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HARMONIC CURRENTS OF FREQUENCY CONVERTERS WITH VOLTAGE SOURCE INVERTERS

ABSTRACT *Using of well-known “1 over h rule” is not sufficient for harmonic current calculation because harmonic values are much bigger and it is necessary to modify results. Therefore so-called “Modified 1 over h rule” is presented. Converter properties on taken harmonic currents are described further. Partly there are properties of design topology and converter component parameters, which user cannot influence. And there are properties of additional devices as well, which are offered with converters and positively influence (decrease) taken harmonic currents. At voltage inverters power factor is very different from power factor (p. f.) by influence of taken current. Harmonic current experimental results of converters with voltage source inverter are compared at the close.*

Keywords: *voltage source inverters, calculation of harmonic currents*

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1. INTRODUCTION

Nowadays a big attention is given to the negative effects of semiconductor devices on the distribution network from the electromagnetic compatibility point of view. As the power electronics devices find their wide application in power systems, power quality is becoming a more important issue to consider. Operation of indirect frequency converters with IGTB (see Fig. 1) brings a lot of advantages, but is often accompanied by some unfavourable effects.

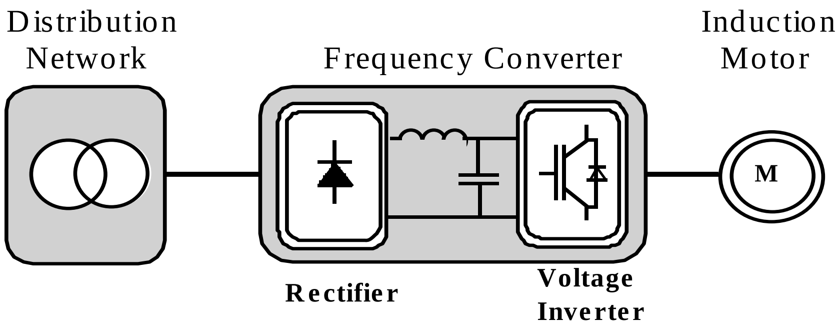

Fig. 1. Block diagram of the drive with frequency converter

The converter adversely influences power distribution network due to non-sinusoidal taken current [1, 2, 3], fed motor by transient motor overvoltage [4] and also converter control circuits.

The frequency converter takes away from distribution network a non-sinusoidal current wave which contents higher frequency components. These harmonic components are transferred to power distribution network where they can arise a distortion of supply voltage, disturbance of connected equipment (e.g. ripple control devices, tuned power filters, compensation units). In this paper there are presented investigation possibilities of these harmonic currents which are taken from power network by frequency converters with voltage source inverter.

According to [5] the low-frequency interference is considered on a frequency range 2.5 kHz and the frequency components can be defined as following:

Harmonic $f = h * f_1$ where h is an integer > 0

DC $f = 0$ Hz ($f = h * f_1$ where $h = 0$)

Interharmonic $f \neq h * f_1$ where h is an integer > 0

Sub-harmonic $f > 0$ Hz and $f < f_1$

Where f_1 is the fundamental power system frequency (50 Hz).

2. SYSTEM MODELLING

In the case of frequency converter with voltage source inverter, we can divide the circuit into inverter part and rectifier part supplying capacitor in the DC Bus.

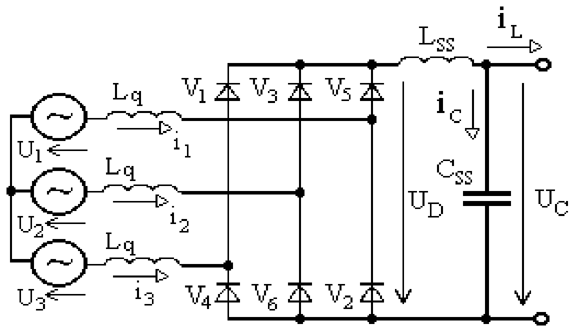

Fig. 2. Three-phase bridge rectifier configuration

Three-phase bridge rectifier as an input part of the static converter (Fig. 2) is modelled with the focus on the calculation of all harmonic components presented in the current taken by rectifier from a power distribution network. It requires making of a mathematical model of the AC/DC converter.

