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The Study of the Deforming Regime of AC/AC Converter using Fourier and Multiresolution Analysis

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Introduction

Power quality problems today are more frequent due to the power disturbances such as harmonics, flicker, swells/sags, interruption, unbalance voltage etc. Lately, the power electronic equipments used in industry and power network have led to negative effects such as higher harmonic distortion [1].

The recent research on the deforming consumers in the electric power system shows that the number of these is growing steadily and with this growth more and more negative consequences appear. Harmonics are a problem for both electricity suppliers and users.

The correct determination of the harmonics characteristics and of as many as possible harmonics is very important for the power quality assessment [2].

For harmonic analysis the discrete Fourier transform (DFT) give satisfactory results when the signals (voltage or current) are periodical [3]. Wavelet transform is a recent signal processing tool used in power quality analysis that is particularly useful for the analysis of non-stationary signals [4]. The Wavelet transform is useful not only in non-stationary signal analysis, but also in deformed stationary signal analysis.

This paper presents the study of the deforming state generated by the AC/AC converter with full-wave AC control using two SCRs (silicon – controlled rectifier) connected in inverse parallel. For this study, we use Fourier and Wavelet transforms. AC/AC converters (also called softstarter) are still widely used in industry for Squirrel Cage Motors softstarting and softstoping.

AC to AC converter

A single-phase (or three - phase) alternating voltage with frequency f and a constant effective value Va, is applied at the input of these converters and a single phase (or three phase) AC voltage of same frequency f, and the RMS voltage V_s adjustable is obtained at the output.

In principle, the converter must allow the current to flow in both directions, so the power semiconductor devices used are bidirectional. Therefore, a single triac or two SCRs connected in inverse parallel may be used. These converters are with natural commutation. The power semiconductor devices will turn off when the current decreases to zero.

Fig. 1 shows the electrical diagram of AC/AC converter with two SCRs (for high power) connected in inverse parallel.

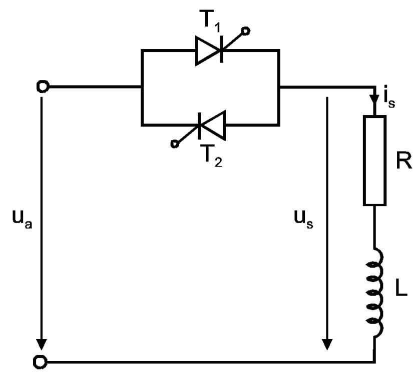


Fig. 1. The electrical scheme of AC/AC converter with two SCRs

The thyristors are controlled with the same delay angle α. It is important to note that the RMS load voltage is determined by the load type and the thyristors delay angle α [5]

$$V_s = V_a \cdot \sqrt{\frac{1}{\pi} \cdot \left[\beta - \alpha - \frac{1}{2} \cdot \left(sin(2 \cdot \beta) - sin(2 \cdot \alpha) \right) \right]}, \quad (1)$$

where β (the angle at which the current passes through zero (Fig. 2)) is the solution of the equation

$$sin(\beta-\varphi_1)=sin(\alpha-\varphi_1)\cdot e^{-\frac{\beta-\alpha}{tan\varphi_1}}, \qquad (2)$$

where α is the thyristors delay angle and $\varphi 1$ is the phase shift between current and voltage (determined by the load type)

$$\varphi_1 = arctan\frac{\omega_1\cdot L}{R}. \qquad (3)$$

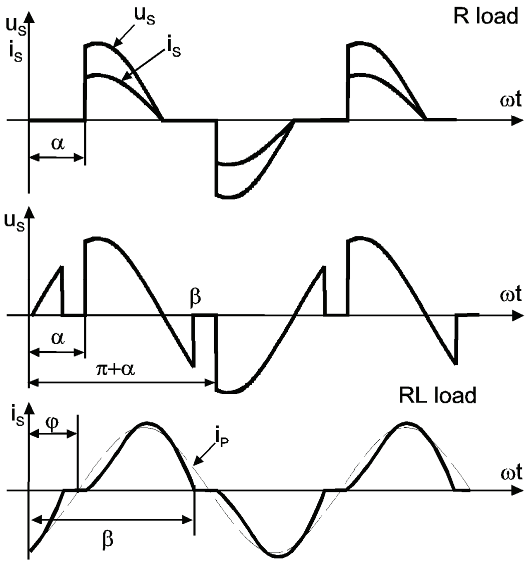


Fig. 2. The time diagram of AC/AC converter with two SCRs

The harmonic analysis of the load voltage v_s shows the presence of only odd harmonics with RMS value V_{sn}

