transformer tank thanks to a magnetic support. In order to have a better acoustic coupling between the sensor and the outer surface of the tank, a thin layer of couplant is applied to the surface of the sensor before being attached to the tank. The partial discharge source and the acoustic sensor are located on the same horizontal plane and separated by a distance of 200mm. The signals from the two types of sensors are acquired by a DSO2020 digital oscilloscope.

2.3. Experimental bench

TheFigure 2presents the entire experimental bench. The combination of elements (1) and (2) makes it possible to generate a high alternating voltage variable from 0 to 50kV. A high voltage protection resistor of 100MΩ connected between the voltage source and the rest of the device plays the role of protection. The transformer prototype is a steel tank 15mm thick and 300mm x 400mm x 700mm in size, filled to a depth of 40mm with mineral oil (nito-libra oil). The entire high voltage system is installed in an area protected by a Faraday barrier and resting on a conductive plane linked to earth.

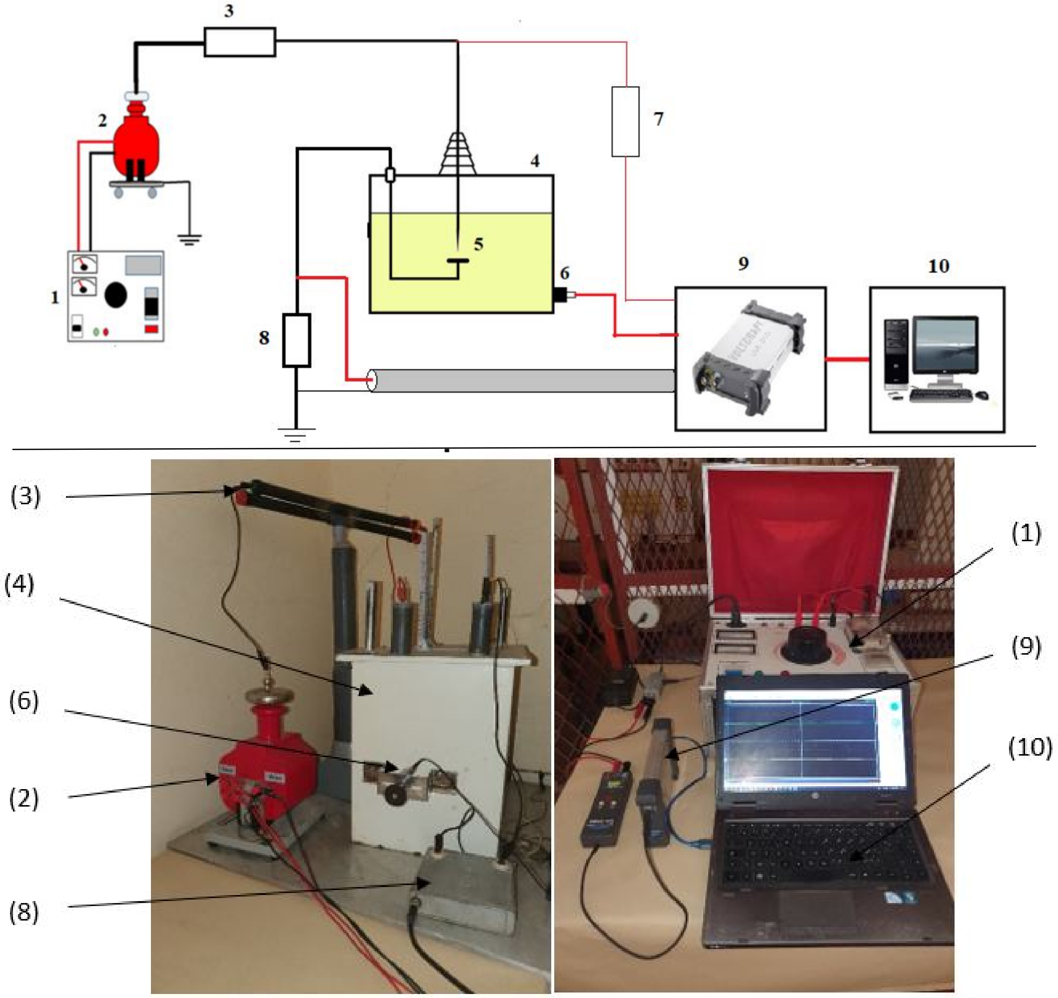

Figure 2 : Experimental test bench: (1) Control case; (2) 220V/50KV HV transformer; (3) Protection resistor, (4) prototype transformer (oil filled tank), (5) electrode system, (6) acoustic sensors, (7) high voltage probe, (8) measurement impedance for measurement shunt, (9) acquisition unit, (10) computer