Typical waveform of taken phase current under ideal operating conditions (symmetrical power supply, indefinite short circuit power etc.) is on the Fig. 3. The non-sinusoidal waveform of phase current creates higher frequency current components. For the harmonic components calculation of phase current it is necessary to simplify the phase current wave.

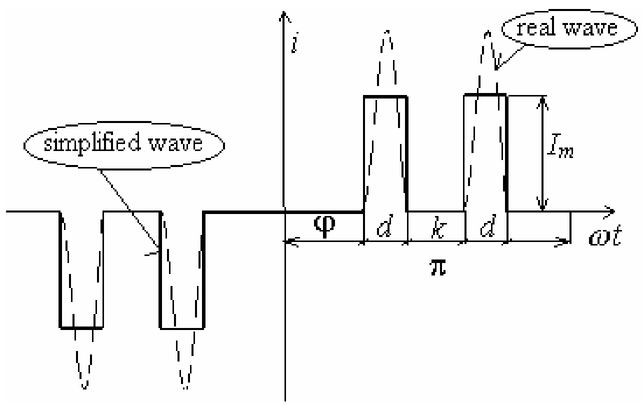

Fig. 3. Real and simplified phase current wave

Amplitude I_m is constituted so as the area of both currents will be identical for the same parameter d (where d is a diode conduction time). From the figure is obvious that used simplification is rough in commensurate with value of parameter d. The error of used simplification is bigger with decreasing of parameter d and for small value d corresponds to reality.

Using the well-known quotation for Fourier analysis we can calculate coefficients a_h and b_h. Since the current waveform from Fig. 3 is symmetrical odd function, coefficients a_h are zero and we can solve coefficients b_h only:

$$b_h = \frac{2}{\pi}\int_0^{\pi} i_f(\omega t)\sin(h\omega t)d\omega t \tag{1}$$

After editing we will get:

$$b_h = -\frac{4I_m}{h\pi}\left[\sin\left(\frac{hk}{2}\right) - \sin\left(\frac{hk}{2} + hd\right)\right]\cdot\sin\left(\frac{h\pi}{2}\right) \tag{2}$$

For symmetrical power network is valid $d+k = 60^0$ and relation (2) we can convert to:

$$b_h = \frac{8I_m}{h\pi}\cdot\sin\frac{hd}{2}\cdot\cos\frac{h\pi}{6}\cdot\sin\frac{h\pi}{2} \tag{3}$$

Back expression of current i by Fourier progression is:

$$i_f(\omega t) = \sum_{h=1}^{\infty}\frac{8I_m}{h\pi}\sin\frac{hd}{2}.\sin\frac{h\pi}{2}.\cos\frac{h\pi}{6}.\sin(h\omega t) \tag{4}$$

For higher current harmonics amplitudes is valid:

$$I_h = \frac{1}{h} I_1 . \frac{\sin\frac{hd}{2}}{\sin\frac{d}{2}} \quad \text{where} \quad I_1 = \frac{8I_{fm}}{\pi}\cdot\sin\frac{d}{2}\cdot\cos\frac{\pi}{6} = 2{,}205.I_{fm}.\sin\frac{d}{2} \tag{5}$$

When we fill to the relation (4), we find out that only harmonics of definite orders (5., 7., 11., 13. etc.) will appear at frequency spectrum (see Fig. 4). These harmonic orders are called characteristic harmonics and their amplitudes are solved by equation (5) so-called “Modified 1over h rule”.

