Determination of isolator damages in electric power transmission lines with continuous wavelet transform and multitape power spectrum density

Received 29 May 2021
Revised 18 June 2021
28 June 2021
Accepted 29 June 2021

Tahir Cetin Akinci
Department of Electrical Engineering, Istanbul Technical University, Istanbul, Turkey and
Winston Chung Global Energy Center, University of California Riverside, Riverside, California, USA

Abstract

Purpose – Detection of deformation of devices in high voltage electricity transmission line systems is an important issue in terms of economy and reuse. This study is aimed to detect devices that are deformed or thought to have suffered due to environmental and electrical reasons.

Design/methodology/approach – In this experimental study, it was ensured that the sound and deformed insulators used in energy transmission lines were determined by the analysis of the sounds obtained by using the impact method. Equal intensity impact was applied to the isolator using the pendulum and the resulting sound noise signal analyses were made using power spectral density (PSD), magnitude scalogram (MS), multitape power spectrum density (MPSD) and continuous wavelet transform (CWT) methods in the study. In the analysis results, the isolators that are not visible to the eye and have certain damage were successfully separated from the intact insulators. Especially, MPSD and CWT analysis results are quite satisfactory.

Findings – Damage analysis of insulators used in electricity transmission lines has been made. A total of 40 insulators were examined in two categories in their group, both damaged and not damaged. Data collection system was established. The data obtained from the data collection system were analysed and compared using four analysis methods. PSD, MS, MPSD and CWT analyses were made in the study. All the analyses carried out generally contain features that distinguish damaged and undamaged insulators from each other, the most successful results are MS and CWT results. CWT results are very successful in terms of time and amplitude, and it has been proposed as a method that can be used to separate damaged and undamaged insulators.

Originality/value – It can be suggested as a result of experimental tests that the results of CWT analysis can be used in the pulse noise method in isolators to be tested for reuse in electrical power transmission lines.

Keywords Isolator, Acoustic impulse method, Continuous wavelet transform, Multitape power spectrum density, Electric power transmission lines

Paper type Research paper

Erratum: It has come to the attention of the publisher that the article, Tahir Cetin Akinci and Winston Chung, "Determination of isolator damages in electric power transmission lines with continuous wavelet transform and multitape power spectrum density" published in World Journal of Science, Technology and Sustainable Development, erroneously included Winston Chun as an author and failed to include the second affiliation of Tahir Cetin Akinci. The correct affiliations for Tahir Cetin Akinci are 'Department of Electrical Engineering, Istanbul Technical University, Istanbul, Turkey and Winston Chung Global Energy Center, University of California Riverside, Riverside, California, USA'. This error was introduced in the editorial process and has now been corrected in the online version. The publisher sincerely apologises for this error and for any inconvenience caused.

This paper should now be cited as Akinci, T.C. (2021), "Determination of isolator damages in electric power transmission lines with continuous wavelet transform and multitape power spectrum density", World Journal of Science, Technology and Sustainable Development, Vol. 18 No. 4. pp. 393-404. https://doi.org/10.1108/WJSTSD-05-2021-0059.

World Journal of Science, Technology and Sustainable Development
Vol. 18 No. 4, 2021
pp. 393-404

2042-5945
DOI 10.1108/WJSTSD-05-2021-0059

1. Introduction

Electric power transmission lines and their components are of great importance for delivering electrical energy to end-users (Baretich, 2020). Regular inspections should be carried out and damaged parts should be replaced to fulfil the high efficiency, reliability and safety requirements of the power transmission lines. These damaged materials may need to be tested regularly from the production stage to the end-use stage (Angrisani *et al.*, 1998; Toussaint *et al.*, 2009). Electric power lines are constantly threatened by environmental influences, impacts such as vandalism and theft by humans. Due to all these threats, it is necessary to constantly monitor the electricity transmission lines (Dzansi *et al.*, 2014; Bompard *et al.*, 2013; Weedy *et al.*, 2012).

The most common damages on the components of electric power transmission lines; Mechanical damages of poles, insulation failures in conductors, insulator damages. These insulator damages are corrosion, cracking, breakage and fatigue. Insulator deformations caused by corona discharge can reach levels that will impair the energy transmission quality (Afif *et al.*, 2018; Akbari *et al.*, 2013; Farzaneh *et al.*, 2013; Salman and Li, 2018).

Most of the malfunctions in electrical power transmission lines can be detected by technicians by remote observation. However, most of the deformations that occur in the insulators can be detected by observing very closely or using vibration and acoustic methods. Since the equipment used in electrical power systems is very expensive and requires labour, the elements used in transmission systems are reused if it is understood that they do not have deformation after testing (McLaughlin *et al.*, 2012; Werneck *et al.*, 2014). In the design of a new electrical power transmission line, all components on the old power transmission line are controlled and put into use again.

Fires that occur as a result of damaging the transmission lines of the trees close to the electric power transmission lines cause the energy to be cut by damaging both the pole and all the elements in the transmission line. As a result of such fires, many elements in the electrical power system become unusable. Most of the malfunctions in the electrical power line are detected by technicians by visual inspection or by technological devices such as unmanned aerial vehicles (drones). Many applications have been developed in this field, and there are studies in the literature for this purpose. Most of these studies are included in the literature as image processing studies (Antwi-Bekoe *et al.*, 2020; Guo *et al.*, 2018; Zengin *et al.*, 2020; Zormpas *et al.*, 2018).