$$V_{sn}=\sqrt{\frac{A_n^{\,2}+B_n^{\,2}}{2}},\quad n=\{2\cdot m+1\,|\,m\in N\} \qquad (4)$$

and phase γ_n

$$\gamma_n = arctan\frac{A_n}{B_n}, \qquad (5)$$

where n is the harmonic number; A_n and B_n are the Fourier coefficients:

$$A_n=\frac{V\cdot\sqrt{2}}{\pi}\cdot\Big(\frac{\cos 2\cdot(m+1)\cdot\alpha-\sin 2\cdot(m+1)\cdot\beta}{2\cdot(m+1)}-$$
$$-\frac{\cos(2\cdot m\cdot\alpha)-\cos(2\cdot m\cdot\beta)}{2\cdot m}\Big), \qquad (6)$$

$$B_n=\frac{V\cdot\sqrt{2}}{\pi}\cdot\Big(\frac{\sin(2\cdot m\cdot\beta)-\sin(2\cdot m\cdot\alpha)}{2\cdot m}-$$
$$-\frac{\sin 2\cdot(m+1)\cdot\beta-\sin 2\cdot(m+1)\cdot\alpha}{2\cdot(m+1)}\Big). \qquad (7)$$

If the load is resistive, β becomes equal with π and the relationships (6), (7) are simplified.

Spectral component of input current can be determined from the relation

$$I_n=\frac{V_{sn}}{\sqrt{R^2+n^2\cdot\omega_1^{\,2}\cdot L^2}}. \qquad (8)$$

The phase shift φ_n between current and voltage harmonic (by order n) is

$$\varphi_n = arctan\frac{n\cdot\omega_1\cdot L}{R}. \qquad (9)$$

The waveform and the harmonic spectrum of current/voltage are determined by the load and the thyristors delay angle.

Experimental results

To study the current and voltage harmonic spectrum of the AC/AC converter with full-wave AC control using two SCRs connected in inverse parallel we make an experimental arrangement with this type of converter, illustrates in Fig. 3. Conditions are created in order to make different phase shift between current and voltage.

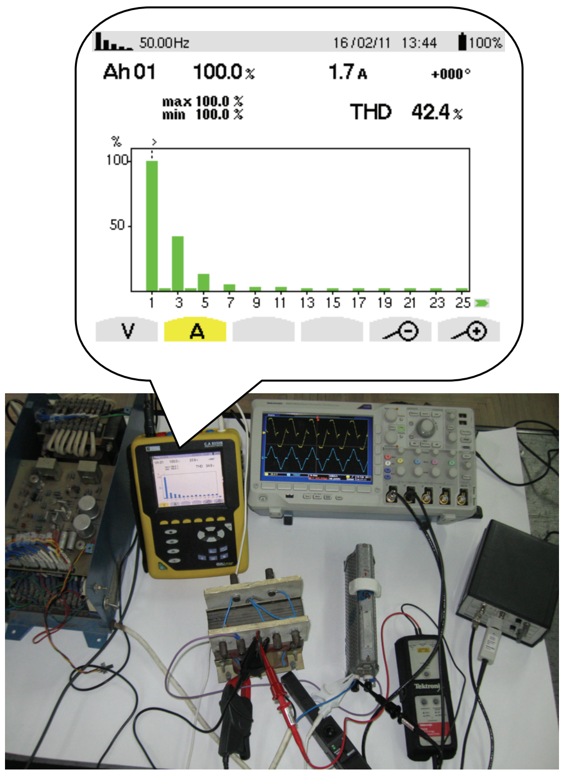
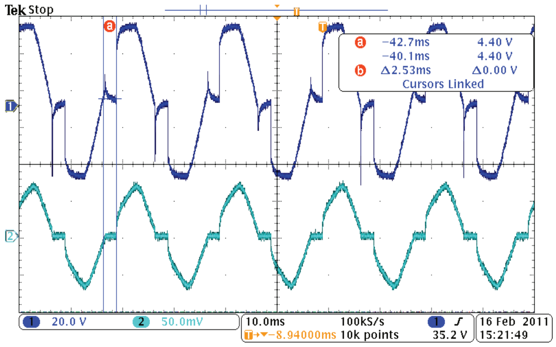


