Trends in
Applied Sciences Research

ISSN 1819-3579

Academic Journals Inc.

www.academicjournals.com

Trends in Applied Sciences Research 7 (10): 813-828, 2012
ISSN 1819-3579 / DOI: 10.3923/tasr.2012.813.828

De-noising of Online PD Signals in Power Transformers Using the Bhattacharyya Distance

[1]Alireza Alesaadi, [2]Amir Ghaedi, [3]Aboozar Ghaffari and [3]Vahid Parvin
[1]Department of Electrical Engineering, Kazerun Branch, Islamic Azad University, Kazerun, Iran
[2]Department of Electrical Engineering, Daiun Branch, Islamic Azad University, Dariun, Iran
[3]Department of Electrical Engineering, Sharif University of Technology, Iran

Corresponding Author: Alireza Alesaadi, Department of Electrical Engineering, Kazerun Branch, Islamic Azad University, Kazerun, Iran

ABSTRACT
Unexpected failures can be prevented in the power system using online condition monitoring of the related apparatus. In high voltage equipments, such as cross linked poly ethylene (XLPE) cables, power transformers, medium voltage switchgears and rotating machines, many of the reported outages arise from insulation failures and deteriorations. Thus, online monitoring of quantities that originate from insulation failures are useful for on time fault recognition and preventive operation performance. When the strength of insulations is decreased, the Partial Discharge (PD) signals occur in primary stages. The extension of such PDs can result an insulation breakdown. As a result, PD signals detection can be used for insulation monitoring of power system equipments. Online PD detection of the power system apparatus is disturbed by the environmental noises which are difficult to be removed from the PD signals. In this study, a new method based on the Bhattacharyya distance, is introduced and used for de-noising of PD signals in power transformers online condition monitoring.

Key words: Condition monitoring, de-noising, PD, power transformers, Bhattacharyya distance

INTRODUCTION
Online condition monitoring is mandatory for fault detection and analysis of power system equipments. Condition monitoring is continuously measurement of related quantities such as currents, voltages, active and reactive powers, temperatures, harmonics and etc. Using on-line monitoring is possible to recognize and remove the faults. Furthermore, the original reasons of the occurred faults are determined from the monitored quantities. Insulation is one of the most important parts of a high voltage device. It is shown that most observed failures in power devices arise from insulation failures (Di Lorenzo del Casale *et al*., 2000) which can cause a total breakdown (Boggs and Densley, 2000), although in the beginning stages, only Partial Discharges (PDs) occur (Boggs, 1990). For condition monitoring of power devices insulation, PD signals detection can be used. Based on the magnitude and occurrence rate of PDs, the condition of the insulation can be determined and sudden insulation outages in power system can be prevented. PDs are signals that do not completely bridge the insulation. In XLPE cables, the PDs are occurred in the air filled cavities and in the oil power transformers; they are occurred in the bulbs filled with air, humidity and voids in the paper insulation. In addition, in the power transformers, surface discharge on the contaminated bushings, corona discharge on the conductors arrived to the bushing

and windings in the oil occur (Nattrass, 1988; Dong *et al.*, 1999). The insulation strength of these cavities and bulbs are less than other parts of the insulation and it cause PD occurrence. PD signals are current impulses with high frequency content and very short pulse width. For detection of PDs, the electrical and non-electrical techniques can be used. Acoustic sensors such as microphones installed on the transformer tank are non-electrical method used for PDs detection (Kreuger, 1964). According to Lundgaard (1992), the sensitivity of the electrical methods is higher than the non-electrical approaches and in PD detection of the power apparatus, it is better to use electrical methods by measuring current impulses. PD detection in the power equipments can be done in offline and online modes. In the online mode, because of the availability of different quantities such as currents, voltages, temperatures and etc, with PD signals, fault detection is instantly performed. Additionally, the trend of the PD signals is monitored and the preventive operation is done in an appropriate situation. However, in the offline mode, the measurements are performed in discrete times and PDs may be occurred between the times. Extension of PD signals may be occurred rapidly and resulted in the total breakdown and insulation failure (Stone, 1991). In power systems, different noises such as radio waves, power electronic firing pulses, corona and switching waves affect the PDs and make online PDs detection difficult. Signal processing methods must be applied for removing the noises from PD signals. So far, many researches were done for de-noising the PDs in power transformers (Zhang *et al.*, 2007). Wang *et al.* (2001) mentions high pass filter and wavelet transform as two methods which are used for noise removing in power transformers. In addition, wavelet transform is used for de-noising the PDs in both distribution and power transformers (Ghaffarian *et al.*, 2008). Ming and Birlasekaran (2002) and Satish and Nazneen (2003) discuss the use of wavelet transform for noise reduction of different discharge signals. Moore *et al.* (2006) has used wireless wideband radio-frequency measurements for detection of the PD signals in power transformers. Zhou *et al.* (2005) mentioned noise removing of the power transformer by using chaotic algorithm. In this study for noise reduction, since broadcast radio signals have a symmetrical probability density function, the effects of the noises are compensated by taking a large number of measurements using the antenna array and finding the mean value of the distribution. These measurements were then processed and the PDs are detected.

In this study the Bhattacharyya distance was used for PD detection in the power transformers as a new method.

PD DETECTION CIRCUIT

For online PD detection of high voltage power transformers, the circuit of Fig. 1 can be used. The circuit consists of a copper strip, ground wire, High Frequency Current Transformer (HFCT), coaxial cable and an oscilloscope.

The copper strips are connected to the bushings. The equivalent circuit model of a bushing can be presented as several series capacitors. The copper strip is connected to these capacitors in series. These capacitors have large impedances in the power frequency and filter high voltage currents. However, the frequencies of PDs are high and can be passed from these capacitors. In some transformers, where a bushing tap is available, the copper strip is not required. The PD signals transmit to the ground through the ground wire. In the measurement circuit, the ground wire is passed in the HFCT and then connected to the ground. When the PD is occurred in a transformer, it travels and goes to the ground through the bushing tap (copper strip) and the ground wire. Based on the ampere law, PD currents generate the magnetic field in the HFCT and induce a current proportional to the PD magnitude in the secondary winding of the HFCT. The induced

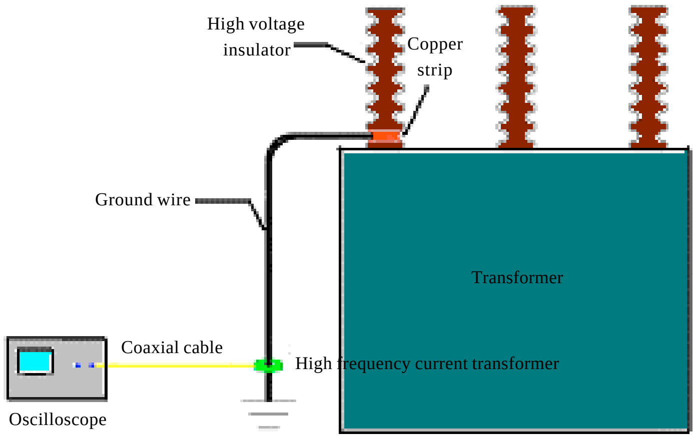

Fig. 1: On-line PD signals detector circuit of a power transformer

current is connected to the oscilloscope using a coaxial cable. The presented PD signals on the oscilloscope screen include noises. The noisy PD signals are recorded and transferred to a PC for de-noising.

