Journal of ELECTRICAL ENGINEERING, VOL 70 (2019), NO6, 494–498

sciendo

PAPERS

Analysis of instantaneous frequency, instantaneous amplitude and phase angle of ferroresonance in electrical power networks

Ömer Akgün*, Tahir Çetin Akıncı, Gökhan Erdemir*** , Serhat Şeker****

Ferroresonance is a nonlinear phenomenon that damages the undesired, destructive system for energy transmission lines. The formation and development of this overvoltage ferroresonance phenomenon is an important research topic as a mysterious event in energy power systems. In this study, Seyit Omer-Iklar energy transmission line from Turkey's electrical transmission networks was modelled using real parameters. Ferroresonance scenario was created on the model. The energy transmission system with the scenario is set to a simulation time of 4 seconds. The first two seconds are set to normal. By cutting off the transmission line in the 2nd sec., the system is provided with ferroresonance drift. According to the data obtained therefrom, spectrograms, instantaneous amplitude, instantaneous frequency and instantaneous phase were conducted. The analyses have made clear that the instantaneous frequency amplitude defined the system's ferroresonance moment very well.

K e y w o r d s: Hilbert-Huang transform, ferroresonance, spectrograms, instantaneous frequency, instantaneous phase

1 Introduction

The development of technology in the world is causing the increase of industrial potential. The need for electricity with industry potential is increasing proportionally. The transmission of electricity to the production and distribution to end users are extremely important. In this sense, the first task of the agencies responsible for the distribution of electricity is to deliver the energy to the users in an uninterrupted, economical and quality manner. Most failures occurring on power transmission lines are the result of short circuits or insulation problems in generators, transformers, line breakers, disconnecting switches. Detailed analysis such as the detection of these failures, determination of the start and end times of the failures, the characteristics of failures, and the elimination and prevention of failures are of great significance [1-3].

The phenomenon of ferroresonance that occurs in energy transmission systems manifests itself as high overvoltage or current in the system. These high currents or voltages that occur as a result of a malfunction in the system lead to massive material and work losses due to wave form and amplitude, causing short-term destructive and irreparable damage to the network [3-6]. The ferroresonance phenomenon is one of the most serious problems of energy transmission systems [5-9]. Although the ferroresonance phenomenon has been known for many years, the mystery of its formation and prevention has not been fully resolved, which is due to the nonlinear properties of devices used in power system equipment [7-12]. In the formation of the ferroresonance phenomenon, especially the magnetic nonlinear elements and the influence of the transformer's capacitance and capacitance are great [10-13].

Ferroresonance is a fault state with a non-symmetrical high-amplitude waveform that occurs as a consequence of the interruption of one of the excesses of a state of charge in a three-phase electric line [1,3,10-17]. Today, the detailed analysis of the ferroresonance phenomenon and the determination of its characterization are carried out with signal processing-based analyses. In this study, the simulation results obtained by modelling ferroresonance phenomenon were made by Hilbert transformation and instant frequency analysis.

2 Hilbert transformation and instantaneous frequency

The Hilbert transform (HHT) is a signal processing algorithm that takes two distinct filters [18-20]. This algorithm was proposed by Huang in 1998 [6]. The Hilbert transformation is a mathematical transformation which shifts every Fourier component by 90 degrees without changing its amplitude. In general terms, Hilbert transform (HT) is a mathematical operation that transforms single and double components of equal amplitude into each other in a length or frequency domain. The signal to be analysed is passed through the intrinsic mod functions

* Marmara University, Department of Computer Engineering, Istanbul, Turkey, oakgun@marmara.edu.tr, ** Istanbul Technical University, Department of Electrical Engineering, Istanbul, Turkey, akincitc@itu.edu.tr, sekers@itu.edu.tr, *** Istanbul Sabahattin Zaim University, Department of Electrical-Electronics Engineering, Istanbul, Turkey, gokhan. erdemir@izu.edu.tr

DOI: 10.2478/jee-2019–0084, Print (till 2015) ISSN 1335-3632, On-line ISSN 1339-309X