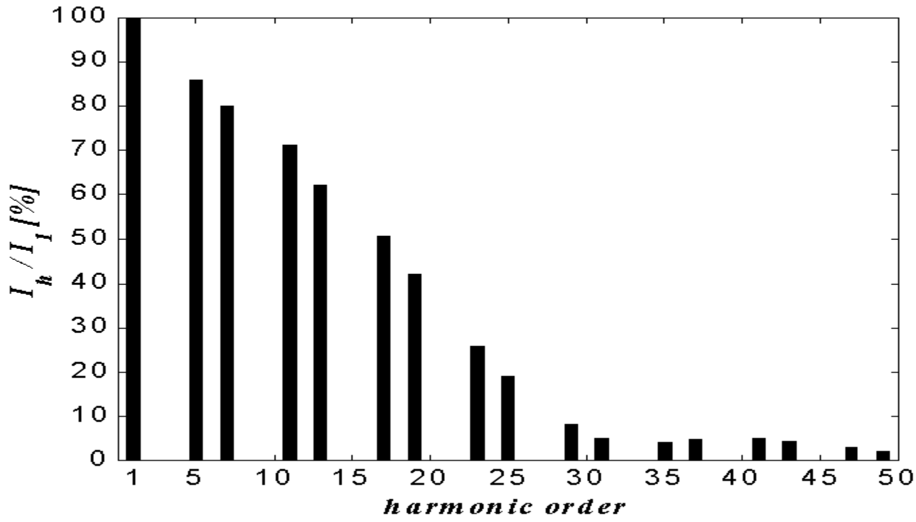

Fig. 4. Frequency spectrum of ideal current wave

There are shown typical waveforms of phase current i_f on Fig. 3, for presented type of semiconductor converter (uncontrolled diode bridge rectifier) can occur following variations of phase currents:

a) Interrupted current
   1) One oscillation – Fig. 5
   2) More oscillations – Fig. 6

b) Uninterrupted current
   1) One oscillation – Fig. 7
   2) More oscillations – Fig. 8
   3) Aperiodic waveform – Fig. 9