BHATTACHARYYA DISTANCE METHOD

This section presents the Bhattacharyya distance technique for de-noising and detection of the PD signals. This method is applied for epileptic seizure detection and phone clustering by Niknazar *et al.* (2010) and Mak and Barnard (1996), respectively. The statistical and mathematical model of PD signal is investigated in the following subsection. Then, detection and de-noising algorithm based on Bhattacharyya distance will be proposed.

Statistical and mathematical model of PD signals: The mathematical form of the PD signals can be presented as follows:

$$x_{pd}(t) = h(t)*s(t) = \sum_k a_k s(t - t_k) \quad (1)$$

Where:

$$h(t) = \sum_k a_k \delta(t - t_k) \quad (2)$$

where, a_k is the magnitude of PD signals, t_k is the time that PD signals are occurred, δ(t) is impulse function and s(t) is the reference PD signal which depends on the occurrence time of the PD. This signal has a finite period time T. In the other words:

$$s(t) - 0, t \notin [0, T] \quad (3)$$

The time difference between t_k and t_j is considered, so the s(t-t_k) and s(t-t_j) have no overlapping. Considering the assumption, the PD signal (x_{pd}) is zero at most times and only at the short duration after the t_k is not zero and the s(t) exists.

The mathematical model of the noisy PD signal (y_{pd}) can be presented as bellow:

$$y_{pd}(t) = x_{pd}(t)+n(t) = \Sigma_k \, a_k \, s(t-t_k)+n(t) \tag{4}$$

where, n(t) is an additive noise. The nature of the PD signals is so that two states would be considered for the noisy PD signals (y_{pd}) as follows:

- At the time t, when the PD signals (s(t)) are zero and only the noises exist
- At the time t, when the PD signals (s(t)) with the noises (n(t)) exist
- On the other hand, the mathematical form of this fact is presented in Eq. 5

$$y_{pd}(t) = \begin{cases} a_k s(t-t_k)+n(t) & \exists k, t \in [t_k, t_k+T] \\ n(t) & \forall k, t \notin [t_k, t_k+T] \end{cases} \tag{5}$$

For detection of the PD signals, it is required to distinguish the two above states using a statistical distance. For statistical distance definition, probability distribution function of noisy signal ($y_{pd}(t)$) is required. To obtain this function, it is considered that the noise n(t) is independent of the PD signals and the PD signal is deterministic. With these two assumptions, the noisy signal probability density function would be as bellow:

$$p_y(y_{pd}) = \begin{cases} p_n(p_{pd} = a_k s(t-t_k)+n(t)) & \exists k, t \in [t_k, t_k+T] \\ p_n(n(t)) & \forall k, t \notin [t_k, t_k+T] \end{cases} \tag{6}$$

where, $p_y(y_{pd})$ is the noisy signal probability density function and $p_n(n(t))$ is the probability density function of the noise n(t). In this stage, it is considered that the noise has the Gaussian distribution with zero mean and σ^2 variance, $N(0,\sigma^2)$ and with this assumption, the probability mass function of the noisy signal would be as Eq. 7:

$$p_y(y_{pd}) = \begin{cases} N(a_k s(t-t_k), \sigma^2) & \exists k, t \in [t_k, t_k+T] \\ N(0, \sigma^2) & \forall k, t \notin [t_k, t_k+T] \end{cases} \tag{7}$$

It can be concluded that the two probability density functions are different only in mean values. As a result, for the detection of PD signals, the mean values can be used. However, the mean value of the PD signal is dependent on the PD signal which is not available. In this stage, PD signal recognition is required and for this purpose the statistical distance between the two distributions is obtained.

Bhattacharyya distance: The Bhattacharyya distance is the theoretical distance between two Gaussian distributions and is equivalent to the up limit of the classified error. For two distributions, i.e., p(x) and q(x), the Bhattacharyya distance is defined as follows:

$$D_B(p,q) = \frac{1}{8}(m_1 - m_2)^T P^{-1}(m_1 - m_2) + \frac{1}{2}\ln\left(\frac{\det(P)}{\sqrt{\det(P_1)\det(P_2)}}\right) \tag{8}$$

where, D_B is Bhattacharyya distance, m_i and P_i are the mean value and covariance matrix of the distribution, respectively and $P = (P_1+P_2)/2$. The first term in Eq. 8, is the ability of separation of the two distributions due to the difference between the distribution mean values and the second term is the ability of decomposition of the two distributions because of the difference in the covariance matrix of the two distributions. From point of the classification, the classification error between two classes is obtained as bellow:

$$\varepsilon \leq \sqrt{p_{w_1} p_{w_2}} \exp(-D_B) \tag{9}$$

where, p_{w1} and p_{w2} are the probability occurrence of the classes, w_1 and w_2, respectively.

Proposed algorithm for detection and De-noising of PD signals: The main idea for detection and de-noising is statistical similarity measurement between the two investigated states in Eq. 7. Hence, for de-noising of the PD signals based on the Bhattacharyya distance, the probability distribution functions p(x) and q(x) are defined as follows.

The probability density function p(x) is for the state with only noises. Thus, $p(x) = N(0,\sigma^2)$. In other words, $m_1 = 0$, $P_1 = \sigma^2$. The Gaussian distribution is considered for the noises and σ^2 is estimated from the Eq. 10 (Donoho and Johnstone, 1994):

$$\hat{\sigma} = \frac{\text{median}(|W_1^D|)}{0.6745} \tag{10}$$

where, W_1^D is the detail coefficients of the first scale of the wavelet transform. Considering the assumption of the stationary characteristic of the statistical distribution of the noises in all times, the parameter of p(x) for each signal is adjusted for one time and is fixed in all times.

