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The Spectrum Analysis of Complex Multi-frequency Signals in the Presence of Interharmonics

Section 6: POWER ENGINEERING

Introduction

In general, interharmonics of a waveform are harmonic fluctuations containing frequencies, which are not multiple the fundamental power system frequency [1]. As it is mentioned in publications, there are a variety of interharmonics power sources such as electric - arc furnaces, disturbance load electrical drives, static frequency converters [2, 3] and also sub-harmonic fluctuations which appear due to ferroresonancein.

Most spectral analysis methods of currents and voltages in the presence of interharmonics are reviewed in [4-7]. These methods are mainly based on Fourier transformation or Hartley's one but authors of this report apt to consider that there is a possibility to apply to spectral estimation method for detection of interharmonics [8-9].

Well - known approaches of spectral analysis of complex multi-frequency signals

The analysis of well - known approaches of spectral analysis of complex multi-frequency signals [2, 6-9] has shown that it would be rationally to apply to advantages of the instantaneous spectrum density method [8, 9] jointly with the volt-ampere characteristic one [9].

Generally, for both methods the input data are data files of instantaneous values $a(t_j)$ where: $t_1, t_2, .. , t_j, .. , t_N$; $t_2 - t_1 = t_3 - t_2 = t_N - t_{N-1} = ... = \Delta t$ is the step of sampling.

$$\Delta t = \frac{T_f}{N_f}, \qquad (1)$$

here: N_f is number of points on a period T_f of frequency f.

The main formula for the instantaneous spectrum density method has been presented as (2):

$$S(f) = \sqrt{S_1^2(f) + S_2^2(f)}\,, \qquad (2)$$

where: $S_1(f)$ is the sine component of a spectrum density; $S_2(f)$ is the cosine component of a spectrum density;

$$S_1(f) = \sum_{j=1}^{N} a(t_j)\sin(w_k t_j)\,;\; S_2(f) = \sum_{j=1}^{N} a(t_j)\cos(w_k t_j)\,, \qquad (3)$$

here: $w_k = 2pf_k$ is a value of a circular frequency; $t_j = j\Delta t$ is a value of corresponding time point with $j = 1..N$.

Maximums of the function $S(f)$ can afford to define frequencies, which are presented in a signal and give spectral description of a signal under $f_k = 0..f_n$, where f_n - maximum of a frequency value of a signal component.

The function $S(f)$ of the single-frequency signal $a(t_j) = 1 * sin(2\pi * 50 * t_j + 30^0)$ is given in figure 1. Parameters for calculation are $N = 10000$; $\Delta t = 0{,}0001$ sec; $\Delta f = 1$ Hz.

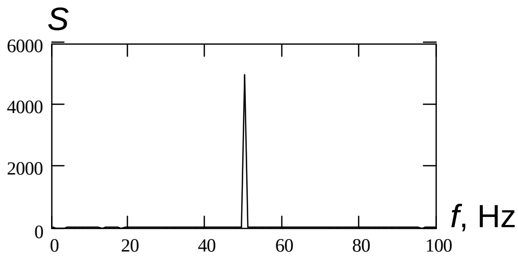


Figure 1 - Function $S(f)$

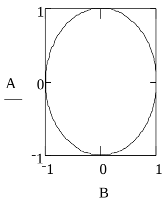
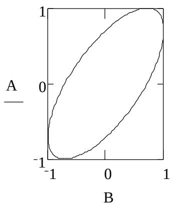
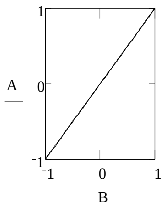
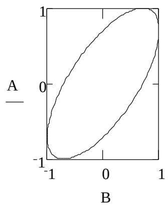
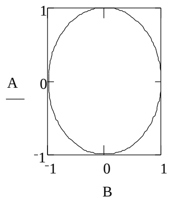
The amplitude of the frequency f_k is calculated by formula (4) [5, 6]:

$$A_{mk} = 2[S(f_k)]\frac{1}{N}\,. \qquad (4)$$

The peculiarity of the volt–ampere characteristic method is that two types of signals in common use. First of them is the analysed signal $a(t_j) = A_{mk} sin(\omega_k t_j + \varphi_k)$ and the second one is the supporting signal $b_s(t_j) = B_{ms} sin(\omega_s t_j + \varphi_s)$. The root of this method is that the area of the volt–ampere characteristic equals nought when $\varphi_k = \varphi_s$.

