Random Components Influence On The Values Characterising Periodic Disturbances In Low Voltage Supply Lines

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Abstract- The paper analyses the random components influence on the values characterising periodic disturbances in the supply line voltage on the example of the total harmonic distortion coefficient (*THD*). It presents the method to determine the uncertainty in the *THD* coefficient measurement, which takes into account the correlations appearing between the fundamental component and the successive harmonics of the supplying voltage, and also between particular harmonics. The analysis of the results from the total harmonic distortion coefficient measurements in the supplying voltage of a motor drive system with the electronic power converter is presented.

Keywords: total harmonic distortion coefficient (*THD*), periodic disturbances, random disturbances, measurement uncertainty

I. Introduction

In low voltage supply lines, apart from fundamental sinusoidal waveform of nominal frequency 50Hz, there also appear disturbances of determined and random waveforms. Generally, the biggest component of periodic disturbances are harmonics of the basic waveform of the supplying voltage. Yet, along with the decrease of the degree of these disturbances there is an increase of the participation of component periodic disturbances not correlated with the fundamental frequency of the voltage supply and random disturbances [1]. Then, the accuracy of the measurements of standard parameters determining the level of periodic disturbances in voltage supply lines decreases. The basic parameter determining electrical energy quality is the total harmonic distortion coefficient (*THD*) in the supplying voltage described by the dependence [2]:

$$THD_{40}[\%] = \frac{\left|\sqrt{\sum_{i=2}^{40} U_{hi}^2}\right|}{U_1} 100 \qquad (1)$$

where: U_1, U_{hi} - voltage levels (amplitudes or rms values) of the fundamental component and *i*-th harmonic respectively.

In some cases when, in the observed waveform, the supply line periodic disturbances not correlated with the supply line fundamental frequency and random disturbances were not taken into account, big errors in measuring the value of the total harmonic distortion coefficient according to the accepted definition (1) occurred [1, 3].

II. Combined standard uncertainty of *THD* measurement

If we apply the law of uncertainty propagation to the equation (1), the combined standard uncertainty $u_c^2(THD)$ in measuring the *THD* coefficient can be determined with the use of the dependence [6]:

$$u_c^2(THD) = \left(\frac{\partial f}{\partial U_1}\right)^2 u^2(U_1) + \sum_{i=2}^{40}\left(\frac{\partial f}{\partial U_{hi}}\right)^2 u^2(U_{hi}) + 2\sum_{i=2}^{40}\frac{\partial f}{\partial U_1}\frac{\partial f}{\partial U_{hi}} u(U_1, U_{hi}) + 2\sum_{j=2}^{40}\sum_{\substack{i=2 \\ i\neq j}}^{40}\frac{\partial f}{\partial U_{hj}}\frac{\partial f}{\partial U_{hi}} u(U_{hj}, U_{hi}) \qquad (2)$$

where: $u(U_1)$, $u(U_{hi})$ - the standard uncertainties in mesuring the fundamental and the i-th harmonic respectively, $c_1 = \frac{\delta f}{\delta U_1}$, $c_{hi} = \frac{\delta f}{\delta U_{hi}}$ - coefficients known as sensitivity coefficients,

$u(U_1, U_{hi})$, $u(U_{hj}, U_{hi})$ - covariances between the fundamental component and i-th harmonic and harmonics respectively.

The sensitivity coefficients determine the participation of particular uncertainty components associated with the successive harmonics in the combined uncertainty of the measurement (tab. 1).

Table 1. Components of the combined standard uncertainty

Sensitivity coefficients c^2		Covariances	
$c_1^2 = (\frac{\delta f}{\delta U_1})^2$	$c_{hi}^2 = (\frac{\delta f}{\delta U_{hi}})^2$	$u(U_1, U_{hi})$	$u(U_{hj}, U_{hi})$
$\frac{THD_{40}^2}{U_1^2}$	$\frac{U_{hi}^2}{U_1^4 THD_{40}^2}$	$\frac{1}{M-1}\sum_{m=1}^{M}(U_{1m} - \overline{U_1})(U_{him} - \overline{U}_{him})$,	$\frac{1}{M-1}\sum_{m=1}^{M}(U_{hjm} - \overline{U}_{hjm})(U_{him} - \overline{U}_{him})$
		where: M is the number of the observations of the examined waveform, $\overline{U}$ is the mean value of these measurements	