The probability density function q(x) is for the state with PD signals and noises. The signal, z(t), is defined as Eq. 11 and 12 for estimation of the parameters, m_2 , P_2 at arbitrary time, t_0.

$$z(t) = y_{pd}(t)\Pi(\frac{t - t_0}{T_w}) \tag{11}$$

$$\Pi(\frac{t}{T_w}) = \begin{cases} 1 & |t| \leq \frac{T_w}{2} \\ 0 & |t| > \frac{T_w}{2} \end{cases} \tag{12}$$

where, T_w is length of PD signal sample. It is considered that the signals are ergodic and the parameters m_2 and P_2 are estimated as Eq. 13 and 14, respectively:

$$\hat{m}_2 = \frac{1}{T_w}\int_{-T_w/2}^{T_w/2} z(t)dt \tag{13}$$

$$\hat{P}_2 = \frac{1}{T_w}\int_{-T_w/2}^{T_w/2} (z(t) - \hat{m}_2)^2 dt \tag{14}$$

For the PD signals detection based on the Bhattacharyya distance, the follow algorithm is proposed. The sampling rate of the PD signals is f_s. In this study, 100 MHz is considered for the sampling frequency of the PD signals (N_w is number of PD signals).

Initialization

$N_w = T_w.f_s,\ m_1 = 0,\ P_1 = (\frac{\text{median}(|W_1^D|)}{0.6745})^2$

for k = 1: N (length of PD signal)

$z_k(nT_s) = y_{pd}(nT_s)\Pi(\frac{nT_s - kT_s}{nT_s})$

$m_2 = \frac{1}{N_w}\sum_n z_k(nT_s)$

$P_2 = \frac{1}{N_w}\sum_n (z_k(nT_s) - m_2)^2$

$Dist(k) = D_B(p,q) = D_B(m_1, P_1, m_2, P_2)$

Dist = Dist-mean[Dist]

Dist = abs(Dist)

DI = Dist, Detection index (DI)

Using the technique, with inserting a simple threshold on the detection index, the location of the PD signals can be detected. In the noisy signal, the Detection Index (DI) is very small, when the PDs don't exist and it is significant, when the PDs exist. Based on this fact, de-noising of the PD signals is performed in Eq. 15:

$$x_{dn}(t) = DI(t)\times y_{pd}(t) \quad (15)$$

When there is no PD signal, with high gain, the noises are reduced but in the times that the PD is available, the noises are not reduced, so the locations of the PD signals are determined. In this method with reduction of the noises around the PD signals, these PDs can be detected successfully. In fact, in this technique, the noises in the times that the PD is available, is not removed. For obtaining PD signal with high quality and without any noises, it can be used from other typical de-noising techniques on the $y_{pd}(t)$ only in the time durations that DI(t) has significant values. The proposed technique is simple and successfully detects the PD signals. Implementation of the method for de-noising of the different PD signals is given in the next section.

IMPLEMENTATION OF THE METHOD TO PD SIGNALS

In this stage, the proposed technique is implemented on different PD measured signals of a power transformers and the effectiveness of the method is investigated.

PD in the 20 kV distribution transformer: The voltages up to 40 kV are applied to the 20 kV side of an old distribution transformer. In this condition, the PD is occurred and the recorded PD signals are presented in Fig. 2. Using the MATLAB software, different Gaussian noises (low and high) are added to this signal. The proposed method for removing the existence noises is used and the de-noised PD signals are extracted. It is presented in Fig. 3 and 4.

From the Fig. 3 and 4, it is shown that the noise removing is successfully done using of the Bhattacharyya distance method.

PD arisen from an air filled bubble in the oil: In this stage, several air filled bubbles in the oil are made and with applying high voltage, PD is occurred. Recorded PD signals are added with the low and high Gaussian noises. The proposed method is applied and the de-noised PD signals are extracted. These signals are presented in Fig. 5 and 6. It is deduced from the figures that the proposed technique can successfully de-noise the PD signals arisen from an air filled bubble in oil.

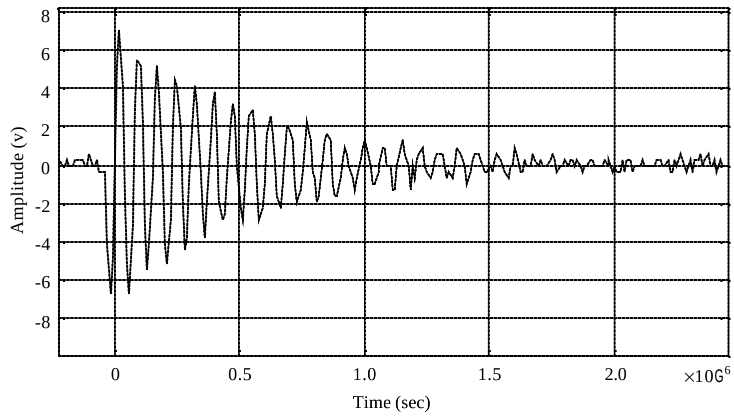

Fig. 2: PD in 20 kV distribution transformer

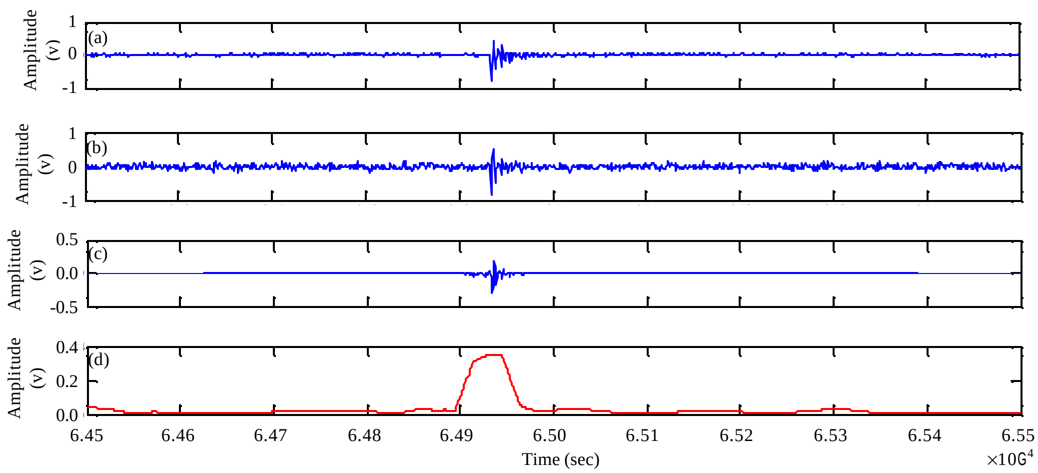

Fig. 3(a-d): De-noising of PD (a) original signal, (b) Noisy signal, (c) Denoised signal and (d) Bhattacharyya in the 20 kV distribution transformer (low noise addition)