Volt–ampere characteristics of the signal $a(t_j) = A_{mk} sin(\omega_k t_j + \varphi_k)$ under $A_{mk} = B_{mk} = 1$; $f_k = 50$ Hz; $j_k = 30^0$; $j_0 = \text{var}$ are given in table 1

Table 1- Types and areas of volt–ampere characteristics

j_0, degrees	-60	-15	30	75	120
Type of V-ach					
Q_{VACh},var	0,5	0,353	0	0,353	0,5

Areas of volt–ampere characteristics have been calculated by formula (5) [9]

$$Q_{V-ach} = \frac{1}{4\pi}\sum_{j=1}^{N}\left[a(t_j) - a(t_{j+1})\right] * \left[b(t_j) + b(t_{j+1})\right]. \quad (5)$$

The procedure of the spectral analysis of complex multi-frequency signals

The multistage method of the spectral analysis has been created by authors. This method includes three main parts, namely

- application of the instantaneous spectrum density method for calculation of frequency and amplitude of each signal component;
- application of the volt–ampere characteristic method for calculation of phase of each signal component;
- calculation of an accuracy by formula (6)

$$ASD = \left[\frac{\sum_{j=1}^{N}(da_j)^2}{N}\right]^{0.5}; \; da_j = a_p(t_j) - a_u(t_j), \quad (6)$$

where: da_j is an absolute accuracy.

Three - frequency signal has been used for the test of procedure (see figure 2 and table 2)

Table 2

f_k, Hz	50	100	187
A_{mk}, A	10	4	1
φ_k ,degrees	70	-26	128

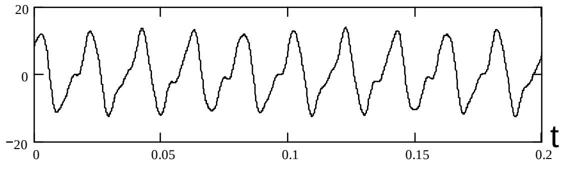


Figure 2 - Oscillogram of tested signal

The result of the spectral density is illustrated in figure 3.

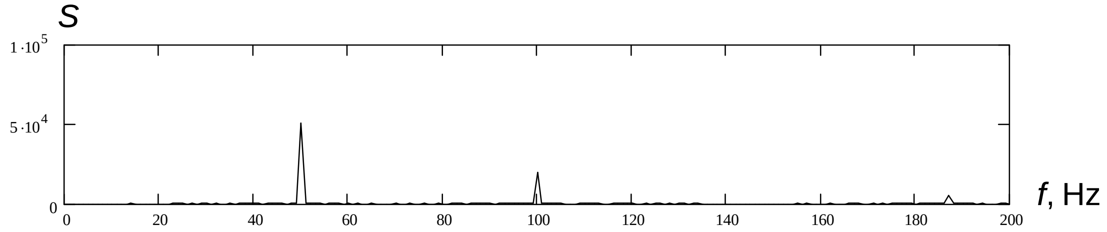


Figure 3 - Distribution of the spectral density

Final results of the spectral analysis are presented in table 3.

Table 3 – Final results

f_k, Hz	50	100	187
A_{mk}, A	10	4	1
φ_k ,degrees	69,99999	-26,00001	127,975
ASD	0,031		

Experimental researches

In order to test the spectrum analysis procedure, experimental data arrays have been measured in the switching point of the frequence converter. The oscillograms of the current and voltage are shown in figure 4 and 5. The length of data arrays are 256 point for the period; the frequency is 50 Hz.