3. TEST PROTOCOL

The experimental protocol consists of generating partial discharges in the prototype transformer and measuring the acoustic signals produced. For this, the high voltage between the electrodes is gradually increased until it reaches the partial discharge initiation voltage, the high voltage is varied between this voltage and the breakdown voltage initially determined using the IEC60156 standard. The various sensors installed will allow the acquisition of the discharge signals produced. For each configuration of electrodes, 6 tests are carried out and make it possible to collect 6 data for processing under MATLAB software.

The high-resolution spectral analysis method uses the noise subspace to estimate unknown frequency parameters for a random process. This method is effective for detecting sinusoidal signals embedded in noise, especially when the signal-to-noise ratio is low. Partial discharge signals can be approximated to exponentially attenuated sinusoidal signals[15]. Among the high resolution methods, the multiple signal classification method very precisely identifies the harmonic components of a signal, which is why it was chosen.[16].

The joint time-frequency analysis method is an effective method for analyzing acoustic signals. It consists in carrying out discrete Fourier transforms in portions of intervals of the signal to be studied thanks to the short-time Fourier transform[19]. It allows not only to determine the variation of amplitude according to the spectrum, but also to detect the signal drowned in a noise with narrow band. It gives a three-dimensional response consisting of amplitude, frequency and time, thus making it possible to evaluate the spectral response over time.[15, 16].

4. RESULTS AND DISCUSSIONS

This paper presents the results of the spectral analysis of the partial discharge signals produced by 8 configurations of electrodes grouped into 3 main types of partial discharges: surface discharges (Figure 4 and Figure 5), discharges in oil or corona (Figure 6 and Figure 7) and discharge between windings (Figure *8*). Figure 3 presents the discharge signal in amplitude and the time-frequency response produced by a tip-plane electrode configuration recorded for a duration of 0.1024ms. We notice a strong spectral concentration between 100KHz and 200kHz.

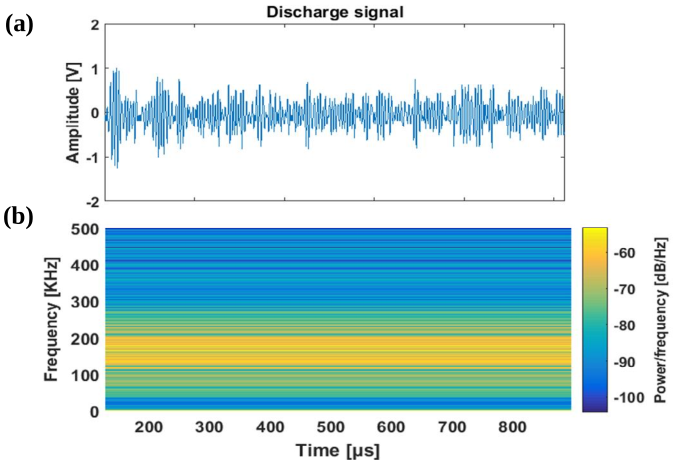

Figure 3 : Discharge time response produced by a tip-plane electrode system: (a) Amplitude; (b) Frequency

TheFigure 4andFigure 5present the normalized power spectral density (PSD) and MUSIC spectrum of surface discharges. There is a similarity with respect to the spectral response. The generation of surface discharges goes through 4 main steps. Stage 1, characterized by the intensification of the electric field which gives rise to small corona discharge. After this stage, the generation of streamer and surface discharge begins which marks stage 2. At stage 3, audible cracklings are superimposed on the existing streamers. Stage 4 is the site of a very high energy discharge producing a large flash of light. The spectrum of surface discharges therefore contains two frequency ranges: one of the order of tens of kilohertz (between 20 and 85kHz) and another greater than 100kHz, which is consistent with the work of[13, 19]. Sikorski uses a resonant sensor with a central frequency of 151kHz (PAC R15D) for the electrode configuration presented in figure1.a, in this same work he shows that with other sensors (Olympus V101-RB, PAC WD and PAC D9241A) the spectral response is not identical. Table 1 presents the different peaks obtained by the MUSIC method of the dominant signals contained in the discharge signal. It can thus be noted that the more an electrode is rounded, the higher the amplitude of the second peak, this due to the intensification of the electric field.