In electrical power transmission and distribution facilities, insulators are one of the most important materials for the safe transmission of electrical energy (Liu *et al.*, 2021; Yang *et al.*, 2020). Insulators are elements that protect the safety of the electrical transmission line and its contact with the pole. Deformations on insulators may cause leakage currents or arcs on the transmission line (Li *et al.*, 2009). Analysis of data collected as a result of such inspections and observations on transmission lines in electrical power systems is important to distinguish between robust and intact components. Personal observations are not enough in these determinations and do not give correct results. For this reason, it is of great importance to developing experimental procedures that determine whether the devices used in transmission lines are intact or not. Researches show that there is not enough research to analyse these data to date. There are very few studies in the literature, especially on insulator malfunctions. In this study, the detection of solid and defective insulators has been achieved by using the acoustic impulse method for different types of insulators (Jiang *et al.*, 2019; Marciniak, 2010; Platt *et al.*, 2005; Zhang *et al.*, 2017; Zhao *et al.*, 2018).

2. Mathematical background

In this experimental study, the most effective result was investigated by comparing the mathematical methods used. Fourier-based analysis techniques are the most effective methods for examining sound signals. However, some of these techniques give clearer results in terms of analysis. Here, power spectrum, multitape pspectrum density, magnitude scalogram and continuous wavelet transform (CWT) methods are used.

2.1 Power spectrum density

Power spectral density (PSD) means that the magnitude of the analysed signal is proportional to the mean square value of the signal, it is not a physical quantity. Similarly, the frequency function represents the spectrum distribution. The term density means that it is normalized to a single frequency bandwidth. PSD is the most common method used in random vibration analysis. Thus, resonances and harmonics that are hidden in the time domain are determined by a PSD analysis (Esen *et al.*, 2015; Seker *et al.*, 2012; Yan and Ren, 2012; psd, 2021).

In a data set, the transformation in $m\Delta f$ frequency for N samples is given in Equation 1. Where Δf is the frequency resolution, the data sampling interval. Auto-PSD is given in Equation 2.

$$X(m\Delta f) = \sum_{k=0}^{N-1} x(k\Delta t)\exp\left[\frac{-j2\pi km}{N}\right] \tag{1}$$

$$Sxx(f) = \frac{1}{N}|X(m\Delta f|^2, \quad f = m\Delta f. \tag{2}$$

2.2 Multitape power spectrum density (MPSD)

The Fourier method is traditionally used to extract information from a signal. Sometimes there are situations where this method cannot respond. MPSD is used to estimate the power at the component frequency in the data taper.

Analyse with K Conic periodograms over samples that are evenly spaced relative to the N mean. MPSD is a PSDand an estimation technique used to reduce the variance of PSD. Here, the estimation of Spectrum $sx(f)$ from N data is given in equation (1). Equation (2) is a windowed periodogram obtained by using the data window (Akinci *et al.*, 2013; Babadi and Brown, 2014; Di Matteo *et al.*, 2020; Rooney and Buck, 2015; Upadhya *et al.*, 2018).

$$\widehat{S}_k(f) = \frac{1}{K}\sum_{k=1}^{K}\widehat{S}_k(f) \tag{3}$$

$$\widehat{S}_k(f) = \left|\sum_{n=0}^{N-1} x(n)h_k(n)e^{-i2\pi fn}\right|^2. \tag{4}$$

2.3 Continuous wavelet transform (CWT) and Morlet wavelet

The CWT of the signals is quite suitable for signals that change in frequency according to time, that is, non-stationary signals. Here, the conversion to be analysed can be selected as desired. This transformation is a generalized form of the Fourier transform. Physically, in this transformation, the variable, the modulated range is during the whole signal. The phase spectrum is investigated for both positions that are shifted. This process is repeated in short and long intervals. Continuous wavelet transform is given in equation 3 (Akgün *et al.*, 2013; Holschneider *et al.*, 1990; Melhem and Kim, 2003; Zhen *et al.*, 2019). Here, $f(t)$ is a signal, and $\psi(t)$ is the analysing function (wavelet). Is the conjugate of the wavelet function, and a, b is the sequence expansion and translation parameter. $W_f(a, b)$ is defined as:

$$W_f(\mathrm{a},\, \mathrm{b}) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t) * \overline{\psi} + \left(\frac{t-b}{a}\right)dt \tag{5}$$

Considering $\psi(t)$ as the bandpass impulse response, it changes the bandwidth of the bandpass in scaling the wavelet (Holschneider *et al.*, 1990). Thus, unlike STFT, CWT provides better resolution in the frequency domain.

$$\psi_{a,\tau} = \frac{1}{\sqrt{a}}\psi\left[\frac{(t-\tau)}{a}\right] \tag{6}$$

Morlet wavelet form is also frequently used in time-frequency analysis. A complex wavelet form is used to remove oscillations from the magnitude of the wavelet coefficients. The square of the real and imaginary part in the equation translates the energy representation in the magnitude scalogram into intuitive form (Equation 6). The Morlet wavelet is also referred to as the gauss form of a complex sinusoidal signal.