Fig. 3. The experimental arrangement

For the data acquisition of the voltage and the current in different work case of converter we use a digital oscilloscope, a differential voltage probe and a current probe. The data are transferred from the oscilloscope to PC with a flash memory. All data are saved in format text in the PC. These data are then imported into Matlab where Fourier and MRA analysis are performed. To validate the results obtained through the software we use a power quality analyzer C.A. 8332B, from Chauvin Arnoux.

Fourier analysis

The Fourier transform is a good mathematical tool for the detection and the analysis of deforming state.



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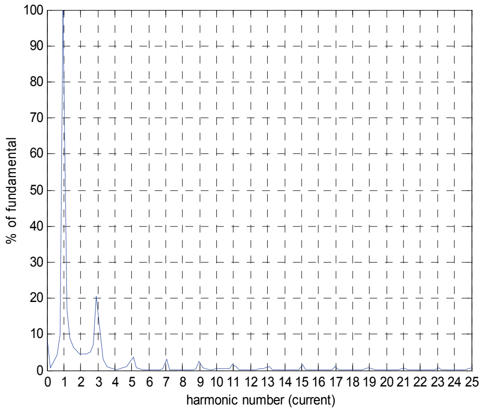

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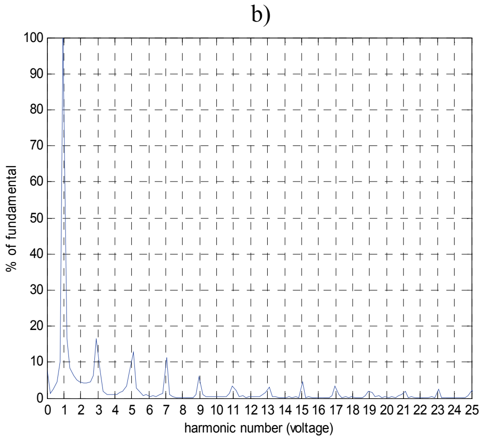


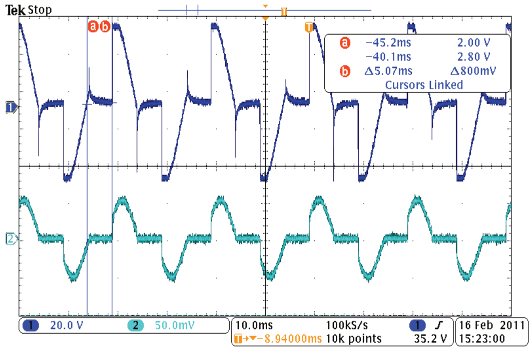
c)

Fig. 4. The current and voltage waveforms/harmonic spectrums for AC/AC converter ($\varphi = 30^0$, $\alpha = 45^0$)

Using Fourier transform we can determine the amplitudes, frequencies and phases of harmonics. It also allows the transfer of signal from the time domain at frequency domain and vice versa. Fig. 4 a, 5 a, show current and voltage waveforms for the AC/AC converter with inductive load when the thyristors delay angle is 45° respectively 90°, and the phase shift between current and voltage is 30°.

The Fig. 6a, 7a, illustrate the same thing but for the phase shift between current and voltage of 60°. The current and voltage harmonics up to the 25th order, for the cases described above are shown in Fig. 4b, 4c, 5b, 5c, 6b, 6c, 7b, 7c.

It is noted that at the same phase shift between voltage and current (introduced by inductive load) both current harmonics and voltage harmonics (expressed as a percentage of fundamental) increase as the thyristors delay angle α increases.



