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The Measurement and Analysis of Harmonics and Interharmonics in Output Waveforms of Frequency Inverter. Part I

Abstract

The paper discusses the measurement and analysis of the voltage and output power distortions of frequency inverter that supplies an induction motor. It covers basic information regarding frequency inverters and norms with definitions and descriptions of terms related to the measurement of harmonics and interharmonics. Moreover, it describes the problems that can occur while analyzing the signal when the inter-harmonics are present during the measurement. Exemplary results of measurements done with power quality analyzer in the laboratory have been presented.

Keywords: interharmonics, inverter, power quality analyzer, measurements.

1. Introduction

With the development of electronics new opportunities arose to multiple common facilities. A good example is an induction motor with its extremely simple structure, high efficiency and reliability, having one fundamental drawback - lack of a simple, ordinary possibility of speed regulation. Owing to the introducing of frequency inverters, that disadvantage has been eliminated and a simple rotational speed regulation of induction motors became possible. Unfortunately, a motor supplied by frequency inverter is a totally nonlinear unit degrading power quality by introducing of harmonics and interharmonics. Adding of nonlinear units to an electrical system always causes deterioration of power quality and generation of extra loss.

Power quality is evaluated in accordance with legal regulations – applicable norms determine admissible values of parameters that characterize power quality [1, 2] and others describe the methods of their measurement and analysis [3, 4]. For example the harmonics and interharmonics occur among these parameters- their presence in electrical system can cause a series of undesirable situations. An extended description of reasons of why harmonics and interharmonics appear and effects of their occurrence can be found in papers [5, 6], methods of location theirs sources describes the work [7]. The most frequent effects of harmonics and interharmonics occurrence are: thermal effects, distortions in control and security systems, energy overload, low-frequency oscillation in motor systems, disruptions in electronic devices operation or telecommunication interference [5, 6].

Problems with measurement of harmonics and interharmonics are discussed in most of works that regard the studies on power quality [8, 9, 10]. There is also a number of works devoted only to measurement and analysis of harmonics and interharmonics [11, 12, 13].

2. Description of periodic deformed wave-forms – harmonics and interharmonicsc

Harmonics are the components of waveforms with frequencies being an integer multiple of the fundamental frequency. Contribution of particular harmonics in the final signal shape was defined as (current and voltage) contribution factor of harmonics and is it calculated as follows:

$$w_k = \frac{X_k}{X_1} \cdot 100\% \qquad (1)$$

where: X_k – RMS of harmonic in succession;
k, $k = 2, 3, 4, \ldots, n$ - harmonics order;
n – global number of harmonics considered in the analysis;
X_1 – RMS of fundamental harmonic.

A coefficient of total harmonic distortion (*THD*) waveform is defined as a proportion of the effective value that is calculated excluding the first harmonic (assuming that the fixed component is zero) to the effective value of the first harmonic:

$$THD = \frac{\sqrt{\sum_{k=2}^{n} X_k^2}}{X_1} \qquad (2)$$

where: X_k is the RMS value of k-harmonic of a particular signal $x(t)$,
X_1 – RMS of fundamental harmonic,
k - harmonic order,
n – global number of harmonics.

The lower the *THD* coefficient, the most the waveform is distorted – *THD* for an ideal sinusoidal wave equals 0.

Interharmonics are the components of the waveform with frequency not being an integer multiple of the fundamental frequency (tab.1). Technically, the interharmonics are also divided into subharmonics which are the waveform components of frequency lower than the fundamental frequency. Total interharmonic distortion (*TIHD*) coefficient has been introduced into *THD* coefficient.

$$TIHD = \frac{\sqrt{\sum_{k=1}^{n} X_k^2}}{X_1} \qquad (3)$$

where: X_k is the RMS value of k-harmonic of a particular signal $x(t)$,
X_1 – RMS of fundamental harmonic,
k - interharmonic order,
n – global number of interharmonics.