3. Measurement and data collection system

A pendulum is used to generate a constant pulse in the measuring system. Rotary Servo Base Unit is used as a pendulum. The pulse pendulum is designed to create equal-sized bumps. The hammer attached to the end of the impact pendulum ensures that the impact pendulum strikes the insulator by producing an equal impact (Akıncı *et al.*, 2011; Akinci *et al.*, 2012; Yumurtaci *et al.*, 2020). Insulators are made of ceramic materials and the sound emanating from the isolator was recorded after the applied equal impact. A computer is used to analyse the sound that comes out afterwards. In this experimental study, an insulator with the same type and model of the impact pendulum, one damaged and one not damaged, was applied. The sound generated by applying equal impacts applied to this same type of damaged and undamaged insulators was transferred to the data collection system and then from the data collection system. The output audio data of the amplifier coupled to the data acquisition system is transmitted to the computer at a 17 kHz sampling frequency via an Advantech 1716L Multifunction PCI card and data analysis is performed using Matlab© (Plate 1).

In this study, 20 undamaged and 20 damaged insulators of different types, 40 of them in total, were used. In this study, analyses of only 4 insulators of two different types were made. In Figure 1, the time-amplitude diagram of the damaged and undamaged insulator belonging to the ×4 type insulator is given.

The damaged and undamaged time-amplitude graph of the ×13 type insulator is also given in Figure 2. When the graph is examined, it is seen that the amplitude starts from an average of 0.6 dB from the first moment of impact to the insulator and decreases over time. It can be seen that the amplitude changes between Figures 1a and 1b after the first second. In Figure 3, the comparison of the time-amplitude graph of the undamaged and damaged insulators is given.

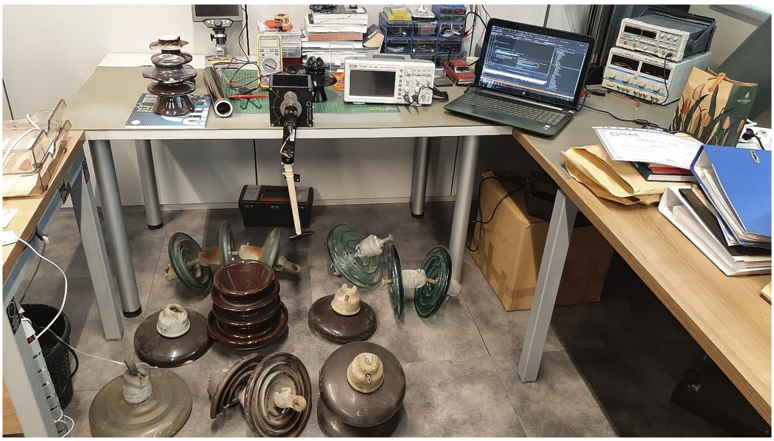


Plate 1.
Experimental hardware setup for insulators tests

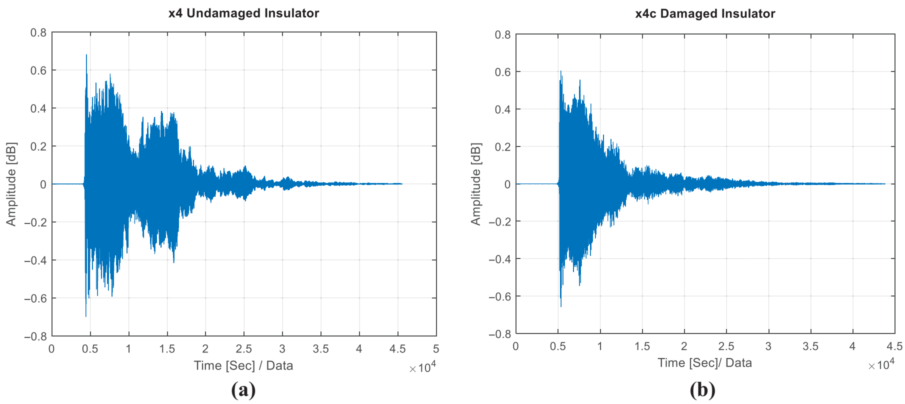


Figure 1. Time-amplitude graphs (a) undamaged (b) damaged insulator for ×4 type

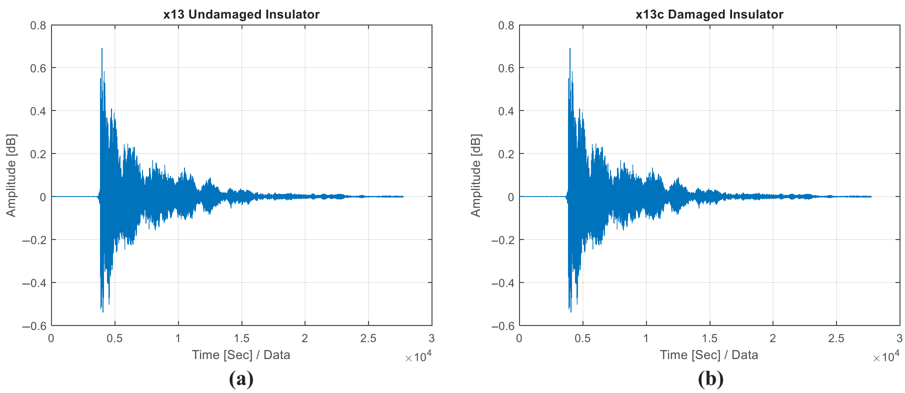


Figure 2. Time-amplitude graphs (a) undamaged, (b) damaged insulator for ×13 type

4. Analysis of MPSD and CWT

MPSD analysis results are given in Figures 4 and 5. MPSD analysis results, these data do not contain distinctive results. Amplitude values for both undamaged and damaged insulators do not contain discriminatory consequences. However, although it has distinctive elements for damaged and undamaged insulators with an amplitude of −120dB around 0.4 s/data, these elements are not as successful as the CWT and magnitude scalogram. For Figures 4 and 5, the normalized frequency value of 0.8 is the threshold value. However, it can be used to compare the amplitude (dB) value.