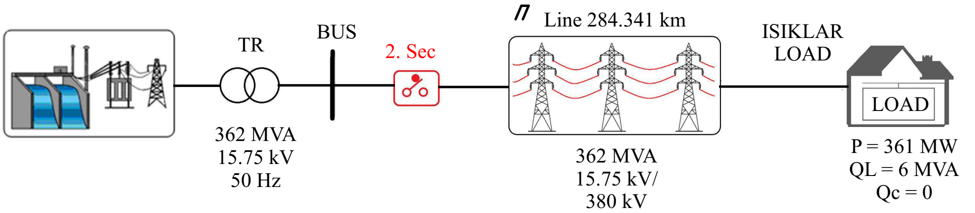

Fig. 1. Schematic representation of the transmission line

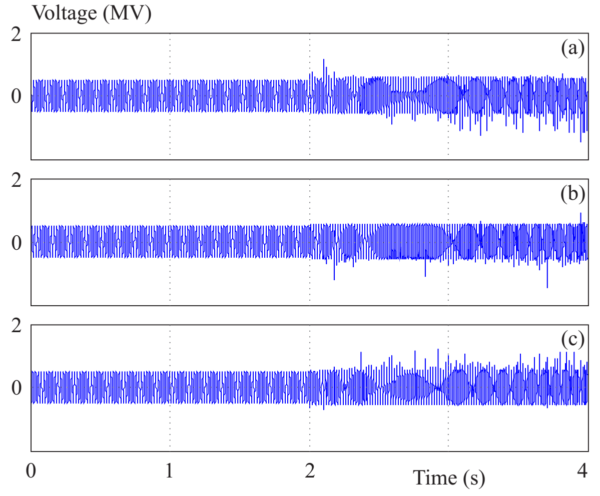

Fig. 2. Voltage variations for all data

(IMF) with meaningful instantaneous frequency and amplitude values [20-22]

In the experimental mode decomposition process, the signal is decomposed into IMFs; In this process, IMFs are ranked towards the lowest frequency of the highest frequency. When the signal is separated from the IMFs, the Hilbert transform is applied to each IMF to obtain the time curve of the instantaneous amplitude (IA) and the instantaneous frequency (IF). This combination of empirical mode decomposition (EMD) process and Hilbert transformation is called Hilbert Huang Transformation (HHT) [18].

For a real signal of $x(t)$ – continuous time mono-component, the Hilbert transform is used to create a complex function $z(t)$ withe the so called instantaneous amplitude $A(t)$ and the instantaneous phase $\varphi(t)$

$$z(t) = A(t)e^{j\varphi(t)} = x(t) + jH\{x(t)\} \tag{1}$$

where

$$H\{x(t)\} = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{x(\tau)}{t-\tau}d\tau \tag{2}$$

The instantaneous frequency of $x(t)$ is then defined as

$$f_{inst}(t) = \frac{1}{2\pi}\frac{\partial\varphi(t)}{\partial t} \tag{3}$$

Similarly, for a real discrete signal of $x[n]$ the continuous time mono-component, the analytical equation is

$$z[n] = x[n] + jHx[n] = A[n]e^{j\varphi[n]} \tag{4}$$

One of the simple estimators of the instantaneous frequency called the central phase difference estimator [17-22], is then

$$\tilde{f}[n] = \frac{\varphi[n+1] - \varphi[n-1]}{4\pi} \tag{5}$$

3 Modelling and simulation

In Fig. 1, a schematic representation of the Seyitomer-Isklar Electric Power Network is given. The electrical parameters of the power plant that feeds the energy transmission line are; 362 MVA, 15,75 kV and 50 Hz. Here, the transmission line is 284,341 km long. The active power on the line is 361 MW and the reactive power is 6 MVA. To be able to create a fault, the switches in front of the transmission line cut the line at the 2 sec. In Figure 2, a graph showing the voltage changes is given in all three phases.

Figure 2 shows the voltage change of R phase. In this change, it is observed that the system displays ferroresonance properties beginning from the 2nd second. The simulation is set to for 4 seconds.

4 Data processing and analysis

The following figures (Figure 4 and Figure 5) show the instantaneous-frequency graphs for the R phase. In Figure 4, instant-frequency values are given before ferroresonance. Here, it is obvious that the fundamental frequency is in the centre of 50 Hz. Due to the effect of the harmonics occurring in the initial conditions, the instantaneous frequency values can reach 150 Hz values.