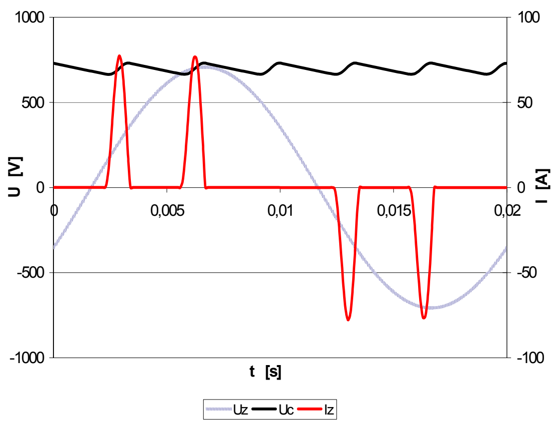

Fig. 5. Interrupted current – one oscillation

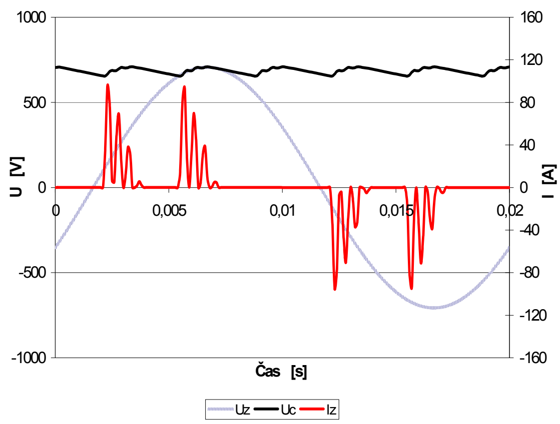

Fig. 6. Interrupted current – more oscillations

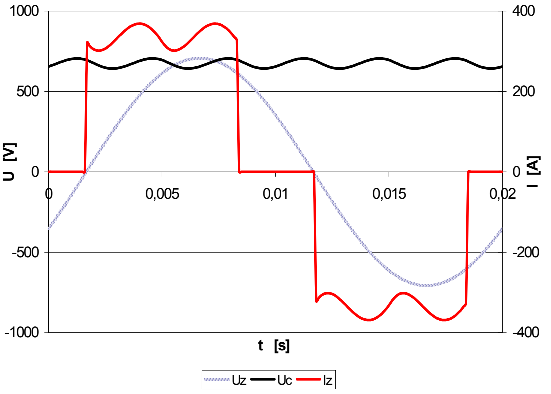

Fig. 7. Uninterrupted current – one oscillation

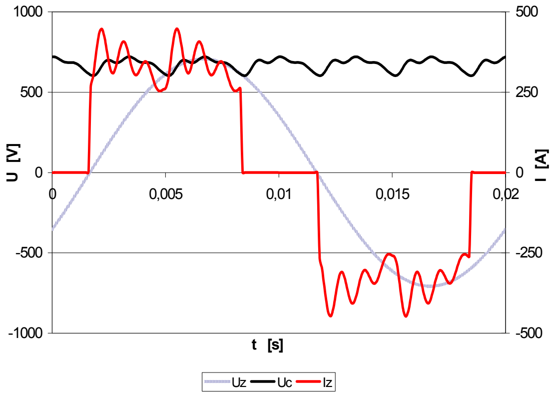

Fig. 8. Uninterrupted current – more oscillations

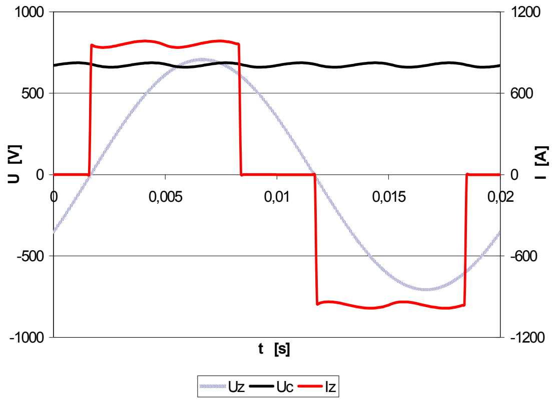

Fig. 9. Uninterrupted current – aperiodic waveform

3. SIMULATION RESULTS

Analytical harmonic calculation of simplified phase currents has been made (chapter 2), however for practical using the analytical calculation is unbearable and in this chapter we will take attention on numerical calculations of semiconductor converters.

It is necessary ensure the appropriate results accuracy and choose simple model as well for simulation. Example of applicable converter model for simulations is shown on Fig. 2. There are simulation results made by model on Fig. 2 under following conditions:

Power on the output side of converter (load) – P = 2.2 – 220 kW

Network short-circuit power – S_K = 1 – 100 MVA

Induktance in input side of converter – L_q = 6.8 – 680 μH

Induktance in converter DC link – L_{SS} = 15 - 1500 μH

Capacitance in converter DC link – C_{SS} = 0.068 – 6.8 mF

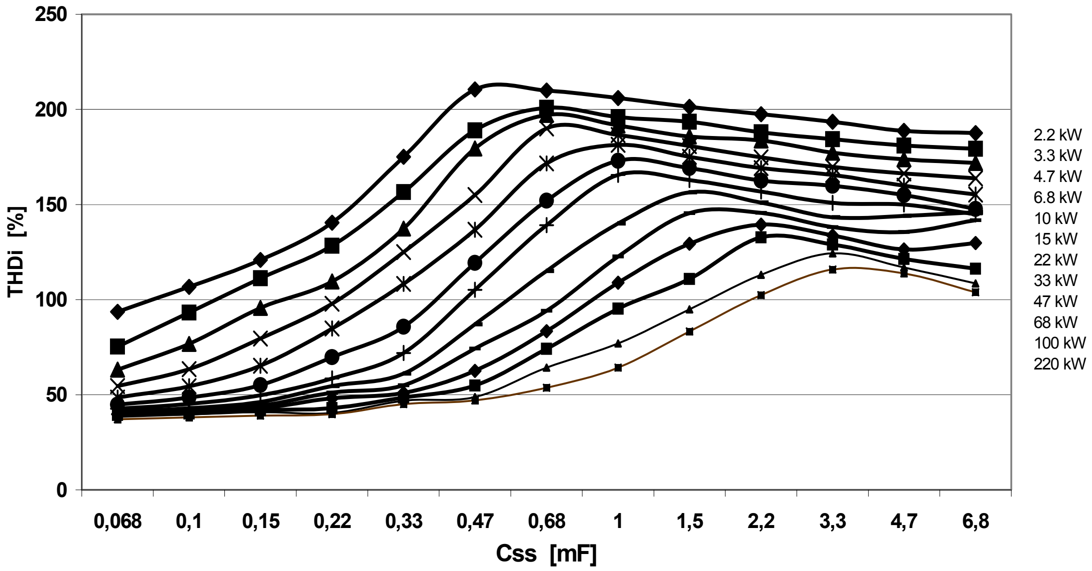

Fig. 10. THDi at S_K = 22 MVA and P = 2.2-200 kW

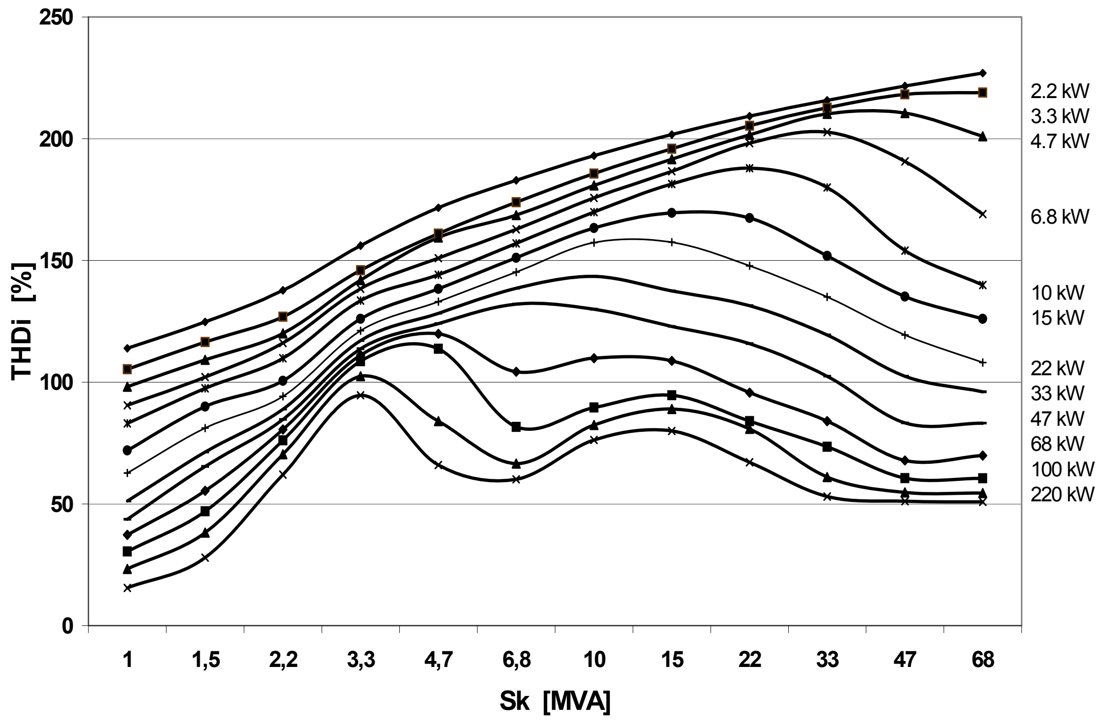

Fig. 11. THDi at C_{SS} = 1 mF and P = 2.2-200 kW

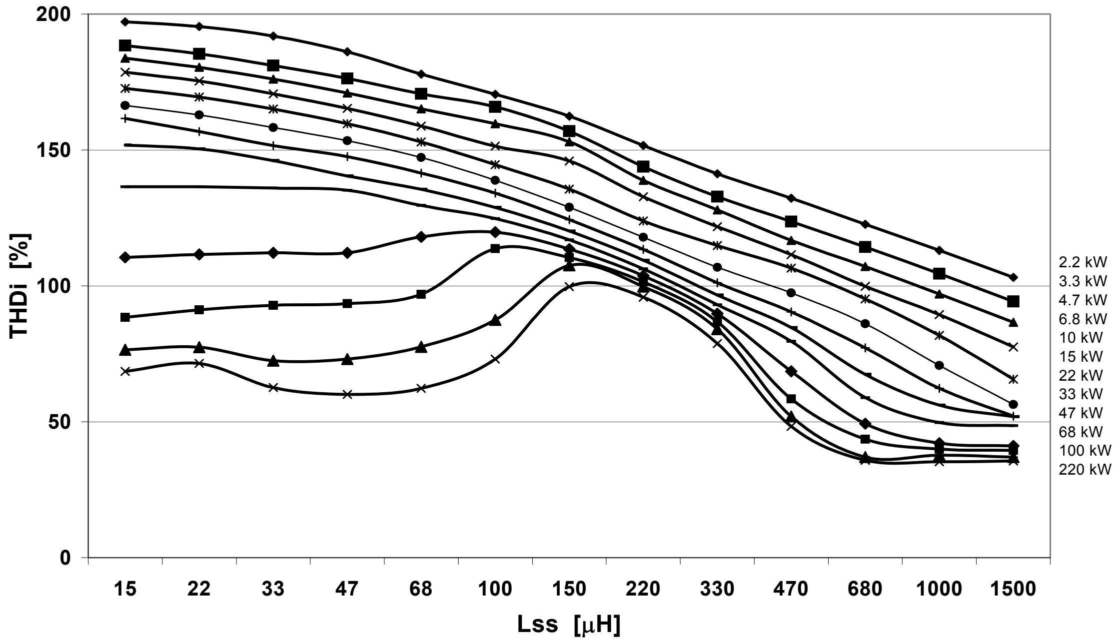

