QUANTIZATION OF TRANSFORMER TRANSIENT WAVEFORMS UNDER NO-LOAD CONDITIONS BY USING HIGUCHI'S METHOD

Cengiz Polat Uzunoğlu
Istanbul University, Electrical and Electronics Engiineering Department, Turkey

Mustafa Karhan
Çankırı Karatekin University, Electronic Communication Tech. Prog., Turkey

Abstract

This paper presents a robust method to investigate transformer time series transient characteristics under no load conditions. As an extreme condition, no-load (or light load) is an undesired event which is constantly monitored to eliminate power system failure. In this study, a 220V/34.5kV test transformer is employed to record no-load voltage and current waveforms via high-speed oscilloscope. During the tests, the transients are analyzed by focusing on fist 0.08s of current and voltage waveforms, which is quite adequate approach. The recorded time series signals are computed by using Higuchi's fractal dimension (HFD) analysis, which is an efficient method to define fractal dimension (complexity) for specific time segments. According to HFD analysis the waveforms exhibit extremely (in terms of fractal dimension) distinctive HFD results for the signals in defined time durations.

Keywords: *Transients, Higuchi's fractal dimension, power transformer, transformer loss.*

INTRODUCTION

Transformers are key elements of power transmission and distribution in electrical networks owing to their unique transformation characteristics. The basic electrical tests are no-load and open-circuit tests in which transformers are observed according to their iron and copper losses [1]. Although no-load losses are relatively small compared with the regular operation, considering whole power system with enormous number of transformers an accurate analysis is required for no-load conditions [2]. No-load results reveal magnetizing inductance, which displays non-linear characteristics, and hence it is challenging task to analyze these phenomenon [3–6].

In this study a dry type 220V/34.5kV, 400VA, 50Hz test transformer is employed to observe voltage and current signals under no-load conditions. To analyze characteristics of test transformer, an open circuit (no load) test procedure is conducted where high voltage side is open circuit. During the tests, it is aimed to investigate initiation (first 0.08s) of the operation of the transformer under no-load condition. The current waveforms and voltage waveforms are recorded low voltage (LV) and high voltage (HV) side respectively. All the signals are collected and recorded via recorded by high-speed Fluke 199C scope meter.

All the recorded signals are analyzed according to their start-up characteristics. The tests have revealed that the test transformers tend to generate undesired harmonics, which are given by fast Fourier transform (FFT) [7]. FFT is an efficient method however, it is not capable of observing time series signal in a limited time segments.

In this study, a useful Higuchi's fractal dimension (HFD) method for time series self-affine signals is proposed to analyze current and voltage waveforms [8]. Fractal geometry and fractal dimension concepts are inspired from nature where fractals have similar subsets in every scale [8-9].

In HFD method, detection of spectral exponents of irregular (complex) time series signal is achieved by fractal dimension calculation. In literature, a number of applications are available where HFD method is employed [10-11]. The waveform transients are investigated for different time segments by using HFD method and distinctive results in terms of transformer no-load startup characteristics are obtained.

TEST SET-UP

The tests are conducted by using dry type 220V/34.5kV, 400VA and 50Hz test transformer. In addition, an autotransformer is employed to connect primary side (LV) of the test transformer with local network for protection and voltage limiting purposes. The test transformer and autotransformer are given in Fig. 1.

Fig. 1. *The test transformer and autotransformer.*

The test transformer is driven by 220V and 50Hz autotransformer, which satisfies isolation and protection of the test transformer from the local AC network. Block diagram of the proposed test set-up is given in Fig. 2.

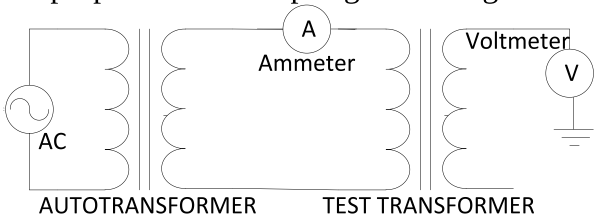

Fig. 2. *Block diagram of test set-up.*

Fluke 199C oscilloscope is used to obtain and record signals. The current signal is recorded from primary side via 1Ω resistor. For the secondary side, the voltage signal is collected by using Amprobe HV231-10A HV probe that operates as capacitive voltage divider (1000:1 division ratio).