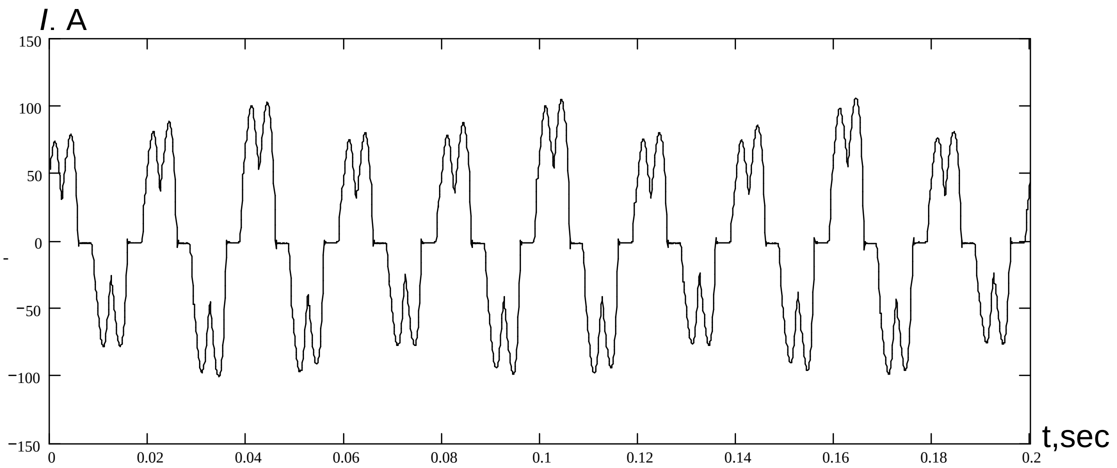


Figure 4 - Oscillogram of current

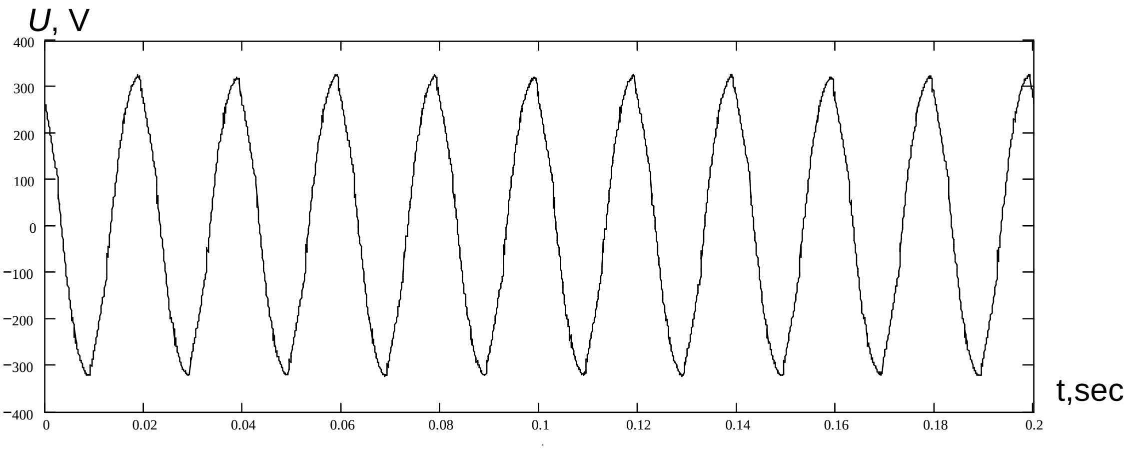


Figure 5 - Oscillogram of voltage

The gain-frequency characteristics are shown in figures 6 and 7.