Tab. 1. Formal records of the definitions of time waveform components

Harmonic	$f=nf_1$; n=1, 2, 3 …
Fixed component	$f=nf_1$; n=0
Interharmonic	$f\neq nf_1$; n=1, 2, 3 …
Subharmonic	$f>0$ i $f<f_1$; n=0
f_1 – fundamental frequency of supply voltage	

2.1. Periodic waveform spectrum

Practically, harmonics and interharmonics are measured by means of spectrum analysis that is based on Fourier transform [6, 13]. Other similar methods for estimating parameters of sinusoidal components such as e.g. Prony method, total least-squares and matrix-pencil methods give more precise results in certain conditions. However, due to its simplicity and easy implementation of the commonly used Fourier transform [14]. Every steady periodic signal $x(t)$ with period $T = 1/f_1 = 2\pi/\omega$ can be presented in the form of a discrete Fourier transform

$$x(t)=\sum_{k=0}^{\infty}\left(A_k\cos(k\omega t)+B_k\sin(k\omega t)\right) \tag{4}$$

where

$$A_k=\frac{2}{T}\int_0^T x(t)\cos(k\omega t)dt\,,\qquad B_k=\frac{2}{T}\int_0^T x(t)\sin(k\omega t)dt \tag{5}$$

Signals almost periodic and aperiodic can be approximated with this series.

When the conditions mentioned in Kotielnikow-Shannon theorem are met, determining a boundary frequency of waveform sampling, time can be noted as follows:

$$t = mT/N, \tag{6}$$

where: m - number of samples of signals $x(t)$,
N - number of samples per signal period.

Taking into consideration that

$$T = 2\pi/\omega, \tag{7}$$

period of discrete signal $x(m)$ can be noted in the Fourier series:

$$x(m)=\sum_{k=0}^{N-1}\left(A_k\cos\left(k\frac{2\pi}{N}m\right)+B_k\sin\left(k\frac{2\pi}{N}m\right)\right) \tag{8}$$

where

$$A_k=\sum_{m=0}^{N-1}x(m)\cos\left(k\frac{2\pi}{N}m\right),\ B_k=\sum_{m=0}^{N-1}x(m)\sin\left(k\frac{2\pi}{N}m\right) \tag{9}$$

Noting the coefficients of the Fourier series in complex form, formula for discrete Fourier transform (DFT) is obtained:

$$X_k=\sum_{m=0}^{N-1}x(m)\exp\left(-\mathrm{j}k\frac{2\pi}{N}m\right),\quad m=0,1,\ldots \tag{10}$$

Traditional, discrete Fourier transform (DFT) as well as its fast option that is fast Fourier transform (FFT) are simple and effective tools helpful in analyzing the signal wave distortion.

The presence of interharmonics in the analyzed signal, with frequencies that fail to be a multiple of the fundamental frequency, implies additional problems [6, 13]: minimum sampling time that is required may be long, and an amount of measurements samples high, fundamental Fourier frequency is unequal to the voltage frequency and it can be hard to determine, boundary Nyquist frequency can be very high.

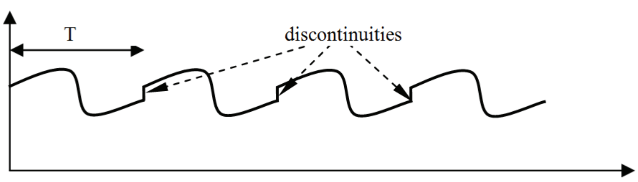

Fig. 1. Periodic waveform achieved as a result of measurement time reduction

The difficulties mentioned above may be caused by using the Fourier transform algorithms without providing proper conditions of use required. As a result, it can lead to wrong interpretations of spectrum as a consequence of the spill of one energy frequency onto other frequencies (so called spectral leakage) or wave signal distortions in the sampling process, caused by the failure of assumptions of Kotielnikow-Shannon theorem (so called aliasing) [6, 13]. Spectral leakage is the consequence of the number of samples being reduced that is reducing also the measurement time. Setting the time different from the fundamental Fourier period causes the signal to "lose" its continuity at the edges of the measurement display (Fig.1). Artificial discontinuities appear in the form of high frequencies in the signal spectrum. This problem can be solved by using the so called "weighted" time windows: rectangular, Hanning, Hamming, Kaiser, etc.