Table 1 : statistical parameters of frequency peaks and amplitude percentage

System type	**Summit 1**		**Summit 2**	
	Frequency [kHz]	**Normalized DSP**	**Frequency [kHz]**	**Normalized DSP**
1	29	1	162	0.7
2	45	1	164	0.4
3	87	1	166	0.68
4	50	1	160	0.16
1.	*Point-plane electrode system separated by solid insulator*			
2.	*Rogowski-plane electrode system separated by solid insulator*			
3.	*Point-plane electrode system on insulating paper*			
4.	*Plane-plane electrode system separated by solid insulator*			

The frequency ranges with a power greater than 20% range from 29kHz to 35kHz and from 147kHz to 155kHz for the configuration presented in figure1.a; from 35kHz to 80kHz and from 150kHz to 175kHz for the configuration presented in figure1.b; from 75kHz to 90kHz and from 140kHz to 170kHz for the configuration presented in figure1.h and finally from 35kHz to 60kHz and from 140kHz to 170kHz for the configuration presented in figure1.g

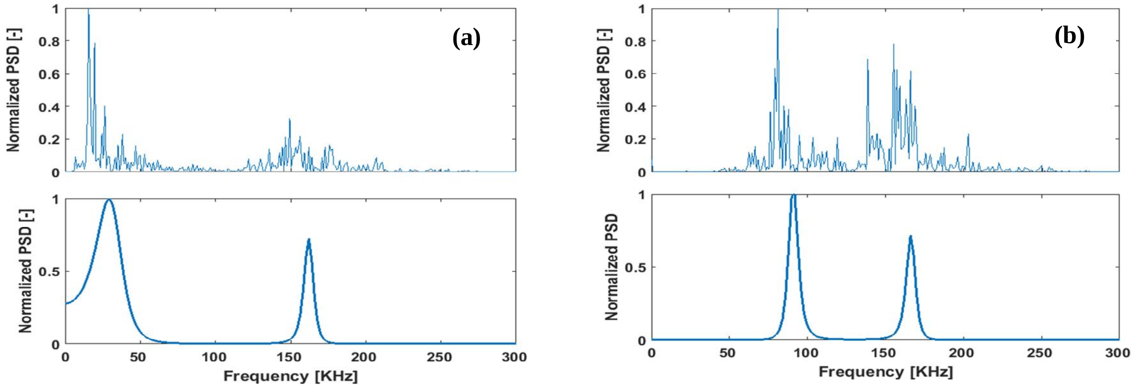

Figure 4 : Normalized power spectral density and MUSIC spectrum (a): configuration 1.a; (b): configuration 1.h