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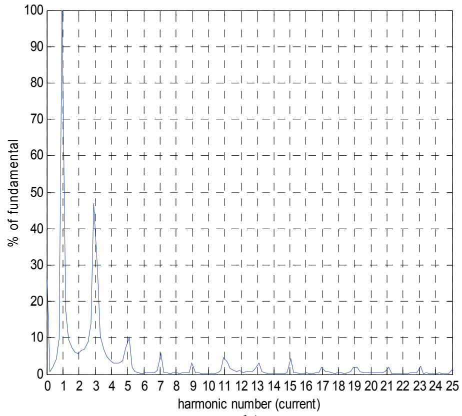

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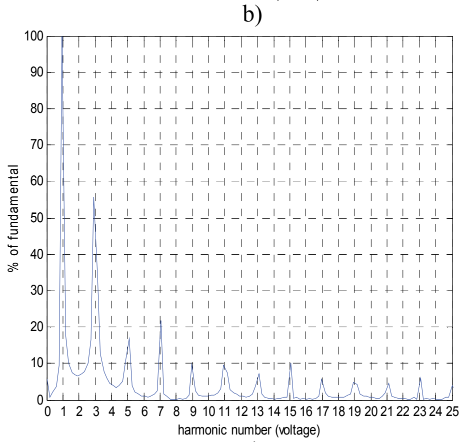


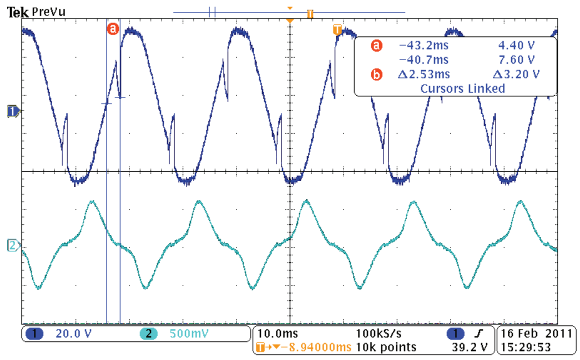
c)

Fig. 5. The current and voltage waveforms/harmonic spectrums for AC/AC converter ($\varphi = 30^0$, $\alpha = 90^0$)

For example the 3rd harmonic current is approximately 20% of the fundamental and harmonic of the same order in voltage is 17% for a thyristors delay angle of 45°. For a delay angle of 90°, these harmonics grow to 47% respectively 55% of fundamental.

At the same thyristors delay angle, the values of harmonic current and the voltage, decrease with increasing of phase shift angle between current and voltage.

For example, at the delay angle of 90°, the values of the 3rd current and voltage harmonics are 47% or 55% of fundamental for a phase shift of 30°, while at the same delay angle but at a phase shift of 60°, the harmonics (current and voltage) are reduced to 35% or 52% of fundamental. The decrease in amplitude is also valid for the other harmonic up to 25th order.



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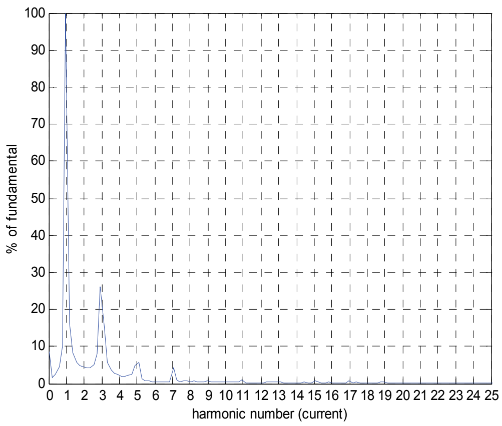

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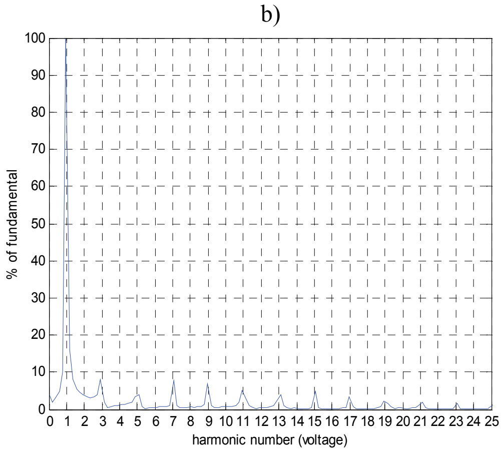