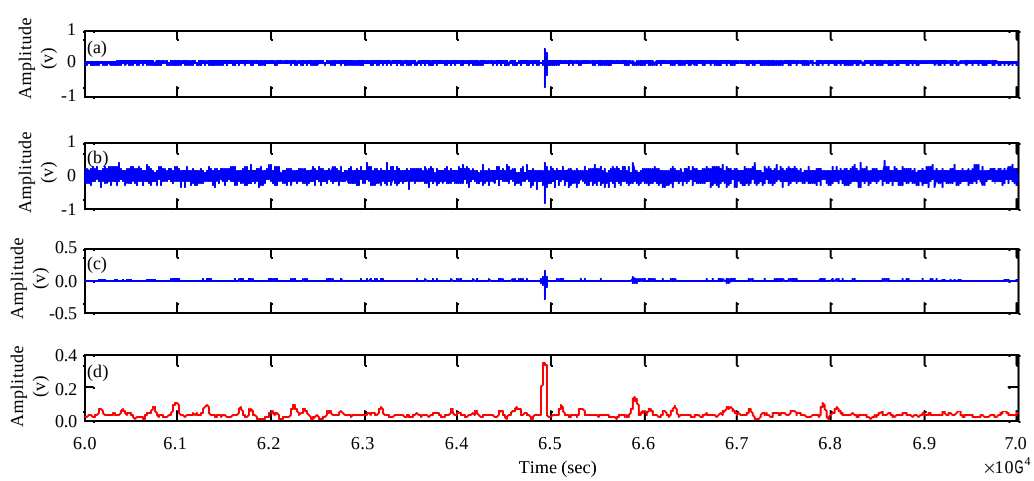

Fig. 4(a-d): De-noising of PD (a) original signal, (b) Noisy signal, (c) Denoised signal and (d) Bhattacharyya in the 20 kV distribution transformer (high noise addition)

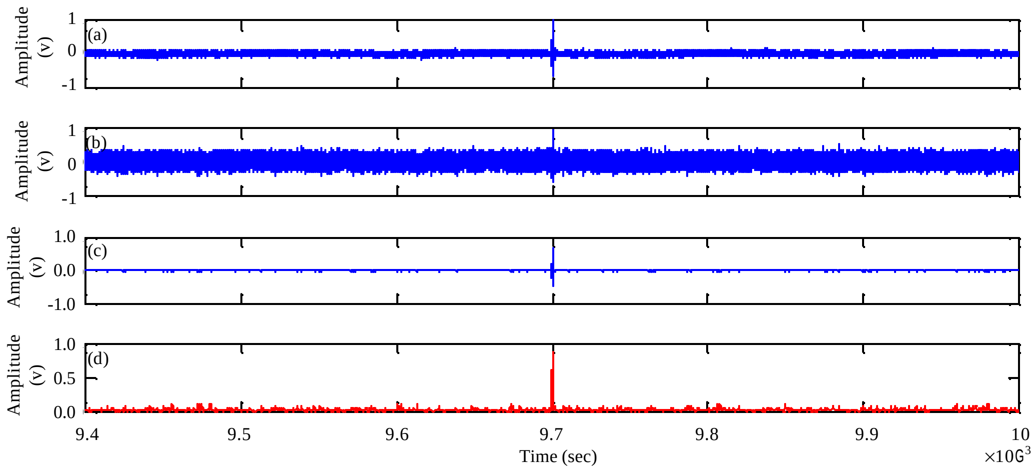

Fig. 5(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from air filled bubbles in the oil (low noise addition)

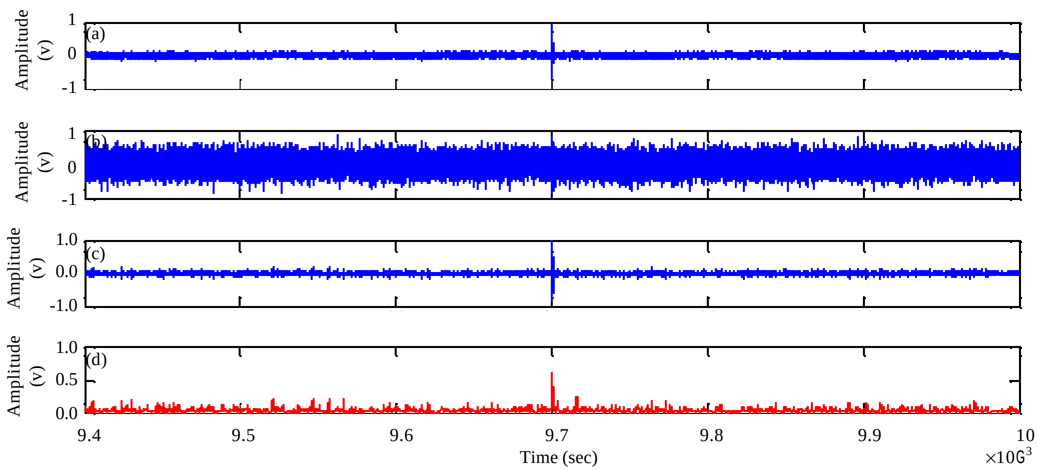

Fig. 6(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from air filled bubbles in the oil (high noise addition)

PD arisen from fixed metallic particle in the transformer oil: In this stage, a fixed metallic particle is inserted in the transformer oil. The PD signals occur with applying high voltage. Then the recorded signals are added with low and high Gaussian noises. The proposed method is applied and the de-noised PD signals are extracted. They are presented in Fig. 7 and 8. From these figures it can be concluded that the proposed technique can successfully de-noise the PD signals arisen from a fixed metallic particle in transformer oil.

PD arisen from single void: In this stage only one void exists in the transformer oil. Then with applying high voltage, the PD signals are occurred and recorded. These signals are added to the low and high Gaussian noises. Then using the proposed method, the de-noised PD signals are

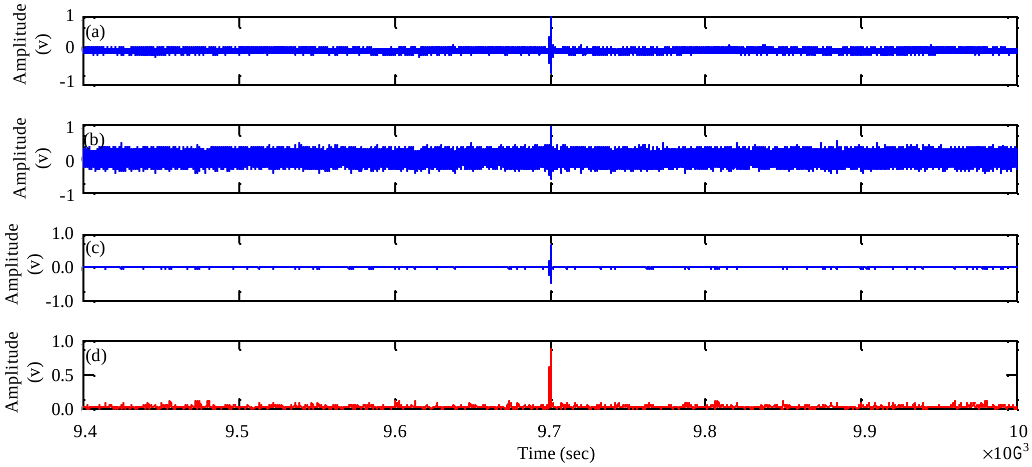

Fig. 7(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from fixed metallic particles (low noise addition)