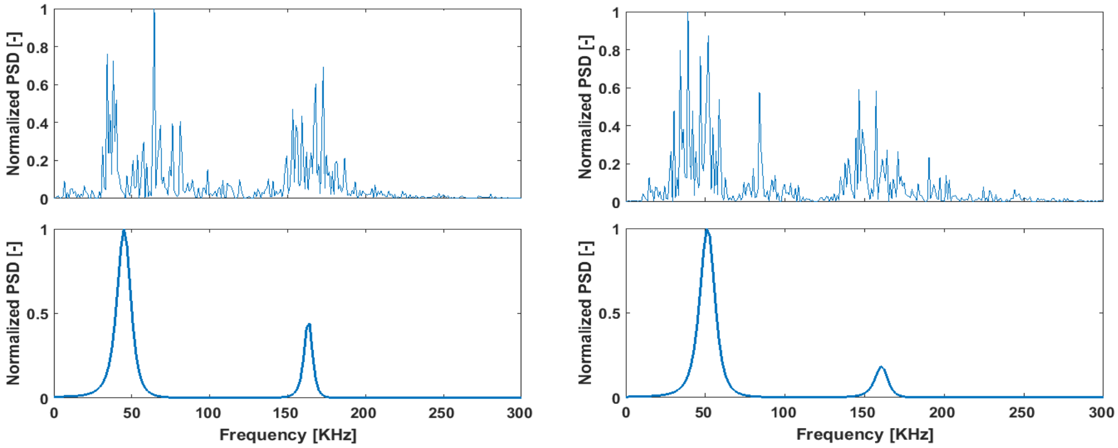

Figure 5 : Normalized power spectral density and MUSIC spectrum (a): configuration 1.b (b): configuration 1.g

With regard to discharges in insulating oils, three electrode structures have been taken into account. The **Figure *6*** and theFigure 7present their DSP and MUSIC spectrum of the signals resulting from the partial discharges produced by these electrodes. The point-plane structure presents a dominant frequency spectrum substantially equal to 170kHz, a result which joins those of[18]. The configuration with tip at high voltage potential gives a response between 115kHz and 205khz while the configuration with tip electrode at ground gives a spectral response containing components up to 300kHz. The plan-plan configuration presented inFigure 7creates in the oil a uniform electric field and gives by the MUSIC method two main frequencies (35kHz and 150kHz). Under these constant field conditions in the oil, the discharges are due to the presence of drops of water or air in the oil. This structure has a strong power component at 35kHz. The work carried out by[18]on this same electrode configuration and thanks to a resonant acoustic sensor with a central frequency of 150kHz highlights a maximum frequency close to 40kHz.

The configuration shown in figure1.d materializes a discharge between windings, its spectral response has two main frequencies among which 21kHz and 158kHz as presented in theFigure 8. The top located at 158kHz corresponds to 10% of that produced at 21kHz, this is explained by the initiating phenomena of these discharges such as corona discharges.

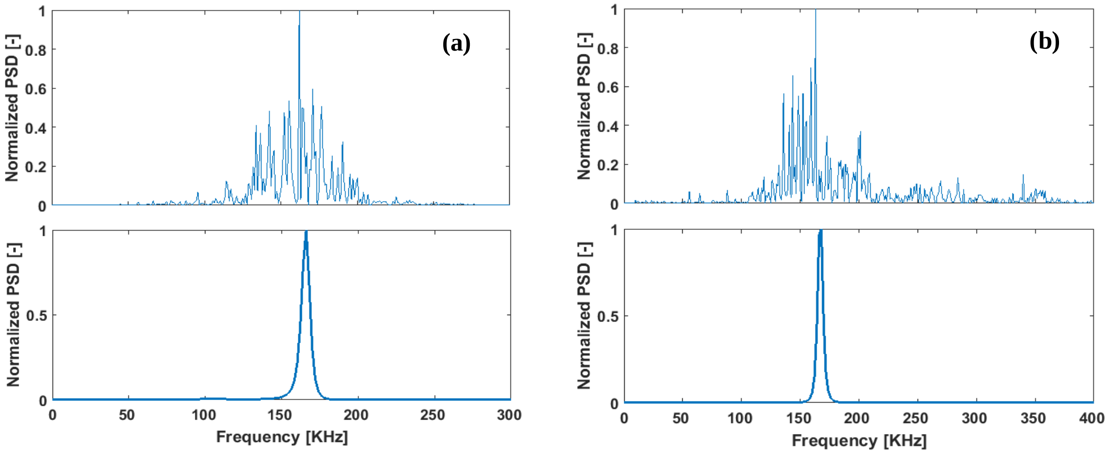

Figure 6 : Normalized power spectral density and MUSIC spectrum (a): configuration in figure 1.e (b): configuration in figure 1.f