The frequency-time domain map after continuous wavelet transform (CWT) is given in Figures 6 and 7. Here the Morlet wavelet is shown as the main wavelet due to the expected symmetry of the returning sound waves.

When Figures 6 and 7 are examined, it is seen that the scale and *Coefs* are quite determinant for damaged and undamaged insulators. Here, the *Coefs* coefficient takes the value 0.8 in the ×13 insulators, while this peak value takes the value 0.5 in the damaged insulator.

Magnitude scalogram analysis is given for both isolators in Figures 8 and 9. Magnitude scalogram analysis contains very successful results for insulators.

In Figure 10, as a result of PSD analysis, damaged and undamaged insulators are compared. In the analyses made, it was determined that the damaged and undamaged insulators around −20 dB contain distinctive features around 5 Hz. The changes are shown in the figure and it has been observed that Magnitude scalogram analysis has more successful results (see Figure 11).

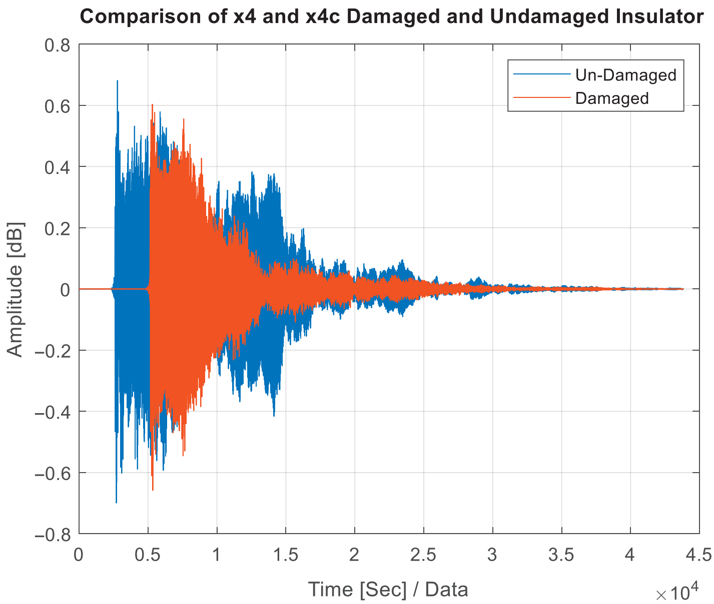


Figure 3.
Comparison of undamaged and damaged insulators

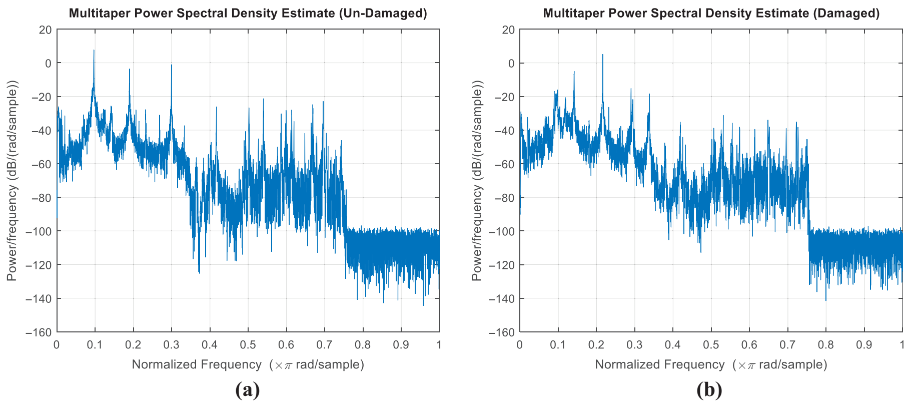


Figure 4.
MPSD analysis for ×4 insulators (a) No damage (b) Damaged

In this analysis, the frequency-amplitude changes can be understood from the change of the peaks on the curve. While for some insulators, these analysis results can only be made using advanced analysis techniques, the change of peaks in these insulators determines.

5. Conclusion

An insolation device is of vital importance in high voltage energy transmission lines. In this study, damage analysis of insulators used in electricity transmission lines has been made. A total of 40 insulators were examined in two categories in their group, both damaged and not damaged.

In Figure 12 and 13, the frequency distributions in the region between the scale 256 and 1,024 show the characteristics of the damaged and undamaged insulators. As is known, scale and frequency are inversely proportional. Again, the scale shows the fundamental frequency of the insulator between 4 and 16.