The influence of the components in uncertainties associated with higher harmonics is bigger for low values of *THD* (the sensitivity coefficient is bigger for low *THD* and decreases rapidly for the increasing *THD*) (fig. 1). Simultaneously, the sensitivity coefficient decreases when the level of U_{hi} goes down. The sensitivity coefficient associated with U_1 dominates for very high *THD*.

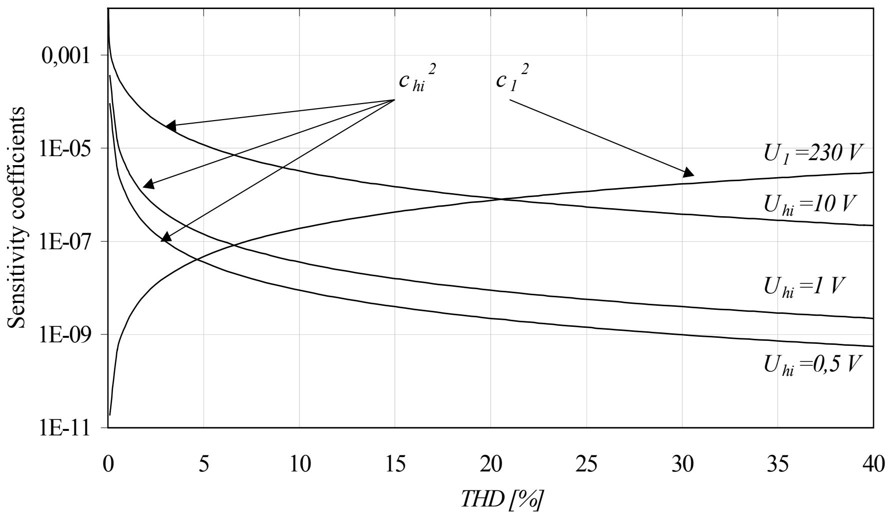

Figure 1. The dependence of any sensitivity coefficient on the values of the *THD* coefficient

The appearance of correlations between particular harmonics is directly connected with nonlinear characteristics of receivers, which are the sources of periodic disturbances in the registered waveform of the supply line voltage, thus with the level of the observed harmonics. The correlations between the fundamental component and higher voltage harmonics (fig. 2), and also between particular harmonics (tab. 2), influence significantly the combined uncertainty in the *THD* coefficient measurement.

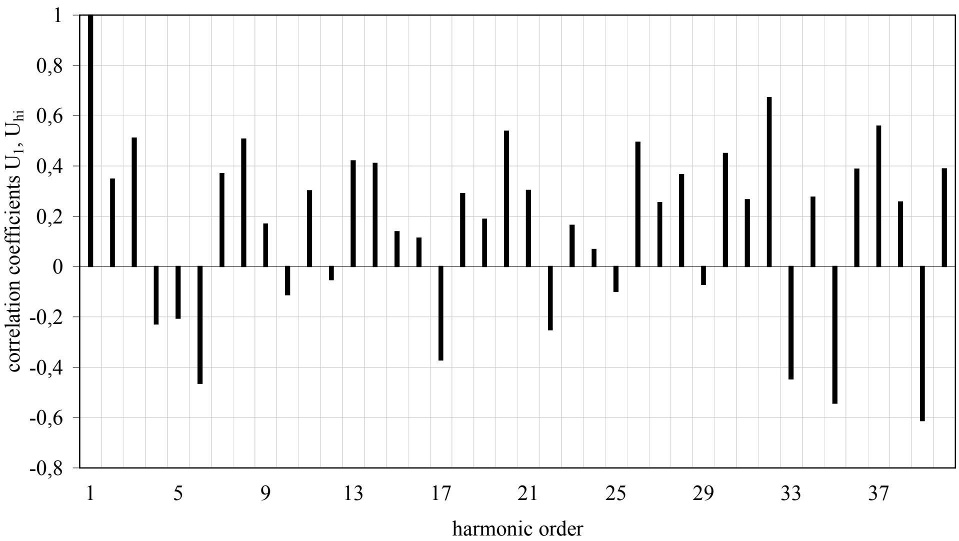

Figure 2. The correlation coefficient of the fundamental component U_1 and U_{hi} *i*-th harmonic component in the supply line voltage in a motor drive system