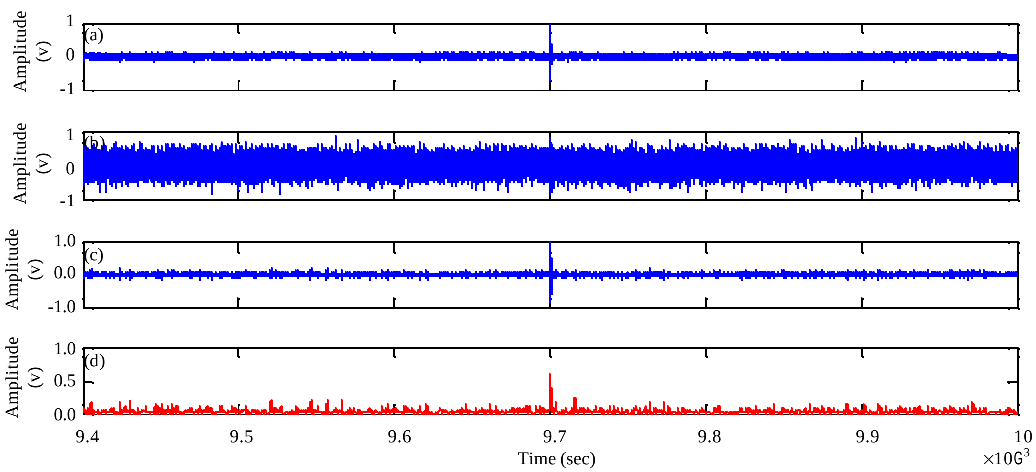

Fig. 8(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from fixed metallic particles (high noise addition)

extracted. They are presented in Fig. 9 and 10. It is deduced from these figures that the proposed technique can successfully de-noise the PD signals arisen from single void in transformer oil.

PD arisen from multiple voids in the oil: In this stage, multiple voids (more than one) exist in the transformer oil. Then with applying high voltage, the PD signals are occurred and recorded. These signals are added to the low and high Gaussian noises. Then, using of the proposed method the de-noised PD signals are extracted. They are presented in Fig. 11 and 12. It is deduced from these figures that the proposed technique can successfully de-noise the PD signals arisen from multiple voids in transformer oil.

Surface discharge: In this stage, the surface discharge signals that occur as a result of the bushing surface contamination are recorded. The low and high Gaussian noises are added to the

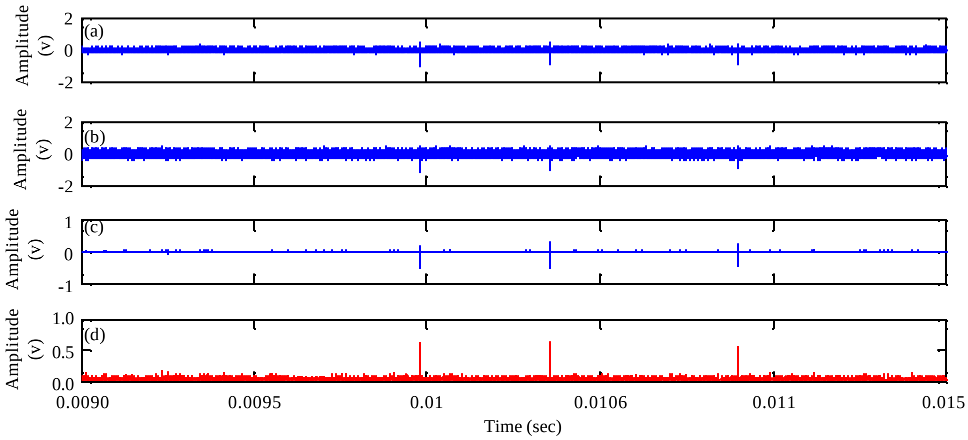

Fig. 9(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from single void in the oil (low noise addition)

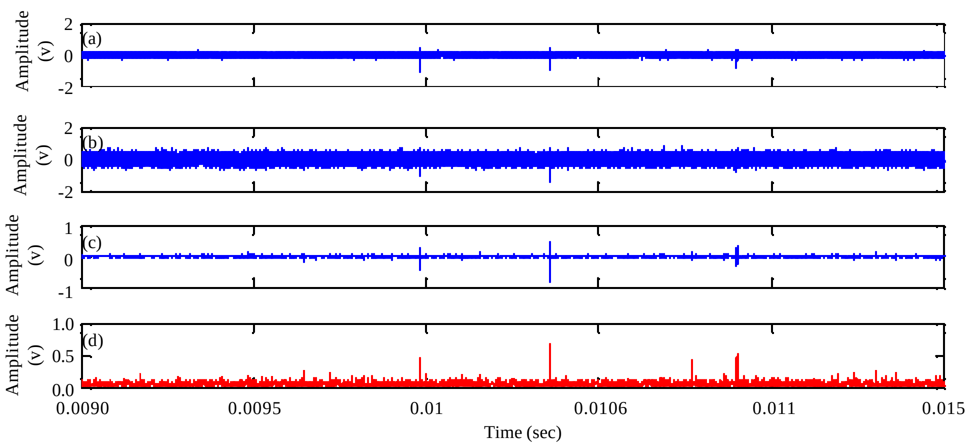

Fig. 10(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from single void in the oil (high noise addition)

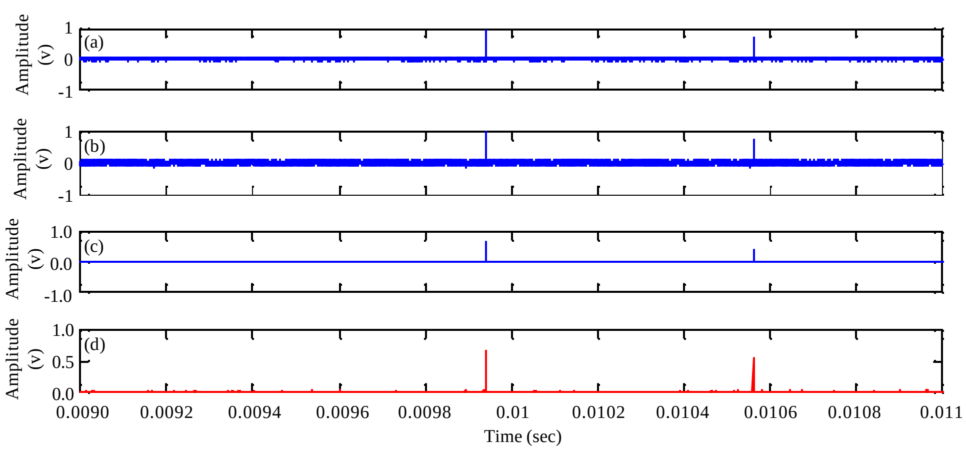

Fig. 11(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from multiple voids in the oil (low noise addition)