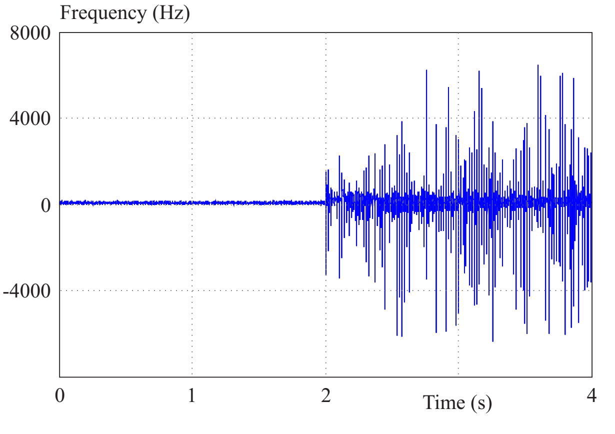

Fig. 3. Instantaneous frequency analysis

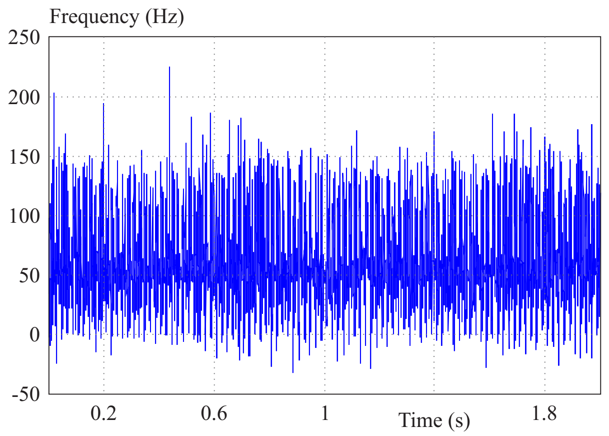

Fig. 4. Instantaneous frequency of before ferroresonance

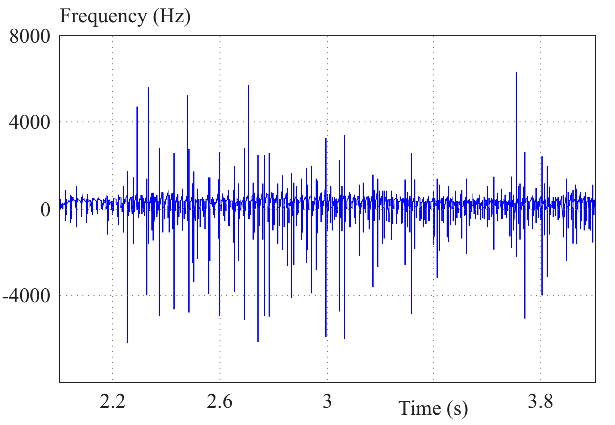

Fig. 5. Instantaneous frequency of after ferroresonance

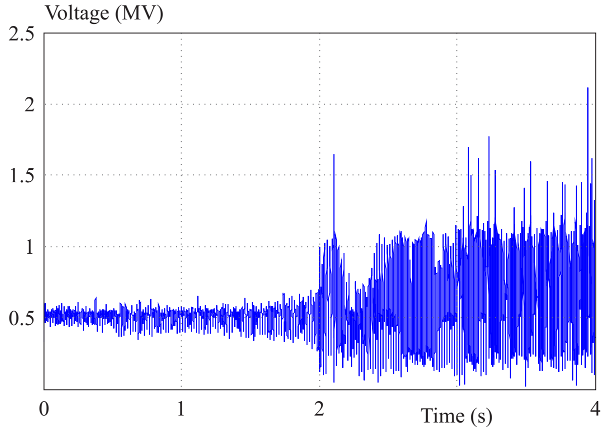

Fig. 6. Instantaneous amplitude analysis

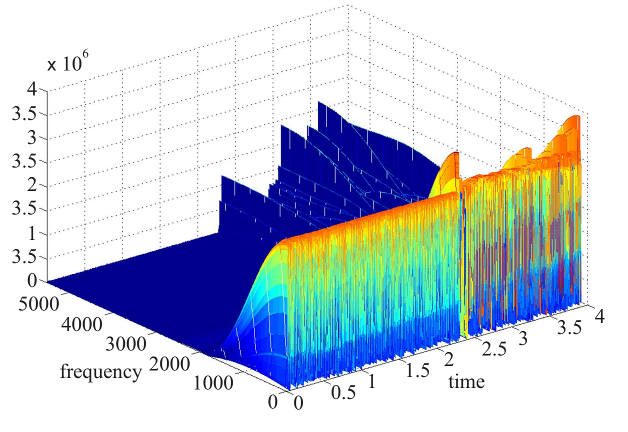

Fig. 7. Spectrogram of the R phase

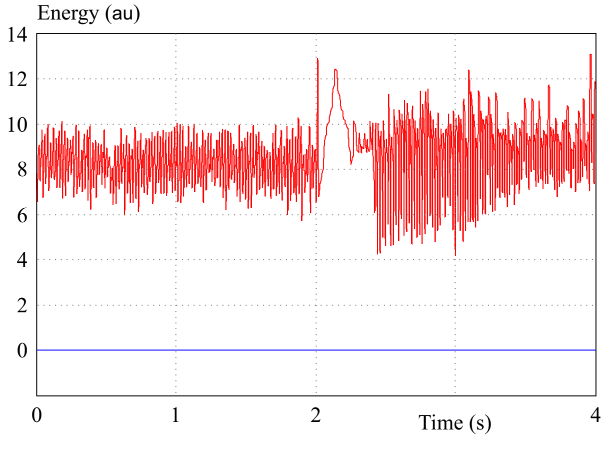

Fig. 8. Energy of the R phase

In Fig. 5, instantaneous-frequency values are given after ferroresonance. After Ferroresonance, high-frequency values have appeared as a result of over-voltage and harmonics. The extreme amplitudes here can be seen from Figure 6 and Figure 7. In particular, Figure 7 is important for comparing frequency and amplitude values.

The instantaneous amplitude analysis, up to 2nd seconds again occurs a change in normal sailing conditions. After the 2nd second, a sudden change in amplitude is observed in the Voltage as well as at the beginning of the ferroresonance event. A sudden drop in amplitude is observed around 2.3 seconds (Figure 6).

In Figure 7, plotted, the 4th second fraction, which includes the moment of ferroresonance of the R phase of the system. In this three-dimensional graph, time-frequency-amplitude variations can be observed.

Amplitude value increases between 0 and 0.5 seconds for the 2nd seconds and after 2 seconds, these values are increasing. Similarly, the frequency values are between 2000 and 5000 Hz. after 2nd seconds. Here the frequency values are doubled. Amplitude values are jumping to 2.5x106 after the second.

Figure 8 shows the time-energy graph of the R phase of the transmission system. Here, with the formation of the moment of ferroresonance event, the energy shows an extreme change between 2 and 2.5 seconds. After 2.5 seconds the amplitude of the energy increases.

In the following figures (Figure 10, Figure 11, Figure 12), the phase angle of all the data, the phase angle of the before ferroresonance data and the phase angle of