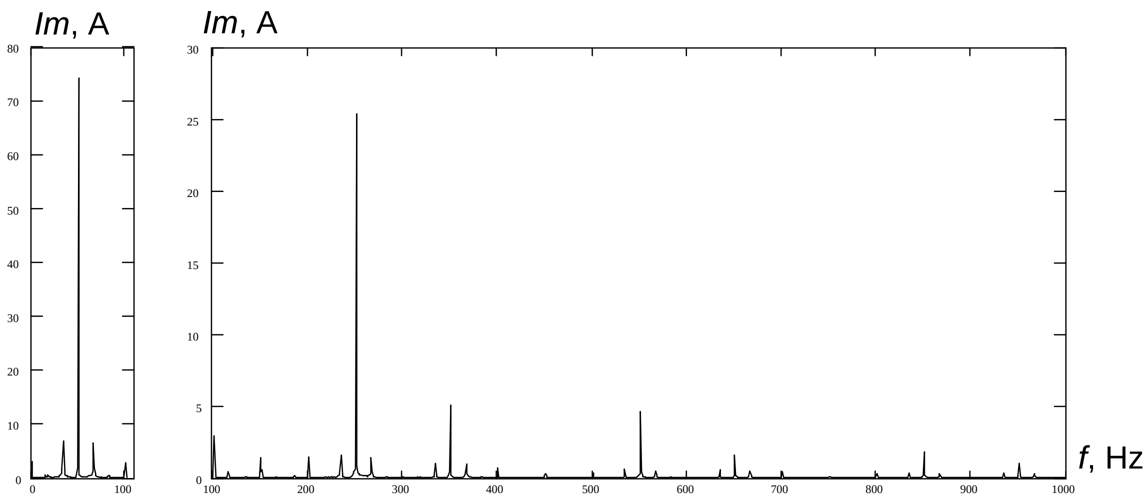


Figure 6 - The gain-frequency characteristic of the current signal

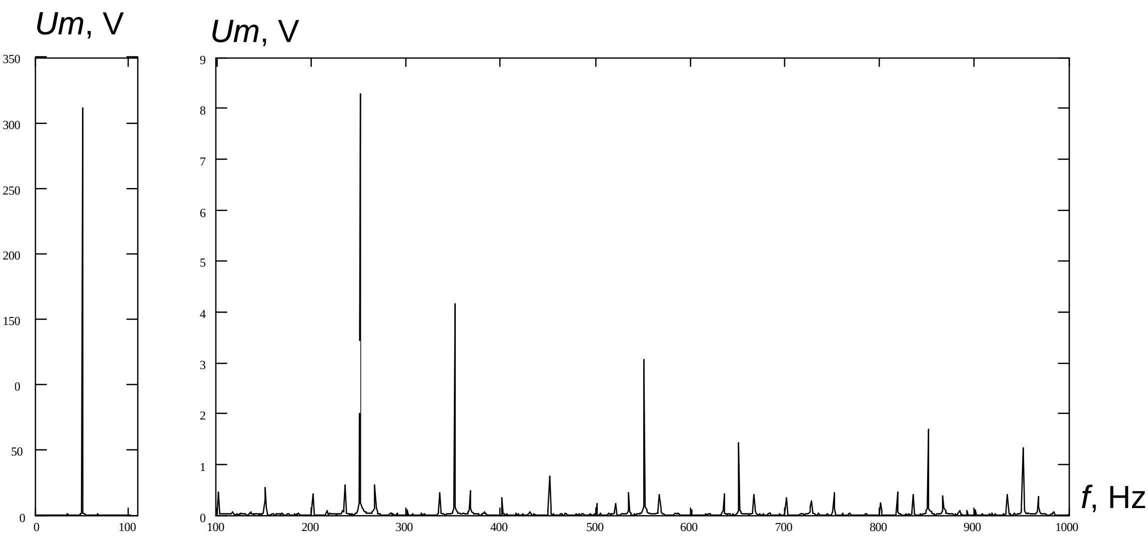


Figure 7 - The gain-frequency characteristic of the voltage signal

Results of the spectrum analysis are presented in tables 4 and 5.

Table 4 – Current components

Amplitude, A	Frequency, Hz	Phase, degree	ASD
74,382	50	46,88	5,196
25,371	250	46,84	
6,879	34	-117,4	
6,615	66	-170,75	
5,096	350	-89,6	
4,654	550	168,55	
2,904	100	-53,2	
1,797	850	-78	
1,639	650	-49,3	
1,598	234	-114,9	
1,478	200	-95,6	
1,432	266	142,7	
1,425	149	-87,1	

Table 5 – Voltage components

Amplitude, A	Frequency, Hz	Phase, degree	ASD
311,537	50	120,568	5,35
8,274772	250	-137,95	
4,153525	350	-156,29	
3,07649	550	-23,4	
1,696578	850	90,6	
1,431096	650	-95,1	
1,326711	950	9,8	
1,006258	34	140,47	
0,914655	66	105,61	
0,785072	450	-153,06	
0,60183	266	-33,62	
0,594184	234	64,05	
0,477466	366	-114,6	

Summary

On the whole, these results demonstrate that application of this method gives us possibility to detect interharmonic components in signals since interharmonics are becoming prevalent as power electronic load levels increase on the power system.

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