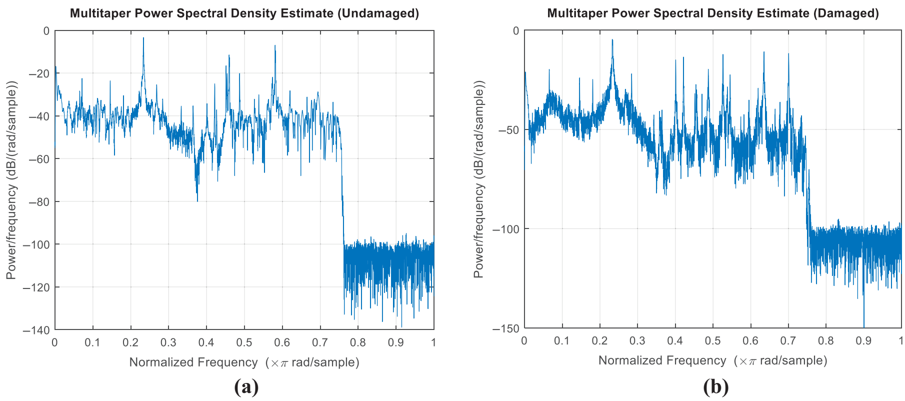


Figure 5.
MPSD analysis for ×13 insulators (a) Undamaged (b) Damaged

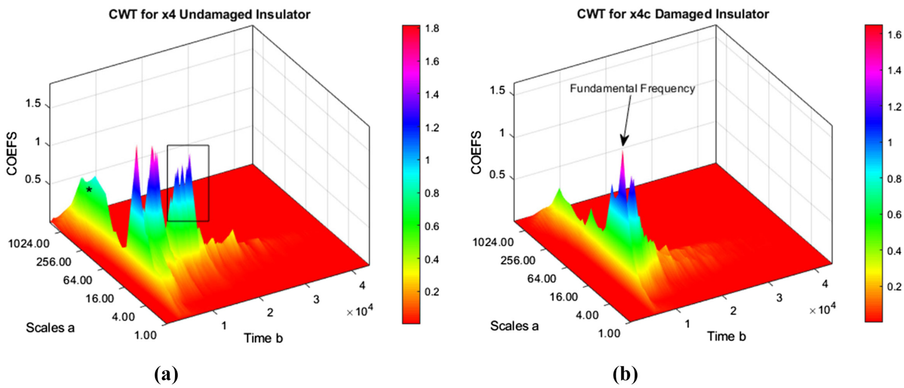


Figure 6.
CWT analysis for ×4 type insulators

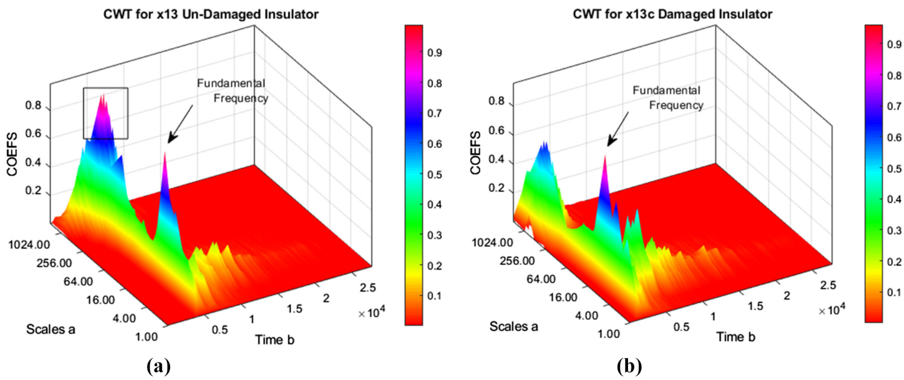


Figure 7.
CWT analysis for ×13 type insulators

Then a data collection system was established. The data obtained from the data collection system were analysed and compared using four analysis methods. PSD, MS, MPSD and CWT analyses were made in the study. Although all the analyses carried out generally contain features that distinguish damaged and undamaged insulators from each other, the most successful results are MS and CWT results. CWT results are very successful in terms of time and amplitude, and it has been proposed as a method that can be used to separate damaged and undamaged insulators. This study also includes the fundamental frequency response analysis results regarding the material structure of electrical insulators. These response analyses are successful for comparing damaged and undamaged isolators. However, CWT