HIGUCHI'S FRACTAL DIMENSION (HFD) ANALYSIS

HFD method is widely used especially in biomedical applications [10-11] since this method is capable of computing direct estimate of fractal dimension for time series signals [8]. Let *X(1), X(2)…X(N)* is a time series sequence (sampled signal). In our scenario, current and voltage signals are analyzed.

HFD concept basically is based on a computation of the different signal lengths of *L(k)*, of the curve which defines corresponding time series signal while employing the segment of *k* unit samples.

$$L(k) \approx k^{-D} \tag{1}$$

In Eq. (1) the exponent *D* is called fractal dimension of the time series signal, which represents the complexity of the curve of a given time series. According to fractal geometry the fractal dimension is one for a simple curve and two for a curve, which approximately scans whole figure (frankly between one and two). For a given time series sequence, new time series sequence X_k^m is obtained and in Eq. (2).

$$X_k^{\,m} = \left\{ \begin{matrix} x(m), x(m+k), x(m+2k), . \\ .., x\left(m + \left\lfloor \frac{N-m}{k} \right\rfloor k\right) \end{matrix} \right\} \tag{2}$$

Where *m=1,2,……k* , *N* is the total number of samples; *m* is the initial time and *k* is the interval time. The └ ┘ function represents integer part of a given real number. The length of each curve ($L_m(k)$) is given by [8].

$$L_m(k) = \frac{1}{k}\left[\left(\sum_{i=1}^{\left\lfloor \frac{N-m}{k} \right\rfloor} \left| \begin{matrix} x(m+ik) - \\ x(m+(i-1)k) \end{matrix} \right| \right)\right]\alpha \tag{3}$$

$L_m(k)$ is not a Euclidean length since it indicates the normalized sum of absolute values of differences where ordinates k parameter (with initial point m) is used [8-10]. The normalization factor (α) is computed for the time series signal subsets, which is shown in Eq. (4).

$$\alpha = \frac{N-1}{\left\lfloor \frac{N-m}{k} \right\rfloor k} \tag{4}$$

The length of the curve for a specific time interval *k*, *L(k)*, is computed by using the mean values with the corresponding *k* values.

$$L(k) = \frac{1}{k}\sum_{m=1}^{k} L_m(k) \qquad (5)$$

The fractal dimension value D is calculated by using a slope of the linear regression of a double logarithmic plot of *ln L(k)* against *ln1/k*. F1 and F2 functions are used to produce HFD plotting.

$$F_1 = \ln\left(L(k)\right), \quad F_2 = \ln\left(\frac{1}{k}\right) \qquad (6)$$

The fractal dimension of current voltage waveforms varies between 1 and 2 where highly spiky(fluctuated) discharges may be represented by fractal dimension between 1.6 and 1.8, however a linear line tends to compute fractal dimension about 1 [11].

RESULTS AND DISCUSSION

During the tests, the initiation of test transformer is fulfilled and corresponding initiation signals are recorded via oscilloscope where 2.5G sample per second sampling rate is satisfied. Under no-load conditions, the current signal of the test transformer is given in Fig. 3.

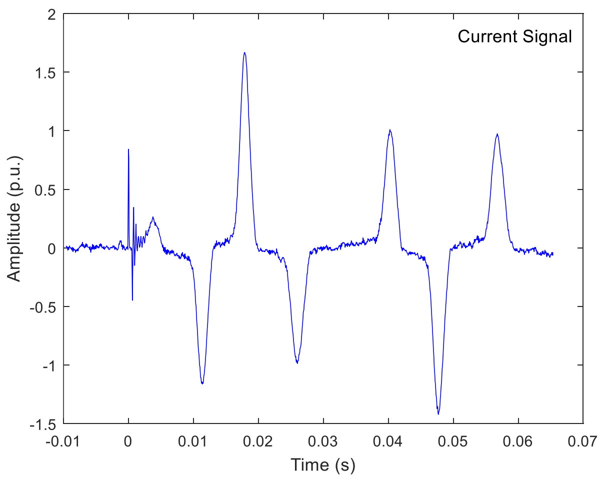

Fig. 3. *The current signal of test transformer.*

To investigate transients, the first 0.08 seconds of the current signal is supplied. Accelerated fluctuations are observed around 0 second. The corresponding voltage signal for the test transformer is shown in Fig. 4. In order to analyze signal harmonics, the fast Fourier transform (FFT) spectrums are obtained.