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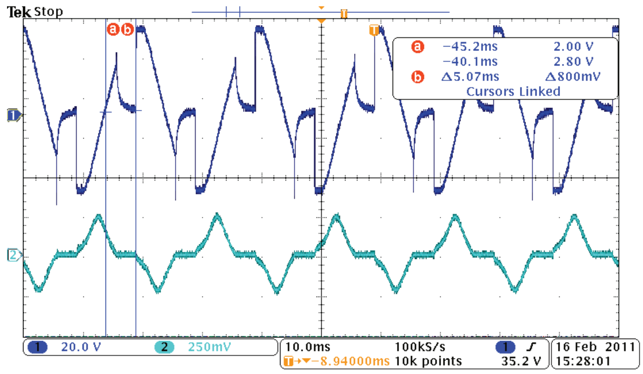
Fig. 6. The current and voltage waveforms/harmonic spectrums for AC/AC converter ($\varphi = 60^0$, $\alpha = 45^0$)

The harmonic values obtained with software developed in Matlab are almost identical to those measured with the power quality analyzer.

MRA analysis

Recently wavelet analysis is proposed in the literature as a new tool for monitoring the deforming state, power system transients and power quality problems [4]. The wavelet transform enables time-frequency representations of the signal, all with different resolutions: high resolution in time and low resolution in frequency for high frequencies and low resolution in time and high in frequency for low frequencies [6].



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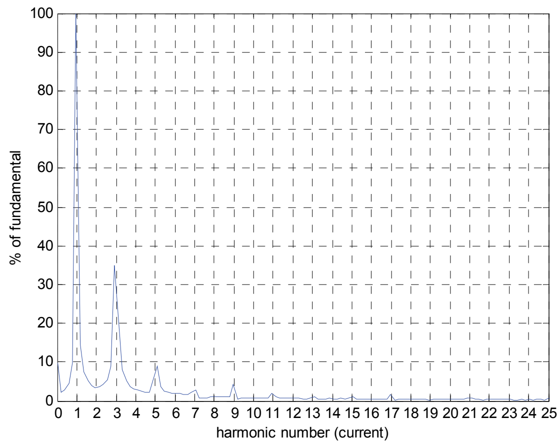

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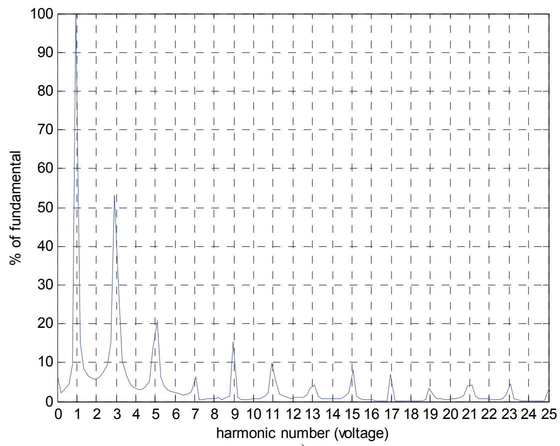

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Fig. 7. The current and voltage waveforms/harmonic spectrums for AC/AC converter ($\varphi = 60^0$, $\alpha = 90^0$)

Wavelet transformations are classified into discrete wavelet transform (DWT), wavelet series (WS) and continuous wavelet transform (CWT). The multiresolution signal decomposition allows valuable information to be gained in order to detect and classify different disturbances such as harmonic distortion and short–duration variation [3]. The multiresolution analysis decomposes a given signal *x(t)* to the approximation signal and detail signal at different resolutions with orthogonal transformation. This technique discriminates disturbances from the original signal, and then analyses them separately. An approximation contains the general trend of the original signal while a detail embodies the high-frequency contents of the original signal.