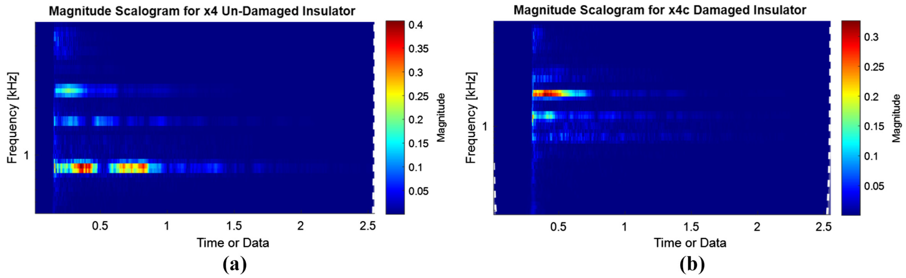


Figure 8.
Magnitude scalogram analysis for ×4 type insulators

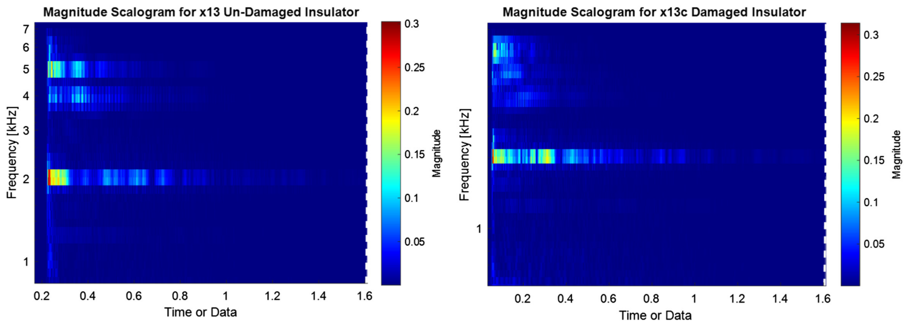


Figure 9.
Magnitude scalogram analysis for ×13 type insulators

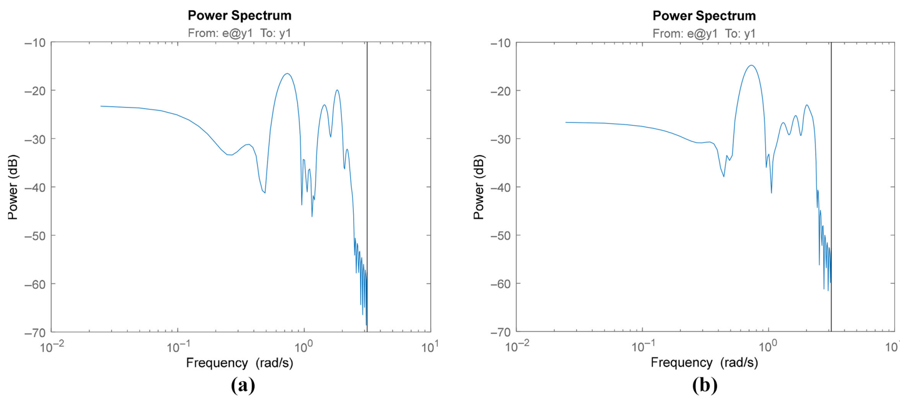
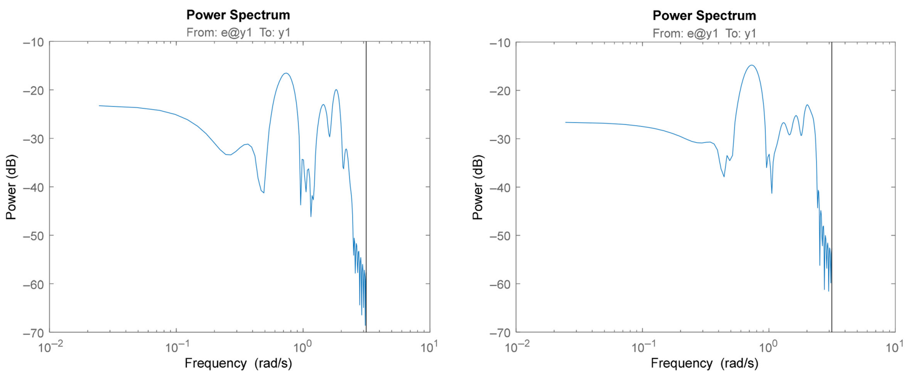
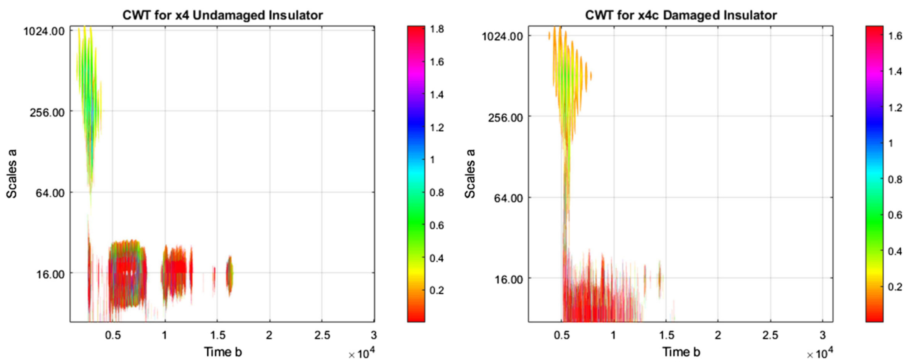


Figure 10.
PSD analysis for ×4 type insulators



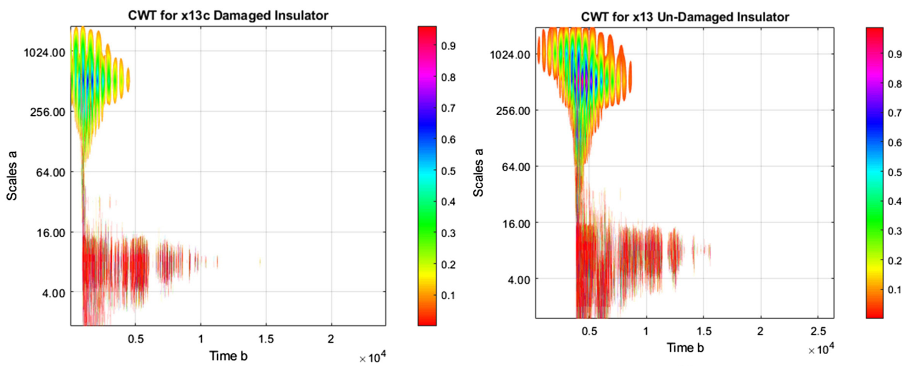
(a) (b)

Figure 11.
PSD analysis for ×13 type insulators



(a) (b)

Figure 12.
Cwt analysis for ×4 type undamaged and damaged insulators



(a) (b)

Figure 13.
Cwt analysis for ×13 type undamaged and damaged insulators

and MS results can be used for damage detection. The frequency changes here are closely related to the structure of the insulator. In this sense, it can be suggested as a result of experimental tests that CWT analysis results can be used in the impulse noise method in insulators to be tested for reuse in electrical transmission lines.