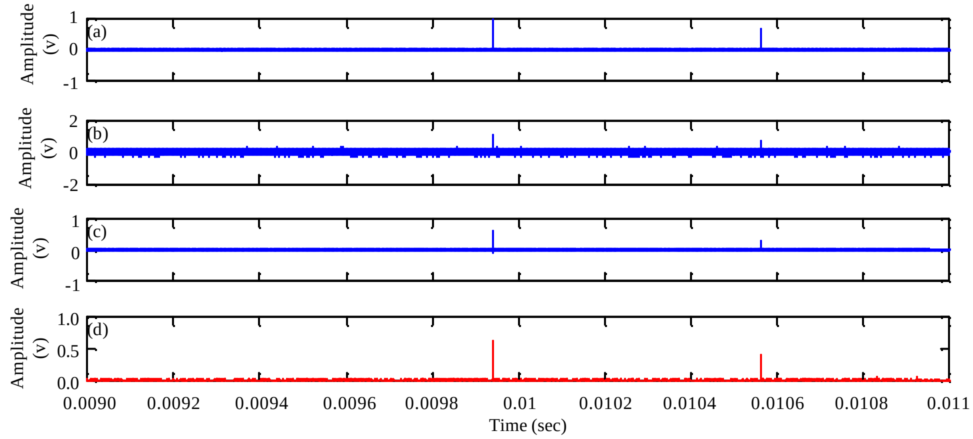

Fig. 12(a-d): De-noising of PD signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya arisen from multiple voids in the oil (high noise addition)

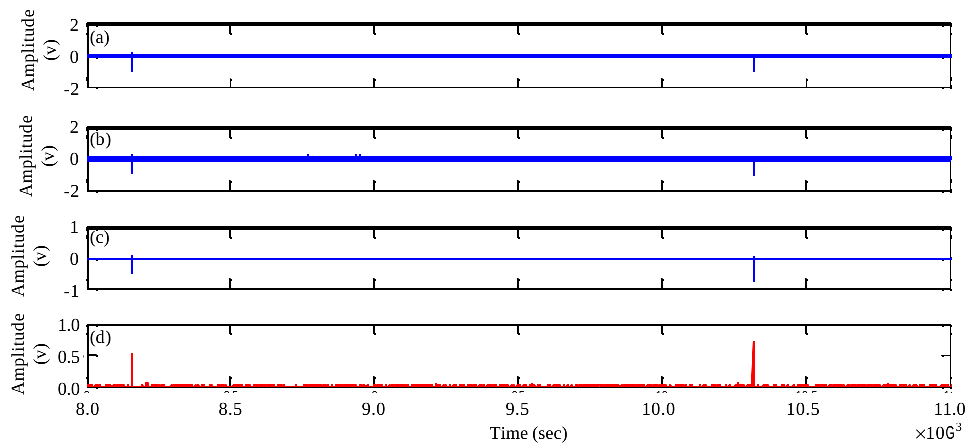

Fig. 13(a-d): De-noising of surface discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya (low noise addition)

surface discharge signals. Then, the proposed technique is applied and de-noised signals are extracted. These signals are presented in Fig. 13 and 14. It is deduced from these Fig. 13 and 14 that the proposed technique can successfully de-noise the discharge signals.

Corona discharge arisen from needle: In a power transformer, the corona discharge may occur on the arrival conductors to the bushings and it results in ionization of the air around the conductors. In this stage, a high voltage is applied to a needle and the corona discharge occur on the air around top of the needle. The corona discharge signals are recorded and added with low and high Gaussian noises. Then using the proposed technique, de-noising is performed and the corona discharge signals are extracted. These signals are presented in Fig. 15 and 16. From the results, it can be concluded that the proposed technique can successfully de-noise the corona signals.

Corona discharge between the needle and ground in the air: In this stage, a high voltage is applied to a needle and the corona discharge occur between the needle and the ground in the air

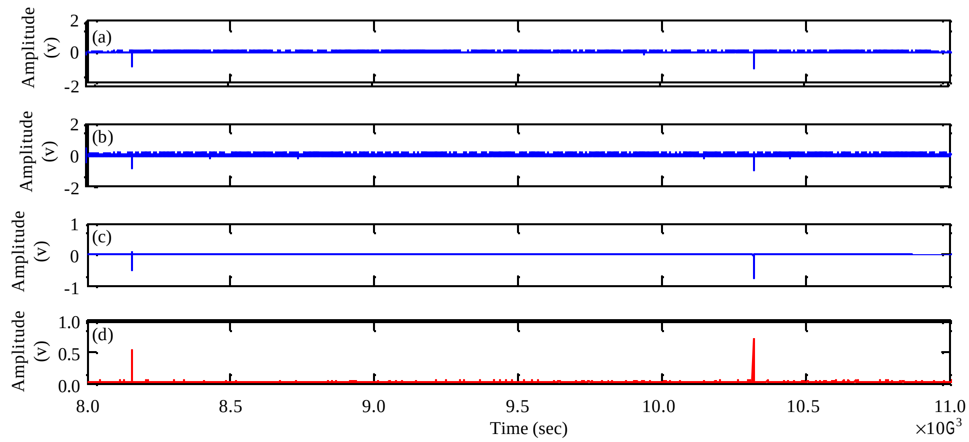

Fig. 14(a-d): De-noising of surface discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya (high noise addition)