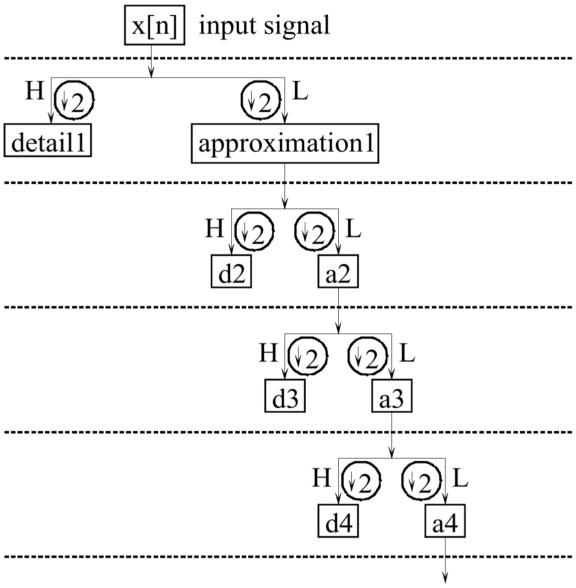
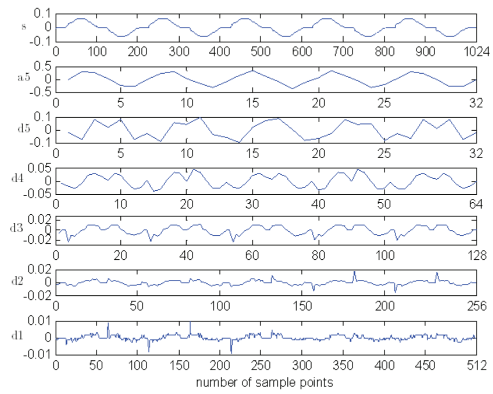


Fig. 8. Four-level multiresolution signal decomposition



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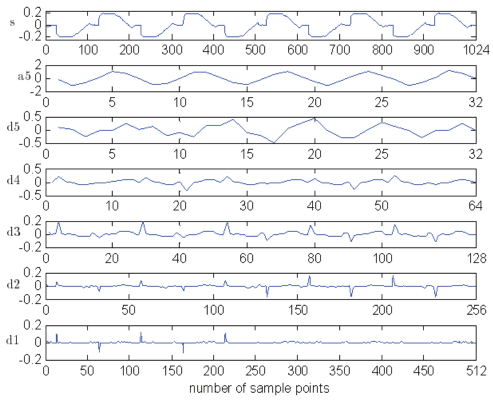


b)

Fig. 9. The decomposition of distorted current (a) and voltage (b) signals in five-detailed version and one approximated

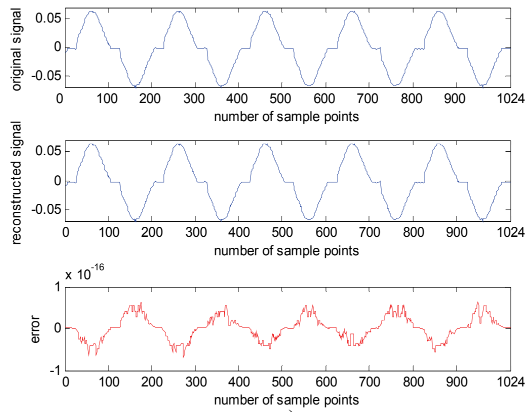
Approximations and details are obtained through a succession of convolution processes [7]. The signal is analyzed at different frequencies with different resolutions. Every spectral component is not resolved equally. In Fig.8 is illustrated the multiresolution decomposition on four levels. The maximum number of wavelet decomposition levels is determined by the length of the original signal and the level of detail required [8].

Using scaled and translation version of the wavelet and scaling functions, the distorted current and voltage signals from the AC/AC convertor (when the delay angle is 45° and the phase shift between current and voltage is 30°) are decomposed to five-detailed version and one approximated using Db1 wavelet, like in Fig. 9. Five periods (100 ms) of signals are considered, with sampling rate of 10KHZ. According to Shannon theorem, the highest frequency of the spectrum which can be analyzed is 5 kHz. The deformed signal is divided in various frequency bands to identify the harmonics.