Fig. 12. THDi at SK = 22 MVA, C_{SS} =1 mF and P = 2.2-200 kW

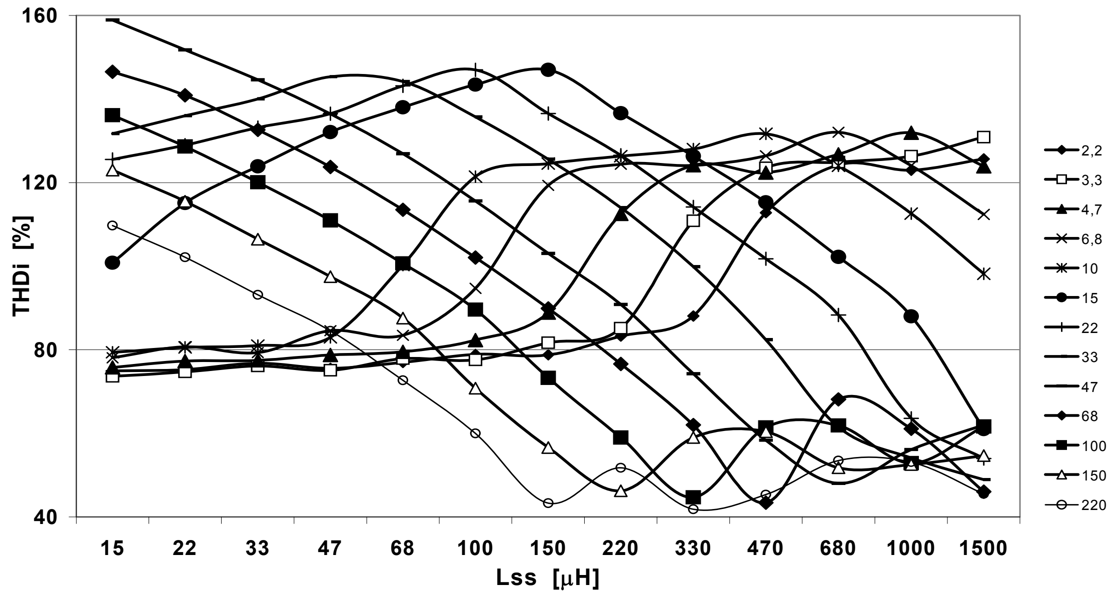

Fig. 13. THDi at C_{SS} = 0.047-10 mF, SK = 22 MVA and P = 2.2-200 kW

4. EXPERIMENTAL RESULTS

On the following figures (Fig. 14-17) the experimental results according chapter 3 have been presented. All measuring have been made from IEC standard 61000-4-7 and 61000-4-30 point of view. We used harmonic analyser for measuring and data storage of voltage and current harmonic components.

