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A novelty digital algorithm for online measurement of dielectric loss factor of electronic transformers

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ABSTRACT

There are many inherent performance limitations using traditional algorithms for online measurement of dielectric loss factor including synchronous sampling, no interharmonics and power system frequency must be invariable. In a non-stationary signal environment where power frequency fluctuation and interharmonic components exist, there is no guarantee of measurement accuracy by using traditional methods. The paper proposed a high-accuracy digital algorithm for online measurement of dielectric loss factor of electronic transformers. Theoretical basis of the new algorithm is based on a new data processing procedure including data truncation and data addition which compensates phase distortion as a result of the spectrum of addition data contains offsets. The algorithm can accurately extract the fundamental signal and calculate dielectric loss factor. Measured results from simulations and practical engineering projects show that the new algorithm has good application feasibility without being affected by the limitations rendered above.

1. Introduction

With the development of SmartGrid and Ultra-High voltage, electronic transformers (ETs) are probably the most important electrical plants in digital substations. Influenced by all directions, including environment situation, strong electromagnetic, the condition insulation will be in deterioration for ETs in service. To ensure the safe and reliable operation of a power system it's necessary to monitor the insulation condition of ETs periodically. This may be accomplished by measuring partial discharge or dielectric loss factor [1]. Dielectric loss factor is one of the most important diagnostic tools monitoring the condition of insulation. Correct diagnosis of their incipient faults is vital for safety and reliability of ETs. For the measurement of dielectric loss factor, it belongs to the category of precise instrumentation and measurement with high voltage and micro-current so accuracy is the most important and choosing the right method has become the biggest concern.

In previous literatures, various approaches have been presented to detect the dielectric loss factor [2–9]. All the methodologies for the measurement of dielectric loss factor can roughly be divided into two categories: hardware measurement [2–6] and measurement based on signal processing [7–10]. Hardware measurement, such as the conventional Schering bridge method [4] and zero-crossing method [6]. But, hardware measurement requires a high level of hardware design and is sensitive to interference and harmonics, and there is no guarantee of measurement accuracy. The methods being widely adopted at present are mostly based on signal processing. The direct application of the FFT has inherent performance limitations, such as spectral leakage and picket fence effect, due to the asynchronous sampling and the finite sampling records [7]. The undesired effects of the spectral leakage can be minimized by weighting the time samples using a suitable time window [8], and the picket fence effect can be reduced by adopting interpolation algorithms in [9,10].

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Several new algorithms were proposed to reduce the picket fence effect and the spectral leakage [11,12]. The self-convolution window algorithm has been employed in [13]. The preceding section showed that FFT interpolation algorithm and self-convolution window algorithm can improve the accuracy but with limited effects and more interharmonics were not considered in previous research. As well known, the growing presence of power electronic devices is at the base of the increasing of both harmonics and interharmonics in recent years. When multiple frequencies are included, phase distortion may become worse. So some work has been done regarding this aspect.

Various algorithms related to the measurement of dielectric loss factor can be easily found in the references. For these algorithms, they have something in common: preliminary researches and improvements were for the algorithms themselves. However, the novelty of the new algorithm is the processing procedure of sample data. So, further analysis of processing procedure for sample data and comparison with other algorithms are fully accounted for in this paper.

2. Principle

Generally, it's directly to calculate with Discrete Fourier Transform (DFT) for sample data to extract phase for calculating dielectric loss factor but in the new algorithm the sample data is processed. In the two methods, data for DFT is different. Voltage and leakage current signals are sine or cosine sequences. Elucidation of the new algorithm for data addition is given in the succeeding sections in detail.

2.1. Traditional DFT of sample data

Take the complex-exponential sequence for any frequency of input signal as an example. The definition of the discrete domain is given by:

$$x(n) = Ae^{j(\Omega_0+\varphi)} = Ae^{j(n2\pi/N+\varphi)} \tag{1}$$

where Ω_0 is the radian frequency, φ is the initial phase angle of the base-frequency, A is the amplitude and N is the sample number. Take into consideration of frequency fluctuation and asynchronous sampling, where λ reflects variation of radian frequency as shown in Fig. 1.