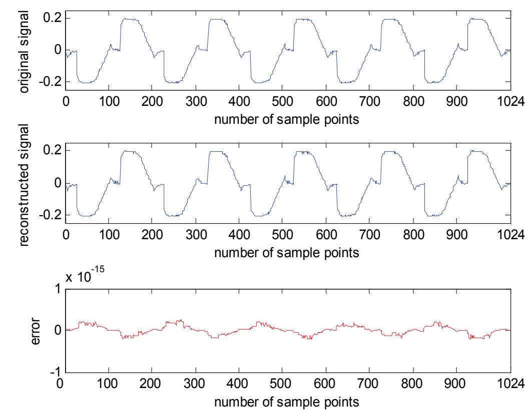
The detail coefficients of the signal are:

- (d1) that includes the frequency band (2500-5000Hz),
- (d2) that includes the frequency band (1250-2500Hz),
- (d3) that includes the frequency band (625-1250Hz),
- (d4) that includes the frequency band (312.5-625Hz),
- (d5) that includes the frequency band (156.25-312.5Hz).

The approximate coefficient signal (a5) includes the frequency band (78.125-156.25Hz).



a)



b)

Fig. 10. The reconstruction of distorted current (a) and voltage (b) signals

The approximation indicates the low frequency in the spectrum (the 3rd harmonic). The detail d5 includes the 5th harmonic, d4 includes the 7th, 9th, 11th harmonics, d3 includes 13th, 15th, 17th, 19th, 21st, 23rd harmonics etc. Higher frequency bands of wavelet decomposition contain several harmonic components than the lower frequency bands. As it can be seen in the Fig. 9, the good time localization is at low scale and good frequency localization at high scales.

Fig. 10 shows the reconstruction of distorted current and voltage signals, obtained by applying the inverse wavelet transform. The original signal can be reconstructed by adding all the detailed versions and the last approximated level of the decomposed signal. It is clear from the figure that the initial signals and the reconstructed signals are identical. The reconstruction error is less than 10^{-16}. Hence, the wavelet transform has high accuracy for the analysis of distorted signals.

Conclusions

It was found that:

- At the same phase shift between voltage and current (introduced by inductive load), the values of both current harmonics and voltage increase as the delay angle increases;
- At the same thyristors delay angle, the values of harmonic current and the voltage, decrease with the increasing of phase shift angle between current and voltage.

For the analysis of the distorted current and voltage signals from converter, the most appropriate mathematical tool is FFT. This enables the determination of harmonic in amplitude, frequency and phase. Also, the wavelet transform can be used for the harmonic frequency bands identification of the deformed signals. Using the MRA decomposition technique we can decompose the distorted signal into different resolution levels. With MRA we extract important information from the analyzed distorted signal.

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For electric power quality improvement should be identified and followed the deforming consumers. This is necessary, because the number of equipments producing harmonic distortion is increasing, primarily by expanding the use of static power converters. This paper presents the study of the deforming state generated by the AC/AC converter with full-wave AC control using two SCRs (silicon – controlled rectifier) connected in inverse parallel. The harmonic spectrums of distorted current and voltage signals are determined by the load and the thyristors delay angle. For this study, we use Fourier and Wavelet transform. A multiresolution signal decomposition technique is presented in the analysis of the deforming signals from the AC/AC converter. Ill. 10, bibl. 8 (in English; abstracts in English and Lithuanian).

G. Rata, V. Popa, M. Rata. AC/AC keitiklio iškraipančiojo režimo studija taikant Furjė ir multirezoliucinę analizę // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 5(121). – P. 7–12.

Elektros energijos kokybei pagerinti turi būti nustatyti iškraipymus sukeliantys energijos vartotojai. Tai yra būtina, nes daugėja įrangos, sukeliančios harmoninius iškraipymus, pirmiausia dėl to, kad vis plačiau naudojami statiniai galios keitikliai. Analizuojamos iškraipymo būsenos, sukeltos visiškai bangą valdančio AC/AC keitiklio naudojant du invertuotai lygiagrečiai sujungtus SCR. Iškraipytos srovės ir įtampos signalų harmonikų spektrai priklauso nuo apkrovos ir tiristorių vėlinimo kampo. Tiriant panaudotos Furjė ir vilnelių transformacijos. Pateikiamas multirezoliucinis signalo dekomponavimo metodas. Il. 10, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).