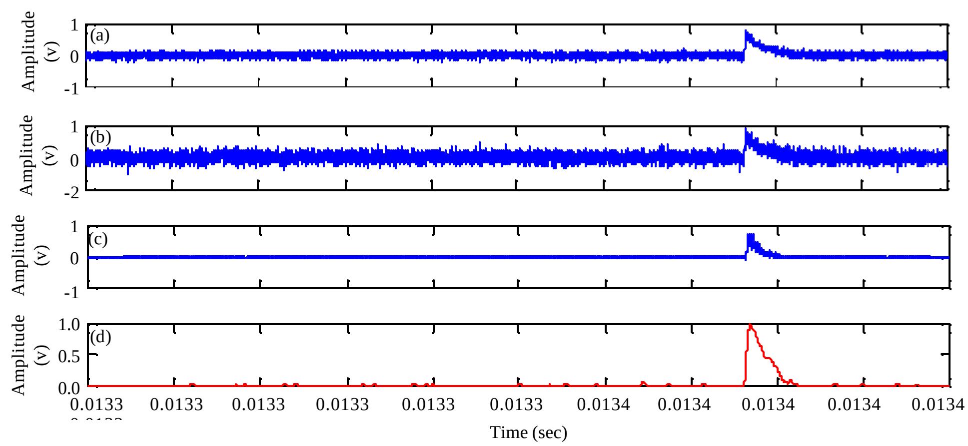

Fig. 15(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya of a needle in the air (low noise addition)

around the needle. The corona discharge signals are recorded and added with low and high Gaussian noises. Then, using the proposed technique, de-noising is performed and the corona discharge signals are extracted. These signals are presented in Fig. 17 and 18. It is deduced from the results that the proposed technique can successfully de-noise the corona signals.

Corona discharge between the needle and ground in the oil: In this stage, a high voltage is applied to a needle and the corona discharge occur between the needle and the ground in the oil around the needle. The corona discharge signals are recorded and added with low and high Gaussian noises. Then, using the proposed technique, de-noising is performed and the corona discharge signals are extracted. These signals are presented in

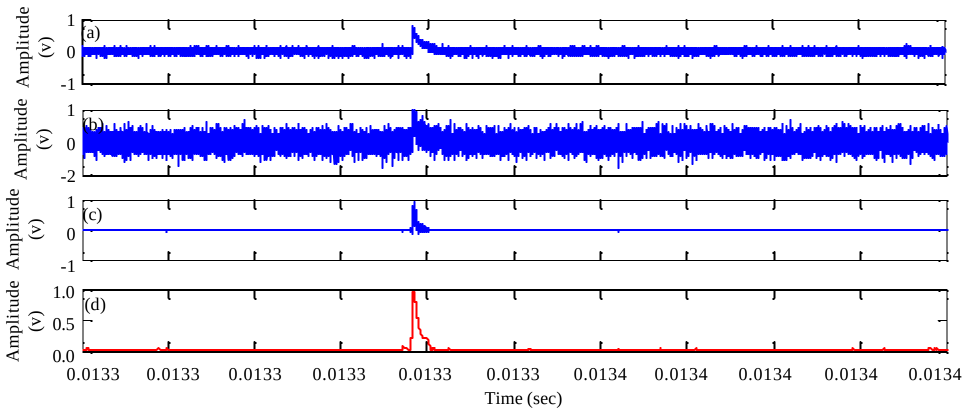

Fig. 16(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya of a needle in the air (high noise addition)

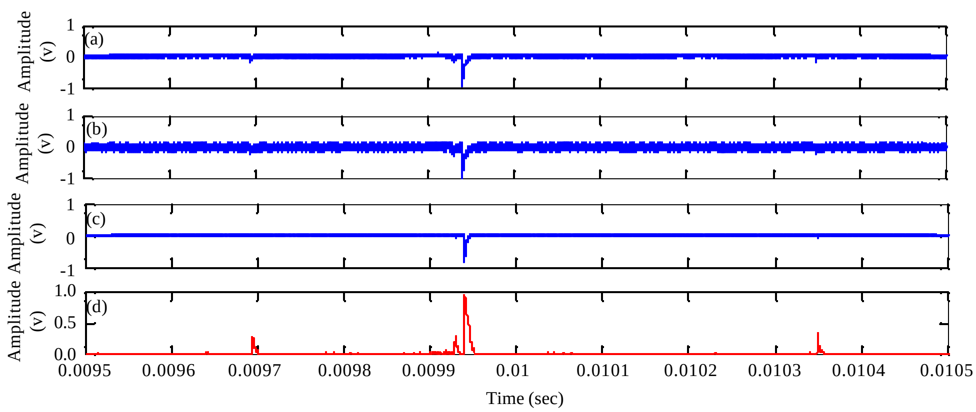

Fig. 17(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya between a needle and ground in air (low-noise addition)

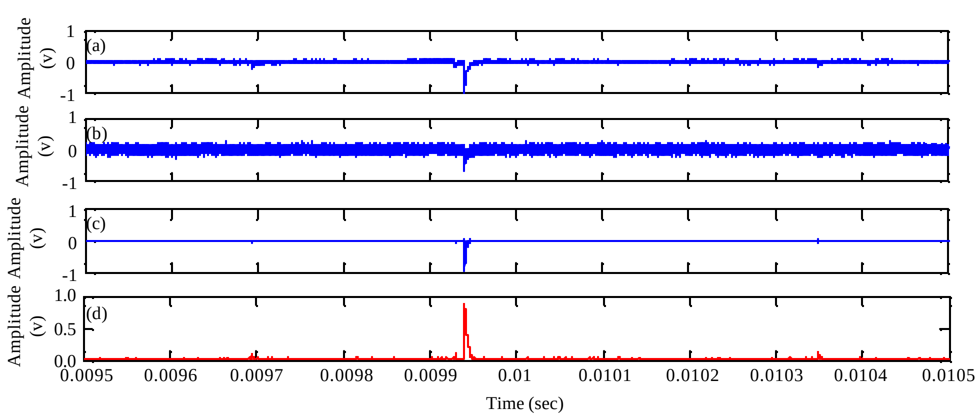

Fig. 18(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya between a needle and ground in air (high-noise addition

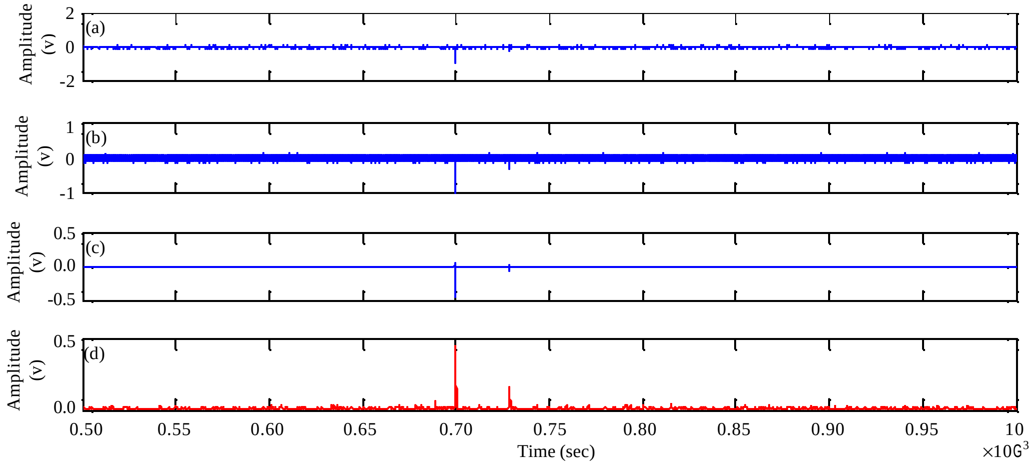

Fig. 19(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya between a needle and ground in the oil (low noise addition)