Table 2. The matrix of correlation coefficients up to the 10th harmonic in the supply line voltage in a motor drive system

Harmonic order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1,00	0,35	0,51	-0,23	-0,21	-0,46	0,37	0,51	0,17	-0,11
2	0,35	1,00	0,43	0,01	-0,06	-0,24	0,49	0,57	0,13	0,02
3	0,51	0,43	1,00	-0,09	0,24	-0,34	0,33	0,59	-0,45	-0,09
4	-0,23	0,01	-0,09	1,00	0,12	-0,01	-0,15	-0,16	0,00	0,84
5	-0,21	-0,06	0,24	0,12	1,00	0,10	-0,19	-0,12	-0,27	0,08
6	-0,46	-0,24	-0,34	-0,01	0,10	1,00	-0,19	-0,40	-0,49	-0,03
7	0,37	0,49	0,33	-0,15	-0,19	-0,19	1,00	0,45	0,05	-0,01
8	0,51	0,57	0,59	-0,16	-0,12	-0,40	0,45	1,00	0,15	-0,18
9	0,17	0,13	-0,45	0,00	-0,27	-0,49	0,05	0,15	1,00	-0,09
10	-0,11	0,02	-0,09	0,84	0,08	-0,03	-0,01	-0,18	-0,09	1,00

The data presented in fig. 1 and tab. 2 are the results of the analyses of the results of the measurements carried out by the authors within the research on disturbances occurring in ship drive systems, which make use of electronic power frequency converters supplying asynchronous squirrel-cage AC motors.

III. Experimental research

The combined uncertainty of *THD* measurement in the supplying voltage of a motor drive system with the electronic power converter was assessed by applying the dependence (2) for two resolutions Δf of the DFT analysis (1 Hz and 5 Hz) (fig. 3). Each coefficient *THD* was measured on the basis of the collected samples during the time periods of 3 seconds and 15 seconds respectively.

When the resolution Δf increases, the value of the *THD* coefficient decreases in the supply line voltage with the operating converter (tab. 3). The value of the *THD* coefficient does not change at the resolution Δf = 1 Hz for various time periods of recording the measured signal. In the supply voltage waveform, in the operation conditions without the converter, which is the main source of periodic disturbances, no influence of the change in DFT analysis resolution on the level of *THD,* as well as on the uncertainty of its measurement, was observed. It results from these observations that the appropriate choice of resolution enables the elimination of additional periodic waveforms appearing in the measured signal. These waveforms are of the frequencies not correlated with the frequency of the fundamental component.

The level of undesired random components can be reduced by using the separation procedure in the measured signal of random and periodic components [1, 3]. It consists in coherent addition of the time sections of the voltage, whose length corresponds to the total multiple of the waveform period of fundamental component. The calculated (for these voltage waveforms) coefficient *THD* assumes the values considerably lower than in the previous case (tab. 4). It confirms the participation of random components in the registered waveforms. The number of averaging of the voltage time sections asserts a significant influence on the level of *THD* coefficient. If this number is bigger, the random component in the measured signal is reduced to a greater degree. Therefore, the *THD* level is the lowest for the bigger number of averaging and bigger resolution.