2.2. The measurement of harmonics and interharmonics of the waveform

The measurement of harmonics and interharmonics of currents and voltages is regulated by IEC 6100-4-7 norm [4]. According to this document, harmonic and interharmonics measurement should be conducted for the 10-period, not overlapping subgroups, harmonic and interharmonic respectively. The norm [3] recommends to average particular values in very short (3 s), short (10 min) and long (2 h) time of measurement.

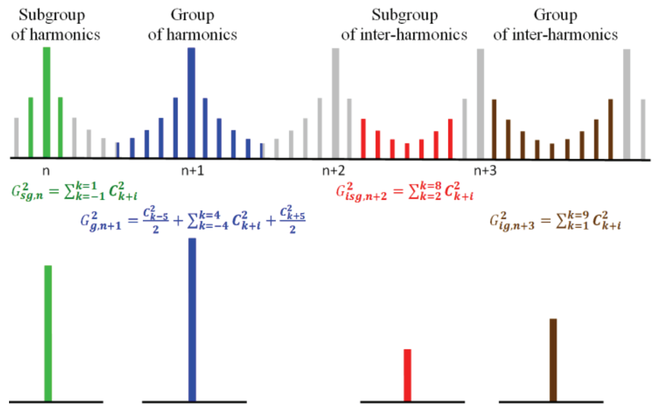

Fig. 2. Rules of creating the harmonic groups and interharmonic groups

Frequency definition (f_W) is a crucial parameter of spectrum achieved as a result of measured waveform analysis. If measurement display is equal to one period:

$$T_W = T_1, \tag{11}$$

where: T_W – measurement window length,
T_1 – signal period,

spectrum definition is equal to the fundamental harmonic frequency (f_1)

$$f_W = f_1 = 1/T_1. \tag{12}$$

If measurement display is lengthened to the total p number of signal periods:

$$T_W = pT_1, \tag{13}$$

Then frequency definition will decrease, according to dependency:

$$f_W = 1/pT_1 = f_1/p. \tag{14}$$

It means that density of stripes in spectra increases; they are not distant from each other of the fundamental frequency (f_1), thanks to which measuring of parameters of sub- and interharmonics is possible. For the frequency of 50 Hz and the window 10-period length, the frequency definition, with accordance to the dependency (15), equals 5 Hz.

Measurement window width can be also noted with dependency:

$$T_W = MT_S = M/f_S \tag{15}$$

where: M – number of samples,
$f_S = 1/T_S$ – sampling frequency.

In order to change the size of measurement window with accordance to dependency (16), the number of samples N or sampling frequency f_S needs to be changed. Both values need to be selected in a way that the number of p periods is a total number. A formula for the frequency definition results from dependencies (14), (15) i (16):

$$f_S = \frac{Mf_1}{p} = Mf_w \tag{16}$$

Sampling is synchronized with frequency of supply network. In order to maintain requirements for sampling frequency, its value must meet the following dependency:

$$f_s > 2f_N \tag{17}$$

where: f_N – Nyquist frequency.

When interharmonics appear in time waveform, determining its spectrum accurately becomes practically impossible, and it very often results in either greater or lesser spectrum blur [6, 13]. Spectrum blur causes that amplitude of particular components are inaccurately determined, as a result the harmonic power with a defined frequency disperses onto the neighboring frequencies. The norm [4] suggests the grouping of neighboring harmonics/ interharmonics. After the grouping is performed, a demanded harmonic „absorbs" neighboring stripes becoming their representation (Fig. 2.). Grouping spectral harmonic and interharmonics components of 5 Hz resolution (according norm [4]) could yield misleading information for cases where an interharmonic component's frequency is very close to a harmonic frequency [15].

3. References

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