References

Afif, Y., Negara, I.M.Y. and Asfani, D.A. (2018), "Effect of corona ring design and placement on the distribution of electric fields on 500 kV gantry substation in Indonesia", *JAREE (Journal on Advanced Research in Electrical Engineering)*, Vol. 2 No. 2, pp. 44-48, available at: http://jaree.its.ac.id/index.php/jaree/article/view/53/37.

Akbari, E., Mirzaie, M., Asadpoor, M.B. and Rahimnejad, A. (2013), "Effects of disc insulator type and corona ring on electric field and voltage distribution over 230-kV insulator string by numerical method", *Iranian Journal of Electrical and Electronic Engineering*, Vol. 9 No. 1, pp. 44-57.

Akgün, Ö., Cetin Akinci, T., Selcuk Nogay, H. and Seker, S. (2013), "The defect detection in ceramic materials based on wavelet analysis by using the method of impulse noise", *Journal of Vibroengineering*, Vol. 15 No. 2, pp. 816-823.

Akinci, T.C., Nogay, H.S. and Yilmaz, O. (2012), "Application of artificial neural networks for defect detection in ceramic materials", *Archives of Acoustics*, Vol. 37 No. 3, pp. 279-286.

Akinci, T.C., Ekren, N., Seker, S. and Yildirim, S. (2013), "Continuous wavelet transform for ferroresonance phenomena in electric power systems", *International Journal of Electrical Power & Energy Systems*, Vol. 44 No. 1, pp. 403-409.

Akıncı, T., Yılmaz, Ö., Kaynaş, T., Özgiray, M. and Şeker, S. (2011), *Detection for Ceramic Materials by Continuous Wavelet Analysis*, Mechanika, available at: http://web.a.ebscohost.com/ehost/pdfviewer/pdfviewer?vid=0&sid=2cc990d1-f0c2-4e6f-83f5-7f55dc4365b7%40sdc-v-sessmgr01.

Angrisani, L., Daponte, P., D'apuzzo, M. and Testa, A. (1998), "A measurement method based on the wavelet transform for power quality analysis", *IEEE Transactions on Power Delivery*, Vol. 13 No. 4, pp. 990-998.

Antwi-Bekoe, E., Zhan, Q., Xie, X. and Liu, G. (2020), "Insulator recognition and fault detection using deep learning approach", *Journal of Physics: Conference Series*, pp. 1-9, doi: 10.1088/1742-6596/1454/1/012011.

Babadi, B. and Brown, E.N. (2014), "A review of multitaper spectral analysis", *IEEE Transactions on Biomedical Engineering*, Vol. 61 No. 5, pp. 1555-1564.

Baretich, M.F. (2020), "Electrical power", *Clinical Engineering Handbook*, Elsevier, pp. 667-669, available at: https://www.elsevier.com/books/clinical-engineering-handbook/dyro/978-0-12-226570-9.

Bompard, E., Huang, T., Wu, Y. and Cremenescu, M. (2013), "Classification and trend analysis of threats origins to the security of power systems", *International Journal of Electrical Power & Energy Systems*, Vol. 50, pp. 50-64.

Di Matteo, S., Viall, N.M. and Kepko, L. (2020), "Power spectral density background estimate and signal detection via the multitaper method", *Journal of Geophysical Research: Space Physics*, e2020JA028748, pp. 1-23, doi: 10.1029/2020JA028748.

Dzansi, D., Rambe, P. and Mathe, L. (2014), "Cable theft and vandalism by employees of South Africa's electricity utility companies: a theoretical explanation and research agenda", *Journal of Social Sciences*, Vol. 39 No. 2, pp. 179-190.

Esen, V., Oral, B. and Akinci, T.C. (2015), "The determination of short circuits and grounding faults in electric power systems using time-frequency analysis", *Journal of Energy in Southern Africa*, Vol. 26 No. 2, pp. 123-132.

Farzaneh, M., Farokhi, S. and Chisholm, W.A. (2013), *Electrical Design of Overhead Power Transmission Lines*, McGraw-Hill Education, available at: https://www.accessengineeringlibrary.com/binary/

mheaeworks/1158d3f250d6dfc6/808c8e45dc6f6617fcdae5efc04645fa17af84f50094ba222795f4907498a7ec/book-summary.pdf.

Guo, L., Liao, Y., Yao, H., Chen, J. and Wang, M. (2018), "An electrical insulator defects detection method combined human receptive field model", *Journal of Control Science and Engineering*, Vol. 2018, pp. 1-9, available at: https://downloads.hindawi.com/journals/jcse/2018/2371825.pdf.

Holschneider, M., Kronland-Martinet, R., Morlet, J. and Tchamitchian, P. (1990), A real-time algorithm for signal analysis with the help of the wavelet transform, *Wavelets*, Springer, pp. 286-297, Berlin, available at: https://link.springer.com/chapter/10.1007/978-3-642-75988-8_28.

Jiang, X., Fan, C. and Xie, Y. (2019), "New method of preventing ice disaster in power grid using expanded conductors in heavy icing area", *IET Generation, Transmission & Distribution*, Vol. 13 No. 4, pp. 536-542.

Li, J., Sun, C., Sima, W. and Yang, Q. (2009), "Stage pre-warning based on leakage current characteristics before contamination flashover of porcelain and glass insulators", *IET Generation, Transmission & Distribution*, Vol. 3 No. 7, pp. 605-615.