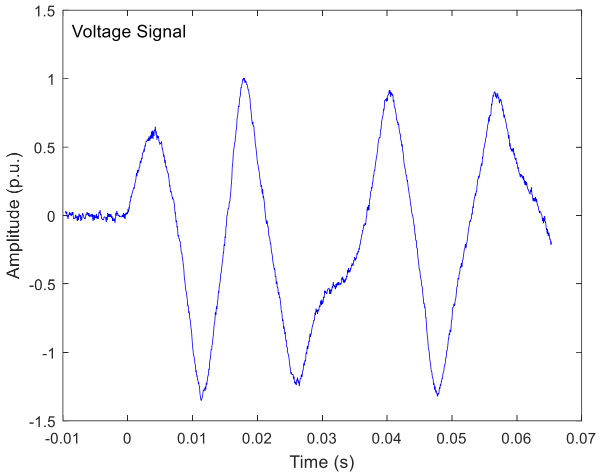

Fig. 4. *The voltage signal of test transformer.*

The frequency spectrums of current and voltage signals are given in Fig. 5. The frequency spectrums have revealed that current signal have wider range harmonics in contrast to voltage signal harmonics.

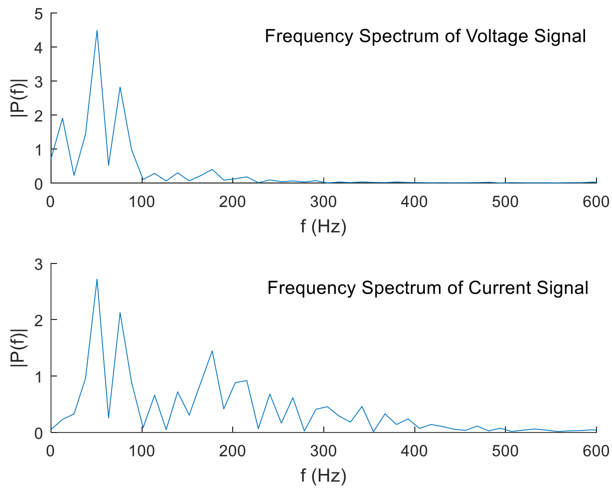

Fig. 5. *The frequency spectrums of current and voltage signals.*

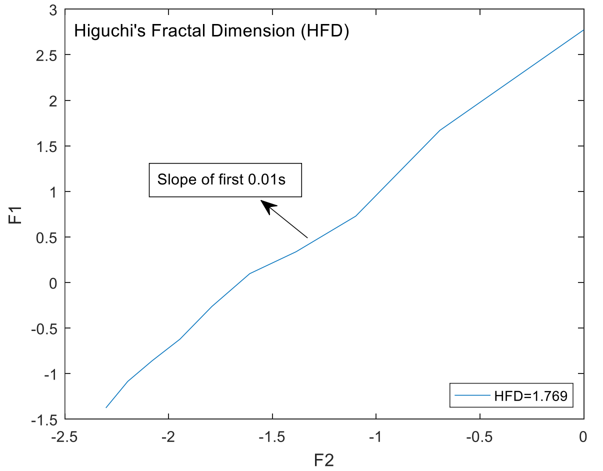

Fig. 6. *HFD computation of current signal for the first 0.01s after initiation.*

As mentioned before the current reading have been collected from primary (LV) side, which is related with losses (leakage currents). To analyze voltage readings of high voltage side, a high voltage probe is needed. Besides, in real time applications it is quite challenging task to investigate high voltage readings. For this purpose, primary side (LV) current signals are analyzed by HFD method for realistic analysis.

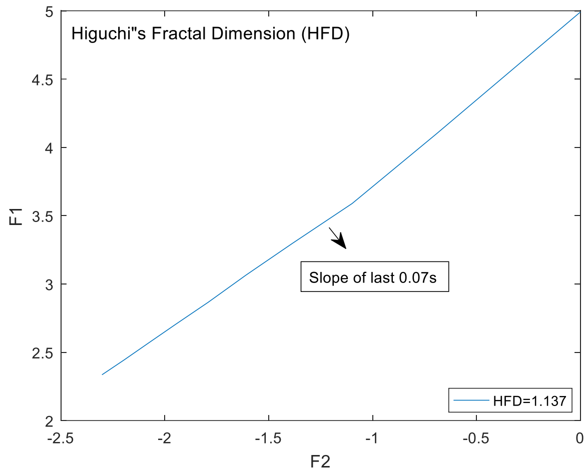

Fig. 7. *HFD computation for the last 0.07s of the recorded current signal.*

To estimate no-load condition initiation, the first 0.01s of current signal is analyzed by HFD method and corresponding dimension (D=1.769) computation is given in Fig. 6. After settlement, the signal exhibits more stable characteristics. The last 0.07s of the current signal is analyzed by HFD method (D=1.137) and shown in Fig. 7.

