

Vaclav KUS  
Pavel DRABEK

# LOW FREQUENCY INTERFERENCE OF SOFTSTARTERS ON POWER DISTRIBUTION NETWORK

**ABSTRACT** *Modern semiconductor converters take high currents from power distribution network (PDN) consequently harmonic and interharmonic currents arise with high values and there are inconsiderable unallowable effects in PDN. We can sort softstarters as often used converters. Principal aim is reducing start up currents, the influence on PDN is not usually monitored and protective devices are not use as well.*

**Keywords:** *power distribution network, semiconductor converter, electronic power devices*

## 1. INTRODUCTION

---

The operation of semiconductor converters (frequency converters, controlled rectifiers, softstarters etc.) brings a lot of advantages (possibility of new control methods of VSI, using new steering algorithms, reducing of start-up currents

---

**Prof. Vaclav KUS, Pavel DRABEK, Ph.D.**  
e-mail: kus@kev.zcu.cz, drabek@kev.zcu.cz  
West Bohemia University,  
Univerzitni 8, 306 14, Plzen, CZECH REPUBLIC

etc.), but is often accompanied by some unfavourable effects. The converter adversely influences the power distribution network due to non-sinusoidal taken current, fed motor by transient motor overvoltage and also converter control circuits. The power quality is primarily influenced by the electric appliances connected to the power grid. If a linear load such as resistive heater is connected to the power grid, the resulting current will be a sine wave and, therefore, only the fundamental frequency will be introduced. However, if the load is non-linear, drawing short pulses of current within each cycle, the current shape will be distorted (non-sinusoidal) and higher frequency current components will occur. Thus, the resulting current will be composed of the fundamental and higher frequency components.

The softstarters are electronic power devices serve fluent start-up and run down AC drives with asynchronous machines. Principal aims of this converter are reduce start up currents and protection and reducing abrasion of drive mechanism and drive protection while in running. Softstarter fundamental disposition is AC voltage converter. They should be complete by additional functions like motor thermal protection, supply voltage sensor, overload watchdog, contactors etc.

During start-up process the phase taken current is changing (RMS value), but also it is heavily distorted. After harmonic analysis we can obtain basic harmonic and wide spectrum of additional frequencies as well. For small power drives and short start-up times there is not risk of dangerous frequency arise, however high power engines in range of hundreds of kW and long start-up times can produce dangerous frequency and consequently unfavourable states. Because this effect is done under transient condition it is not easy to find causes in practise.

## 2. SINGLE PHASE VOLTAGE CONVERTER

---

Basic scheme of single softstarter is shown in figure 1. Current waveform is identical with voltage waveform for resistor load (e.g. electrical resistance oven, lamp etc.).

Voltage and current waveforms for inductance load only are displayed in Fig. 2.

It results from the Fig. 2 that taken phase current contains high values of higher orders of harmonics (in the figure the current wave is dashed). Self analytical expression of current wave is:

$$i_1 = i_z = \frac{U_m}{Z} \sin(\omega t - \varphi) - \frac{U_m}{Z} \exp\left(\left(-\frac{R}{\omega L}(\omega t - \alpha)\right) \cdot \sin(\alpha - \varphi)\right) \tag{1.1}$$

From the equation it is evident that analytical description of this relatively simple circuit is relatively complicate. More complex problem occurs with following analytical calculation of harmonic analysis.