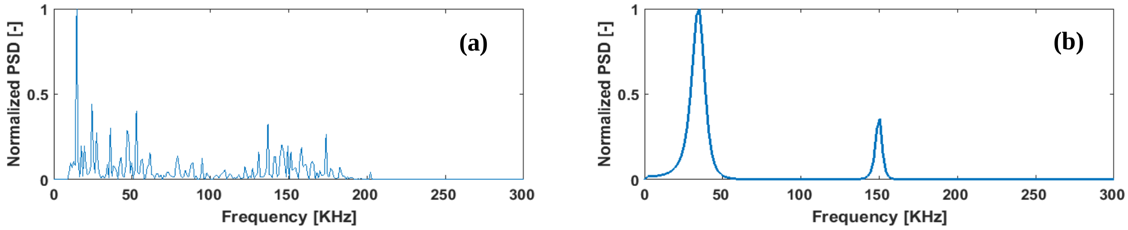

Figure 7 : Normalized power spectral density and MUSIC spectrum of the configuration in figure 1.c

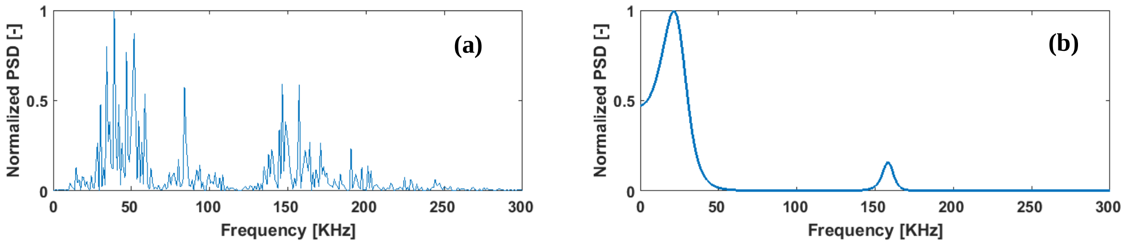

Figure 8 : Normalized Power Spectral Density and MUSIC Spectrum of Setup 1.d

5. CONCLUSION

This paper presents an analysis in the frequency domain of the acoustic signals produced by partial discharges in an electrical power transformer. For this fact, eight electrode structures have been produced, grouping together three main types of partial discharges (surface, internal and in the oil). A broadband acoustic sensor (GI150 with a bandwidth of 3-500kHz and a central frequency of 150kHz) was used for the measurement of the signals. Spectral analysis using advanced signal processing methods (MUSIC and JTFA) shows that it is possible to identify the type of partial discharge produced in power transformers. It emerges from this study that surface discharges have a frequency response with high energy in frequencies below 90kHz and a certain response in frequencies between 120kHz and 170kHz. As far as corona discharges are concerned, the spectral response is central is close to 165kHz and almost all of the energy is transmitted in the frequency range between 130 and 205kHz with the exception of the plane-plane configuration which presents a strong component at low frequencies.

REFERENCES

1. L. A. Nobrega, E. G. Costa, A. J. Serres, G. V. Xavier, and M. V. Aquino.**UHF Partial Discharge Location in Power Transformers via Solution of the Maxwell Equations in a Computational Environment**, *Sensors,* vol. 19, no. 15, p. 3435, 2019.
2. M. E. Senoussaoui. **Contribution des techniques intelligentes au diagnostic intdustriel des transformateurs de puissance**, Doctoral thesis, Faculty of Electrical Engineering, University of Sidi Bel Abbes, Algerie, 2019.
3. S. S. Refaat, M. Sayed, M. A. Shams, and A. Mohamed. **A review of partial discharge detection techniques in power transformers**," in *2018 Twentieth International Middle East Power Systems Conference (MEPCON),* 2018, pp. 1020-1025: IEEE.
4. W. Si, C. Fu, and P. Yuan.**An integrated sensor with AE and UHF methods for partial discharges detection in transformers based on oil valve**, *IEEE Sensor Letters,* vol. 3, no. 10, pp. 1-3, 2019.
5. W. Sikorski, K. Walczak, and P. Przybylek.**Moisture migration in an oil-paper insulation system in relation to online partial discharge monitoring of power transformers**, *Energies,* vol. 9, no. 12, p. 1082, 2016.
6. B. Gao, R. Yu, G. Hu, C. Liu, X. Zhuang, and P. Zhou.**Development processes of surface trucking and partial discharge of pressboards immersed in mineral oil: Effect of tip curvatures**, *Energies*, vol. 12, no. 3, p. 554, 2019.
7. N. Akashah *et al.*.**A review: Partial discharge detection using acoustic sensor on high voltage transformer**, in *Journal of Physics: Conference Series*, 2020, vol. 1432, no. 1, p. 012004: IOP Publishing.
8. B. Phung, T. Blackburn, and Z. Liu.**Acoustic measurements of partial discharge signals**, *Journal of Electrical and Electronics Engineering, Australia,* vol. 21, no. 1, pp. 41-47, 2001.
9. M. Kunicki and D. Wotzka.**A Classification Method for Select Defects in Power Transformers Based on the Acoustic Signals,***Sensors* vol. 19, no. 23, p. 5212, Nov 28 2019.
10. Y. Chen.**Partial Discharge Monitoring of Dry Distribution Transformer Based on Grid Search Scheme and Characteristic Analysis**, in *Proceedings of PURPLE MOUNTAIN FORUM 2019-International Forum on Smart Grid Protection and Control*, 2020, pp. 761-772: Springer.