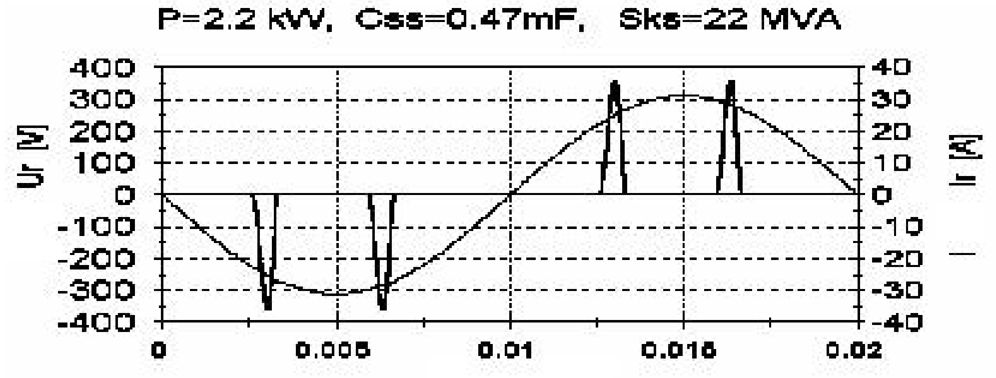

Fig. 14. Phase current i_f and phase voltage U_f

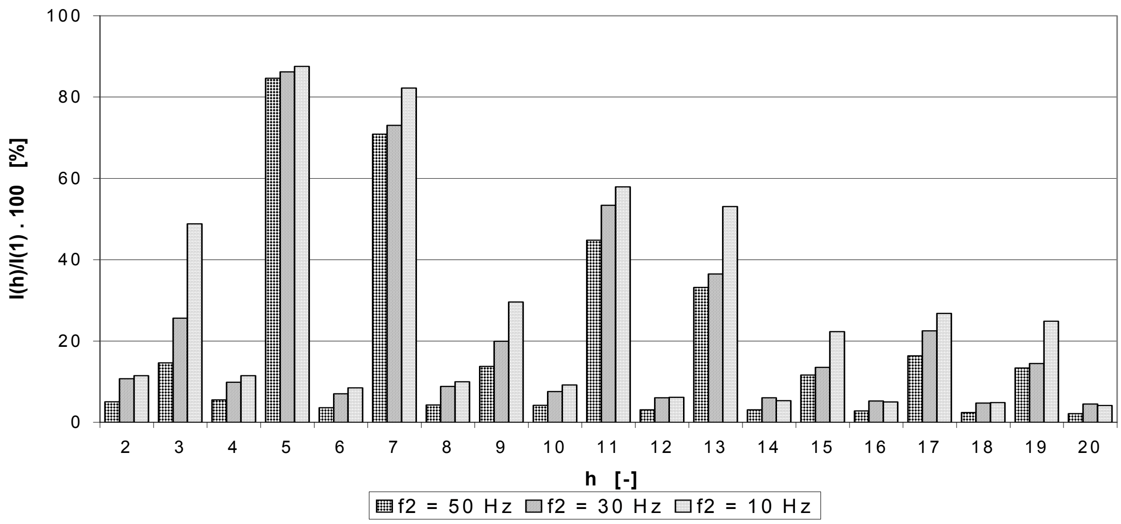

Fig. 15. Harmonics of input converter current

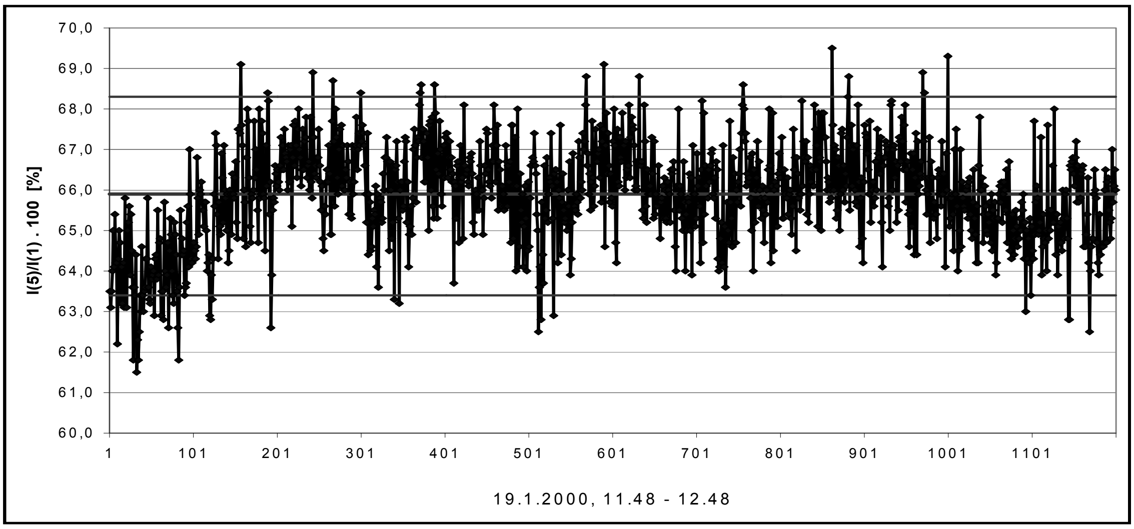

Fig. 16. 1 hour measuring of 5th current harmonic

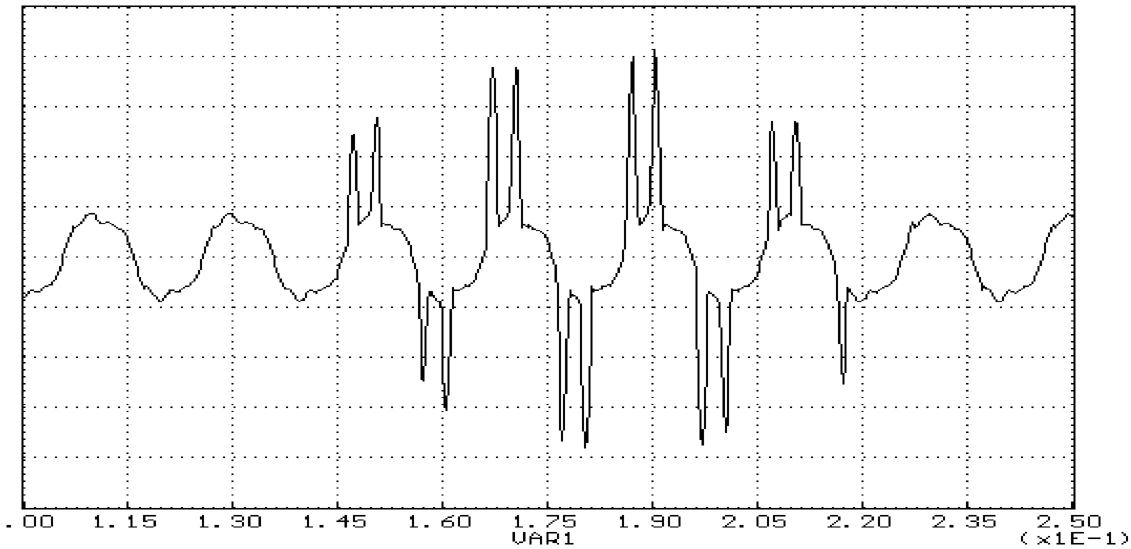

Fig. 17. Phase current at arc initiation of welding unit

5. CONCLUSION

The converter adversely influences not only load (e.g. fed motor by transient motor overvoltage) but also power distribution network due to non-sinusoidal taken current. Examples of converter properties influence on taken harmonic currents have been presented. Partly there are properties of design topology and converter component parameters which user cannot influence. There are additional protective approaches (e.g. tuned filters, choking coils at input part of converter etc.) as well, which are offered with converters and positively influence (decrease) taken harmonic currents. Power factor value is monitoring together with harmonic currents. Harmonic current experimental results of converters with voltage source inverter are compared at the close.

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PRĄDY HARMONICZNE PRZETWORNIKÓW CZĘSTOTLIWOŚCI Z PRZEKSZTAŁTNIKAMI TYPU ŹRÓDŁA NAPIĘCIOWEGO

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STRESZCZENIE *Użycie znanej reguły "1nad h" nie wystarcza dla obliczania prądów harmonicznych, ponieważ wartości harmoniczne są dużo wyższe i wyniki muszą być modyfikowane. Dlatego przedstawiono regułę „Modyfikowane 1 nad h". W artykule opisano własności przetworników dotyczące topologii i parametrów elementów przetwornika, na które użytkownik nie ma wpływu. Omówiono własności dodatkowych przyrządów, które są oferowane wraz z przetwornikami i wpływają pozytywnie obniżając pobierane prądy harmoniczne. W przekształtnikach napięcia współczynnik mocy różni się znacznie pod wpływem pobieranego prądu. Porównano eksperymentalne wyniki przetworników z przekształtnikami typu źródła napięcia.*