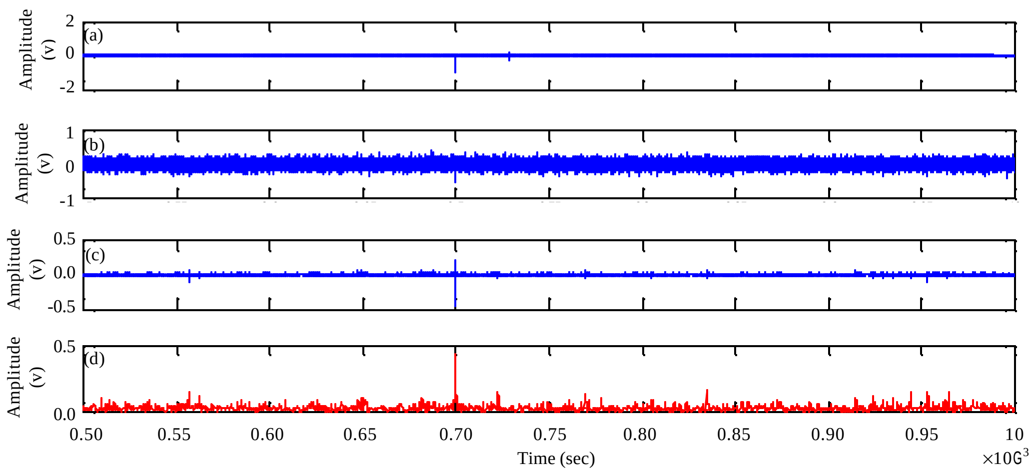

Fig. 20(a-d): De-noising of corona discharge signals (a) Original, (b) Noisy, (c) Denoised and (d) Bhattacharyya between a needle and ground in the oil (high noise addition)

Fig. 19 and 20 with low and high noise additions, respectively. It is deduced from the figures that the proposed technique can successfully de-noise the corona signals.

CONCLUSION

In this study, a new method based on the Bhattacharyya distance is proposed to detect PD signals and remove different noises from the PD signals in high voltage power transformers. This method is applied to different discharge signals, including PD in the 20 kV distribution transformer, PD in air filled bubbles in the transformer oil, PD arisen from fixed metallic particles, PD arisen from single void, PD arisen from multiple voids, surface discharge, corona discharge in the air, corona discharge between the needle and ground in the air and corona discharge between the needle and ground in the oil. It is concluded from the results that this technique can successfully de-noise different PD signals.

REFERENCES

Boggs, S. and J. Densley, 2000. Fundamentals of partial discharge in the context of field cable testing. IEEE Electr. Insul. Mag., 16: 13-18.

Boggs, S.A., 1990. Partial discharge: Overview and signal generation. IEEE Electr. Insul. Magaz., 6: 33-39.

Di Lorenzo del Casale, M., R. Schifani and J.T. Holboll, 2000. Partial discharge tests using cigre method II. IEEE Trans. Dielectr. Electr. Insul., 7: 133-140.

Dong, X., D. Zhu, C. Wang, K. Tan and Y. Liu, 1999. Simulation of transformer PD Pulse propagation and monitoring for a 500 kV substation. IEEE Trans. Dielectr. Electr. Insul., 6: 803-813.

Donoho, D.L. and I.M. Johnstone, 1994. Ideal spatial adaptation by wavelet shrinkage. Biometrika, 81: 425-455.

Ghaffarian, M., M. Vakilian, V. Parvin and A. Ghaedi, 2008. Investigation of online detected partial discharges in power transformer. Proceedings of the Australasian Universities Power Engineering Conference, December 14-17, 2008, Sydney, NSW, pp: 1-6.

Kreuger, F.H., 1964. Discharge Detection in High Voltage Equipment. Temple Press Books Ltd., London.

Lundgaard, L.E., 1992. Partial discharge. XIII. Acoustic partial discharge Detection-fundamental considerations. IEEE Electr. Insul. Magaz., 8: 25-31.

Mak, B. and E. Barnard, 1996. Phone clustering using the Bhattacharyya distance. Proceedings of the 4th International Conference on Spoken Language, October 3-6, 1996, Philadelphia, PA.

Ming, Y. and S. Birlasekaran, 2002. Characterization of partial discharge signals using wavelet and statistical techniques. Proceedings of the IEEE International Symposium on Electrical Insulation, April 7-10, Boston, MA. USA., pp: 9-13.

Moore, P.J., I.E. Portugues and I.A. Glover, 2006. Partial discharge investigation of a power transformer using wireless wideband Radio-frequency measurements. IEEE Trans. Power Delivery, 21: 528-530.

Nattrass, D.A., 1988. Partial discharge measurement and interpretation. IEEE Electr. Insul. Magaz., 4: 10-23.

Niknazar, M., S.R. Mousavi, B.V. Vahdat, M.B. Shamsollahi and M. Sayyah, 2010. A new dissimilarity index of EEG signals for epileptic seizure detection. Proceedings of the 4th International Symposium on Communications, Control and Signal Processing, March 3-5, 2010, Limassol, Cyprus, pp: 1-5.

Satish, L. and B. Nazneen, 2003. Wavelet-based denoising of partial discharge signals buried in excessive noise and interference. IEEE Trans. Dielectr. Electr. Insul., 10: 354-367.

Stone, G.C., 1991. Partial discharge. VII. Practical techniques for measuring PD in operating equipment. IEEE Electrical Insul. Magazine, 7: 9-19.

Wang, X., D. Zhu and F. Li, 2001. Interference analysis and rejection of Partial Discharge (PD) monitoring signal on-site. Proceedings of the International Symposium on Electrical Insulating Materials, November 19-22, 2001, Himeji, pp: 111-114.

Zhang, H., T.R. Blackburn, B.T. Phung and D. Sen, 2007. A novel wavelet transform technique for on-line partial discharge measurements. 1. WT de-noising algorithm. IEEE Trans. Dielectr. Electr. Insul., 14: 3-14.

Zhou, L., W. Li and Z. Chen, 2005. Chaotic algorithm for detecting partial discharge of transformer. Proceedings of the IEEE/PES Transmission and Distribution Conference and Exhibition: Asia and Pacific Dalian, August 14-18, 2005, Dalian, pp: 1-5.