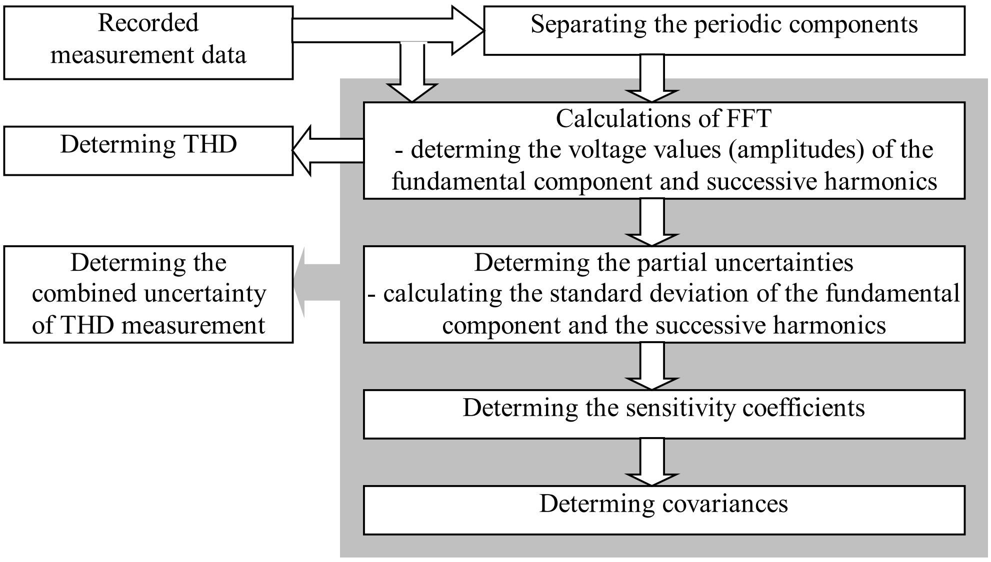

Figure 3. The algorithms of measuring the *THD* coefficient and the combined uncertainty of *THD* measurement

Table 3. *THD* measurement uncertainty in the supply line voltage of a motor drive system

Voltage		Average value of *THD* [%]			*THD* measurement uncertainty [%]		
Fundamental frequency [Hz]	Converter switching frequency [kHz]	Number of averaging M			Number of averaging M		
		15		3	15		3
		Δf =5 Hz	Δf =1Hz	Δf =1Hz	Δf =5 Hz	Δf =1Hz	Δf =1Hz
50	12	2,95	2,51	2,5	0,27	0,05	0,27
50	6	2,09	2,07	2,07	0,066	0,033	0,065
50	without converter	2,01	2,01	2,01	0,01	0,01	0,01

The combined uncertainty in measuring *THD* depends generally on the length of the analysed waveform (the number of samples) [4, 5]. It results from the carried out analyses that the influence of the DFT analysis resolution on the measurement uncertainty for the identical time length of the observation of the signal measured is negligibly small (tab. 3 and tab. 4). On the other hand, significantly lower values of *THD* measurement uncertainty were obtained for the longest observation time of the measured signal (15 s) at the resolution Δf equal 1Hz. The application of this procedure of components separation in the supply line voltage waveform for this measurement data caused an increase in *THD* measurement uncertainty.

Table 4. *THD* measurement uncertainty in the supply line voltage of a motor drive system after separating the components of the frequencies, which are the multiple of 50 Hz.

Voltage		Average value of *THD* [%]			*THD* measurement uncertainty [%]		
Fundamental frequency [Hz]	Converter switching frequency [kHz]	Number of averaging M			Number of averaging M		
		15		3	15		3
		Δf =5 Hz	Δf =1Hz	Δf =1Hz	Δf =5 Hz	Δf =1Hz	Δf =1Hz
50	12	1,82	1,68	1,87	0,26	0,243	0,26
50	6	1,46	0,54	1,53	0,147	0,024	0,141
50	without converter	1,79	0,65	1,81	0,069	0,01	0,064

IV. Summary

At low values of the *THD* coefficient a great influence on its value is asserted by the periodic components of the frequencies not correlated with the fundamental frequency of the supplying voltage and random disturbances. The measurements showed that uncertainties in measuring THD could exceed 100% (e.g. the value of *THD* after the separation of components in the measured signal drops from 2.01 % to 0.65 % — tab. 3 and tab. 4). It results from the carried out research that in such cases it would be necessary to give also the information about the levels of the fundamental component, its harmonics, random components and periodic components of the frequencies not correlated with the fundamental frequency of the supply line for the definite frequency band.

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