11. V. Sokolov, V. Mayakov, G. Kuchinsky, and A. Golubev. **On-Site Partial Discharge Measurement of Transformers**,*eaton*, pp. 1-19.
12. V. Sokolov.**Power Transformer: Post Failure and Post Mortem Analysis**, *Proceedings of the My Transfo, Rio de Janeiro, Brazil*, pp. 7-9, 2007.
13. W. Sikorski.**Development of Acoustic Emission Sensor Optimized for Partial Discharge Monitoring in Power Transformers**, *Sensors (Basel),* vol. 19, no. 8, p. 1865, Apr 18 2019.
14. D. Zhu, K. Tan, and X. Jin.**The study of acoustic emission method for detection of partial discharge in power transformer**, in *Proceedings., Second International Conference on Properties and Applications of Dielectric Materials*, 1988, pp. 614-617: IEEE.
15. W. Sikorski and W. Ziomek.**Detection, recognition and location of partial discharge sources using acoustic emission method**, *Acoustic Emission*, pp. 49-74, 2012.
16. W. Ziomek, E. Kuffel, W. Sikorski, P. Staniek, and K. Siodła.**Location and recognition of partial discharge sources in a power transformer using advanced acoustic emission method**, *Przegląd Elektrotechniczny,* vol. 84, no. 10, pp. 20-23, 2008.
17. T. Boczar.**Identification of a specific type of PD from acoustic emission frequency spectra**, *IEEE transactions on Dielectrics Electrical Insulation,* vol. 8, no. 4, pp. 598-606, 2001.
18. P. Kundu, N. Kishore, and A. Sinha.**Frequency domain analysis of acoustic emission signals for classification of partial discharges**, in *2007 Annual Report-Conference on Electrical Insulation and Dielectric Phenomena*, 2007, pp. 146-149: IEEE.
19. M. Kunicki, A. Cichoń, and S. Borucki.**Study on descriptors of acoustic emission signals generated by partial discharges under laboratory conditions and in on-site electrical power transformer**, *Archives of Acoustics*, vol. 41, no. 2, 2016.
20. T. Sakoda, T. Arita, H. Nieda, K. Ando, M. Otsub, and C. Honda.**Studies of elastic waves caused by corona discharges in oil**, *IEEE Transactions on Dielectrics Electrical Insulation,* vol. 6, no. 6, pp. 825-830, 1999.
21. H. Zainuddin, P. Mitchinson, and P. Lewin.**Investigation on the surface discharge phenomenon at the oil-pressboard interface**, in *2011 IEEE International Conference on Dielectric Liquids*, 2011, pp. 1-4: IEEE.
22. R. T. Harrold.**Ultrasonic spectrum signatures of under-oil corona sources**, *IEEE Transactions on Electrical Insulation,* no. 4, pp. 109-112, 1975.
23. P. Mitchinson, P. Lewin, G. Chen, and P. Jarman.**A new approach to the study of surface discharge on the oil-pressboard interface**, in *2008 IEEE International Conference on Dielectric Liquids*, 2008, pp. 1-4: IEEE.
24. P. Mitchinson, P. Lewin, B. Strawbridge, and P. Jarman.**Tracking and surface discharge at the oil‐pressboard interface**, *IEEE Electrical Insulation Magazine,* vol. 26, no. 2, pp. 35-41, 2010.