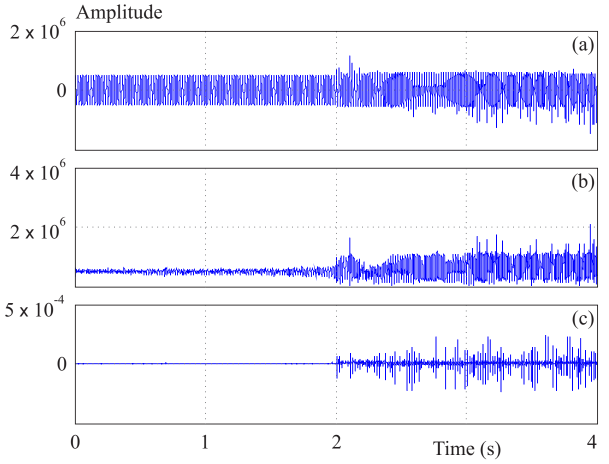

Fig. 9. Comparison of signs

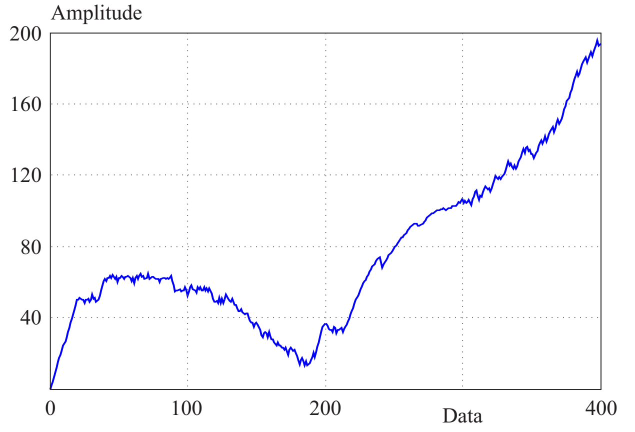

Fig. 10. Phase angel of all data

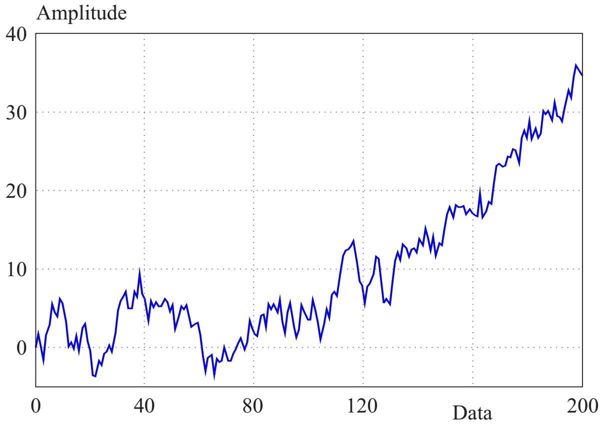

Fig. 11. Phase angel of before ferroresonance

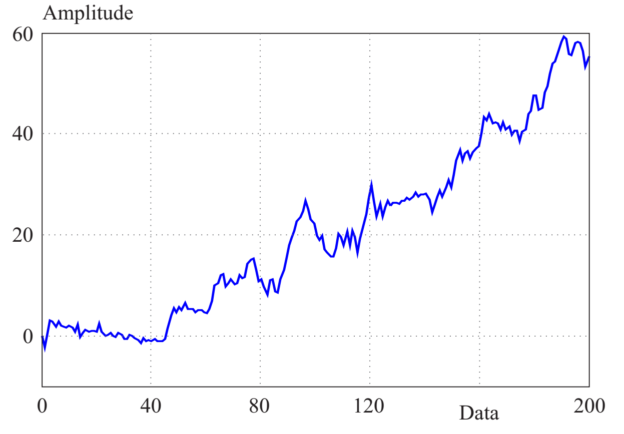

Fig. 12. Phase angel of after ferroresonance

the after ferroresonance data are given respectively. Especially when Figure 10 is examined, the angles before and after the ferroresonance region can be clearly seen. This is not very effective in distinguishing pre- and post-ferroresonance situations. Nevertheless, it can be seen that both the pre-ferroresonance phase and the post-ferroresonance phase tend to increase.

5 Conclusion

In this study, Seyitomer-Isklar energy transmission line is modelled. As a result of simulations made in this model, spectrograms, instantaneous amplitude, instantaneous frequency and phase angle were analysed. Ferroresonance event scenarios were created and after Ferroresonance events in the 2nd second, similar analysis results were obtained when examined in all three phases. Ferroresonance is a phenomenon with sudden changes, so it has been understood that it is appropriate to analyse this phenomenon by means of sudden change analyses. The instantaneous frequency analysis and the instantaneous frequency amplitude analyses clearly define the system's Ferrorezonans moment. The frequency of the system has climbed to very high values such as 5000Hz from the 2nd second when ferroresonance has come to the scene. Likewise, amplitude values jumped from 0.0x106 to 2.5x106. The energy analysis results also showed that the energy generated after ferroresonance climbed to twice the amplitude of the energy.