Liu, C., Wu, Y., Liu, J. and Han, J. (2021), "MTI-YOLO: a light-weight and real-time deep neural network for insulator detection in complex aerial images", *Energies*, Vol. 14 No. 5, p. 1426.

Marciniak, L. (2010), *Wavelet Criteria for Identification of Arc Intermittent Faults in Medium Voltage Networks. 2010 Modern Electric Power Systems*.

McLaughlin, S., Holbert, B., Zonouz, S. and Berthier, R. (2012), "AMIDS: a multi-sensor energy theft detection framework for advanced metering infrastructures", *2012 IEEE Third International Conference on Smart Grid Communications (SmartGridComm)*.

Melhem, H. and Kim, H. (2003), "Damage detection in concrete by Fourier and wavelet analyses", *Journal of Engineering Mechanics*, Vol. 129 No. 5, pp. 571-577.

Platt, S.R., Farritor, S., Garvin, K. and Haider, H. (2005), "The use of piezoelectric ceramics for electric power generation within orthopedic implants", *IEEE/ASME Transactions on Mechatronics*, Vol. 10 No. 4, pp. 455-461.

Psd (2021). available at: https://vru.vibrationresearch.com/lesson/what-is-the-psd/.

Rooney, I.M. and Buck, J.R. (2015), "Multitapered power spectral density estimation for co-prime sensor arrays", *2015 49th Asilomar Conference on Signals, Systems and Computers*.

Salman, A.M. and Li, Y. (2018), "A probabilistic framework for multi-hazard risk mitigation for electric power transmission systems subjected to seismic and hurricane hazards", *Structure and Infrastructure Engineering*, Vol. 14 No. 11, pp. 1499-1519.

Seker, S., Akinci, T.C. and Taskin, S. (2012), "Spectral and statistical analysis for ferroresonance phenomenon in electric power systems", *Electrical Engineering*, Vol. 94 No. 2, pp. 117-124.

Toussaint, K., Pouliot, N. and Montambault, S. (2009), "Transmission line maintenance robots capable of crossing obstacles: state-of-the-art review and challenges ahead", *Journal of Field Robotics*, Vol. 26 No. 5, pp. 477-499.

Upadhya, S.S., Cheeran, A. and Nirmal, J.H. (2018), "Thomson Multitaper MFCC and PLP voice features for early detection of Parkinson disease", *Biomedical Signal Processing and Control*, Vol. 46, pp. 293-301.

Weedy, B.M., Cory, B.J., Jenkins, N., Ekanayake, J.B. and Strbac, G. (2012), *Electric Power Systems*, John Wiley & Sons, available at: https://books.google.com/books?hl=tr&lr=&id=JkQdhXtGBtYC&oi=fnd&pg=PP9&dq=weedy+B.M.,+Cory+BJ,+Jenkins+N.+Ekanayake+JB,+Stbac,+2012,+electric+power+system+willey&ots=qRNTdmaF3B&sig=dq6N57V2qIjqf-ibyV2GEUD-D40#v=onepage&q&f=false.

Werneck, M.M., dos Santos, D.M., de Carvalho, C.C., de Nazaré, F.V.B. and Allil, R.C.d. S.B. (2014), "Detection and monitoring of leakage currents in power transmission insulators", *IEEE Sensors Journal*, Vol. 15 No. 3, pp. 1338-1346.

Yan, W.J. and Ren, W.X. (2012), “Operational modal parameter identification from power spectrum density transmissibility”, *Computer-Aided Civil and Infrastructure Engineering*, Vol. 27 No. 3, pp. 202-217.

Yang, L., Fan, J., Liu, Y., Li, E., Peng, J. and Liang, Z. (2020), “A review on state-of-the-art power line inspection techniques”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 69 No. 12, pp. 9350-9365.

Yumurtaci, M., Gokmen, G. and Akinci, T.C. (2020), “Determining damages in ceramic plates by using discrete wavelet packet transform and support vector machine”, *International Journal of Electrical and Computer Engineering*, Vol. 10 No. 5, p. 4759.

Zengin, A.T., Erdemir, G., Akinci, T.C. and Seker, S. (2020), “Measurement of power line sagging using sensor data of a power line inspection robot”, *IEEE Access*, Vol. 8, pp. 99198-99204.

Zhang, S., Wang, Y., Liu, M. and Bao, Z. (2017), “Data-based line trip fault prediction in power systems using LSTM networks and SVM”, *IEEE Access*, Vol. 6, pp. 7675-7686.

Zhao, H., Sun, S. and Jin, B. (2018), “Sequential fault diagnosis based on LSTM neural network”, *IEEE Access*, Vol. 6, pp. 12929-12939.

Zhen, D., Wang, Z., Li, H., Zhang, H., Yang, J. and Gu, F. (2019), “An improved cyclic modulation spectral analysis based on the CWT and its application on broken rotor bar fault diagnosis for induction motors”, *Applied Sciences*, Vol. 9 No. 18, p. 3902.

Zormpas, A., Moirogiorgou, K., Kalaitzakis, K., Plokamakis, G.A., Partsinevelos, P., Giakos, G. and Zervakis, M. (2018), “Power transmission lines inspection using properly equipped unmanned aerial vehicle (UAV)”, *2018 IEEE International Conference on Imaging Systems and Techniques (IST)*.

Corresponding author
Tahir Cetin Akinci can be contacted at: akincitc@itu.edu.tr