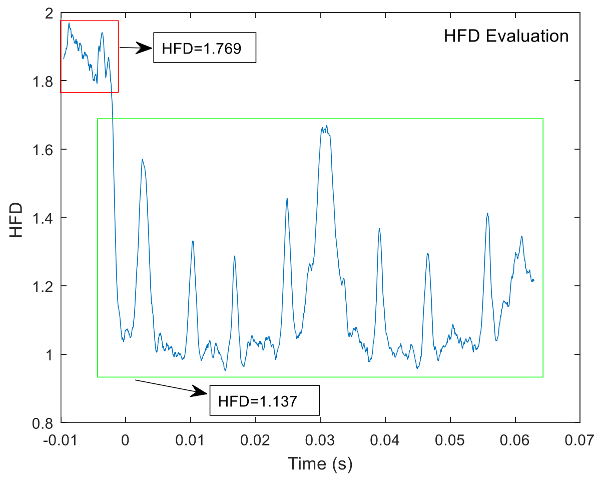

Fig. 8. *Time depended HFD evolution of current signal.*

The HFD evaluation of current signal is shown in Fig. 8, in which time depended fractal dimension is computed.

CONCLUSION

Safe and proper operation of a power network should be satisfied by using real time surveillance against system failure. In this study, a special scenario, which contains no-load conditions of transformers, is investigated. During this operation mode, undesired transients such as voltage and current fluctuations are observed. A tests transformer is employed for no-load tests and corresponding signals are obtained. In order to examine complex signal characteristics of transformer signals, HFD analysis is conducted efficiently. Fractal dimensions are quite distinctive for specific time segments and may reveal no-load condition initiation by using current signal of transformers. Online detection of transformer current by using proposed technique may accelerate system response.

REFERENCE

[1] The J&P Transformer Book, in: M.J. Heathcote (Ed.), 13th ed., Newnes, Burlington, MA, (2007): 42–43.

[2] Ismail, Daut, et al. "The effects of harmonic components on transformer losses of sinusoidal source supplying non-linear loads." American Journal of Applied Sciences 3.12 (2006): 2131-2133.

[3] Chiesa, Nicola, and Hans Kristian Hoidalen. "Analytical algorithm for the calculation of magnetization and loss curves of delta-connected transformers." IEEE Transactions on Power Delivery 25.3 (2010): 1620-1628.

[4] Taci, M. Salih, M. Hadi Sarul, and G. Yildirmaz. "The effects of the harmonic components upon transformer active losses in case of (non) sinusoidal sources and (non) linear loads." Proc. of IEEE Int. Conf. Vol. 1. 2000.

[5] Arslan, E., S. Sakar, and Murat E. Balci. "On the no-load loss of power transformers under voltages with sub-harmonics." ENERGYCON, IEEE International, 2014.

[6] Ramamurthy, Jayanth R., et al. "Influence of voltage harmonics on transformer no-load loss measurements and calculation of magnetization curves." Electric Power Systems Research 146 (2017): 43-50.

[7] Liu, Yanli, et al. "Power system harmonic analysis based on windowed FFT and wavelet transform." Electric Utility Deregulation and Restructuring and Power Tec., 2011.

[8] Higuchi, Tomoyuki. "Approach to an irregular time series on the basis of the fractal theory." Physica D: Nonlinear Phenomena 31.2 (1988): 277-283.

[9] Vega, Christian Flores, and Julien Noel. "Parameters analyzed of Higuchi's fractal dimension for EEG brain signals." SPSympo, 2015. IEEE, 2015.

[10] Kesić, Srdjan, and Sladjana Z. Spasić. "Application of Higuchi's fractal dimension from basic to clinical neurophysiology: A review." Computer methods and programs in biomedicine 133 (2016): 55-70.

[11] Gómez, Carlos, et al. "Use of the Higuchi's fractal dimension for the analysis of MEG recordings from Alzheimer's disease patients." Medical engineering & physics 31.3 (2009): 306-313.