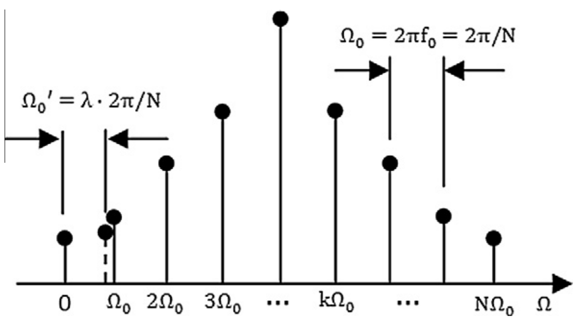

Fig. 1. Spectrum of frequency fluctuation or asynchronous sampling.

The frequency of the power signal is supposed to vary as defined in:

$$x(n) = Ae^{j(\Omega_0 n+\varphi)} = Ae^{j(n2\pi\cdot\lambda/N+\varphi)} \tag{2}$$

where $n = 0, 1,\ldots,N$; $\lambda = 0.990, 0.992,\ldots,1.010$. Then, according to the new definition of sequence with frequency fluctuation, traditional DFT of sample data can be deducted in:

$$\begin{aligned}X(k) &= \sum_{n=0}^{N} x(n)e^{-j(n\cdot 2\pi k/N)} \\ &= \sum_{n=0}^{N} Ae^{j(n2\pi\cdot\lambda/N+\varphi)}\cdot e^{-j(n\cdot 2\pi k/N)} \\ &= Ae^{j\varphi}\sum_{n=0}^{N} e^{jn2\pi/N(\lambda-k)} \quad = Ae^{j\varphi}\frac{1-e^{j2\pi(\lambda-k)}}{1-e^{j2\pi(\lambda-k)/N}} \\ &= Ae^{j\varphi}\frac{\left[e^{-j\pi(\lambda-k)}-e^{j\pi(\lambda-k)}\right]\cdot\left[e^{j\pi(\lambda-k)}\right]}{1-e^{j2\pi(\lambda-k)/N}} \\ &= A\frac{\sin[\pi(\lambda-k)]}{\sin[\pi(\lambda-k)/N]}e^{j[\varphi+\frac{N-1}{N}(\lambda-k)\pi]} \\ &\quad \text{for } k = 0,1,\ldots,N-1\end{aligned} \tag{3}$$

As can be seen in Eq. (3), the phase error is:

$$\Delta\varphi = \varphi + \frac{N-1}{N}(\lambda-k)\pi \tag{4}$$

The sample number of traditional DFT is also N/α to ensure that the number is the same as that of truncated data. So the expression is:

$$\Delta\varphi = \frac{N-\alpha}{N}(\lambda-k)\pi \tag{5}$$

Obviously, when λ changes, the phase angle has errors with frequency fluctuation and asynchronous sampling.

2.2. DFT of sample data addition

The sample data is divided into several parts through truncating and there are α truncated sequences that can be defined as:

$$\begin{cases} x'(1) = \{x(0), x(1), \ldots x(N/a-1)\} \\ x'(2) = \{x(N/a), x(N/a+1), \ldots x(2N/a-1)\} \\ \cdots \\ x' = \{x((a-1)N/a), x(x((a-1)N/a+1, \ldots x(N-1)\} \end{cases} \tag{6}$$

where α is times of truncation, $\alpha - 1$ is addition times and N is the sample number and the number of every part is N/α. The truncated data of every part performs addition correspondingly and the value of α can be changed to achieve more data addition so that the following equation group is developed:

$$\begin{cases} y(0) = x(0) + x\left(\frac{N}{a}\right) + \cdots + x\left(\frac{(a-1)N}{a}\right) \\ y(1) = x(1) + x\left(\frac{N}{a}+1\right) + \cdots + x\left(\frac{(a-1)N}{a}+1\right) \\ \cdots \\ y\left(\frac{N}{a}-1\right) = x\left(\frac{N}{a}-1\right) + x\left(\frac{2N}{a}-1\right) + \cdots + x(N-1) \end{cases} \tag{7}$$