References

[1] P. Ferracci, *Ferroresonance*, Cahier Technique 190 Groupe Schneider Technique Publication, 2002.

[2] S. Seker, T. C. Akinci, S. Taskin, "Spectral statistical analysis for ferroresonance phenomenon in electric power systems", Electrical Engineering, vol. 94, no. 2, pp. 117-124, 2012.

[3] Sutherland PE, Manning R, Ferroresonance in a 13.8 kV distribution line, IEEE, pp. 2238-2241, 2006.

[4] T. C. Akinci, N. Ekren, S. Seker and S. Yildirim, "Continuous Wavelet Transform for Ferroresonance Phenomena in Electric Power Systems", vol. 44, pp. 403-409, 2013.

[5] S. A. Ijaz, "Ferroresonance On Power Systems", *Master of Science in Electrical Engineering The University of Texas at Arlington*, USA, (1992),.

[6] B. Tanggawelu, R. N. Mukerjee, and A. E. Arifin, "Ferroresonance Studies in Malaysian Utility's Distribution Network",

IEEE Power Engineering Society General Meeting vol. 2, 13-17 July, pp. 1216-1219, 2003.

[7] Cadick Corporation Technical Bullettin-004a, "Ferroresonance" 29 May 2002.

[8] N. Janssens, V. Vanderstockt, H. Denoel, and P. A. Monfils, "Elimination of Temporary Overvoltages due to Ferroresonance of Voltage Transformers: Design Testing of a Damping System", no. 33-204 CIGRE, September, pp. 1-8, 1990.

[9] S. R. Naidu and B. A. Souza, "Analysis of Ferroresonant Circuits in the Time Frequency Domains", *IEEE Transactions on Magnetics*, vol. 33, no. 5, pp. 3340-3342, September 1997.

[10] R. Rudenberg, "Nonharmonic Oscilations as Caused by Magnetic Saturation", *Transactions AIEE* vol. 68 I, pp. 676-685, 1949.

[11] A. Tokic, V. Madzarevic, and I. Uglesic "Numerical calculations of three-phase transformer transients", IEEE transactions on power delivery, vol. 20(4), 2005.

[12] R. Rudenberg, *Transient Performance of Electric Power Systems*, McGraw-Hill Book Company New York, NY, USA, 1950.

[13] D. M. Scoggin and J. E. Hall Jr, "Ferroresonance", *IBM Journal Research Development*, vol. 31, no. 6, November 1987.

[14] Z. Emin and Y. K. Tong, "Ferroresonance Experience in UK: Simulations Measurements", *IPST'01 International Conference Power System Transients*, Rio de Jenerio, Brasil, 24-28 June 2001.

[15] ABB s.r.o., "Ferroresonance" http://www.abb.de [19.12.2008].

[16] Trench Group Brochure, "Ferroresonance Phenomena Strategy", http://www.trenchgroup.com, [18.06.2017].

[17] M. Inigo, L. Carlos, R. Jorge, G. Antonio, and M. C. Antonio Juan, "Classification of electrical disturbances in real time using neural networks", *IEEE Trans Power Deliv* 200722(7):1288-96.

[18] B. Picinbono, "On Instantaneous Amplitude Phase of Signals", *IEEE Transactions on Signal Processing*, vol. 45, no. 3, pp. 552-560, March 1997.

[19] B. Picinbono, "Some Remafws on Instantenous Amplitude Frequency of Signals", IEEE, pp. 293-300, 1998.

[20] E. H. Norden, S. Zheng, R. L. Steven, C. W. Manli, H. S. Hsing, Z. Quanan, Y. Nai-chyuan, C. T. Chi, and H. L. ve Henry, "The empirical mode decomposition the Hilbert spectrum for nonlinear non-stationary time series analysis"454:903-995, 1998.

[21] B. V. Manuel, W. Binwei, and E. B. Ve Kenneth, " ECG signal denoising baseline wander correction based on the empirical mode decomposition", 38(1): 1-13, 2008.

[22] R. Gabriel, F. Patrick, and G. C. Ve Paulo, "On Empirical Mode Decompostion And It's Algorithms", IEEE-EURASIP Workshop, 2003.

Received 10 October 2018