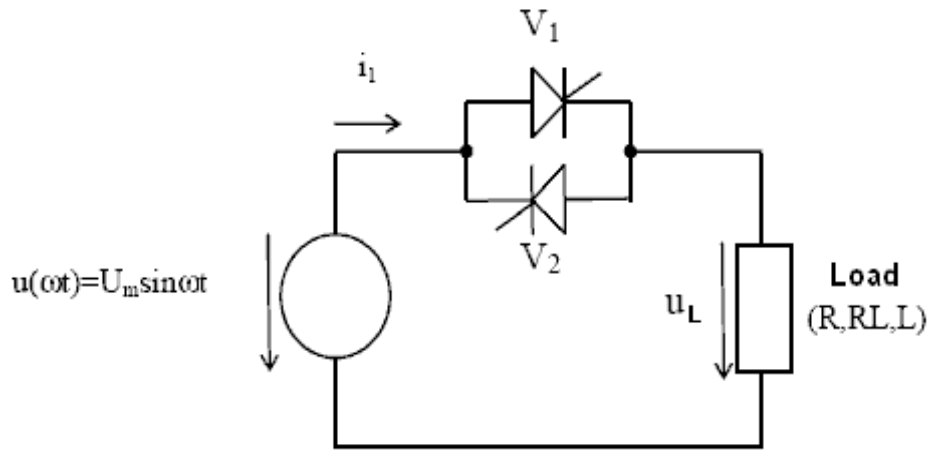


Fig. 1. Basic disposition of 1-phase voltage converter

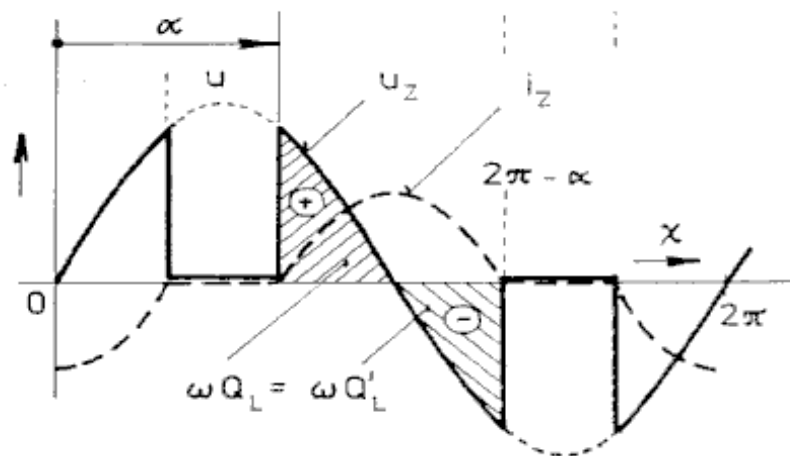


Fig. 2. Current and voltage at inductance load, delay angle > 90°

Waveforms of harmonic currents for both extreme cases – resistance load (left) and RL load (right) are shown in figures 3-4.

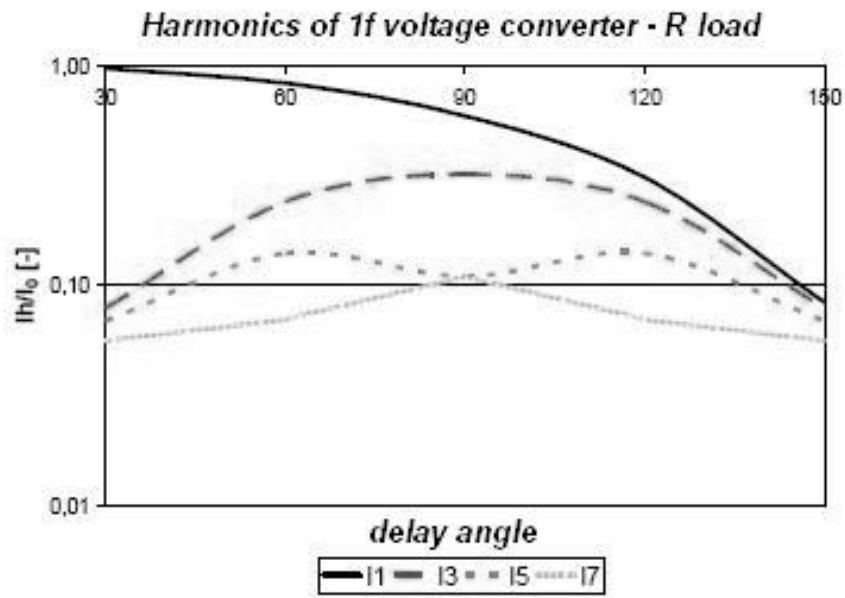


Fig. 3. Harmonics of single phase voltage converter for resistance load

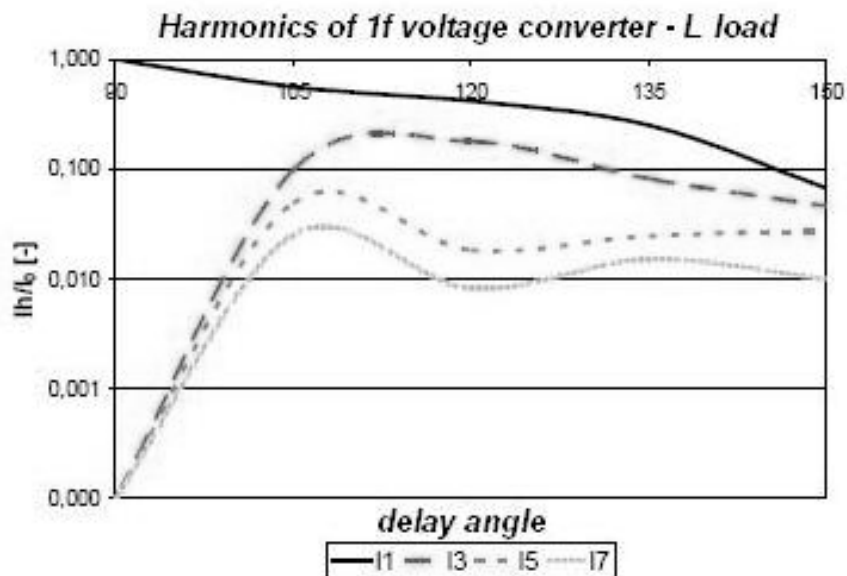
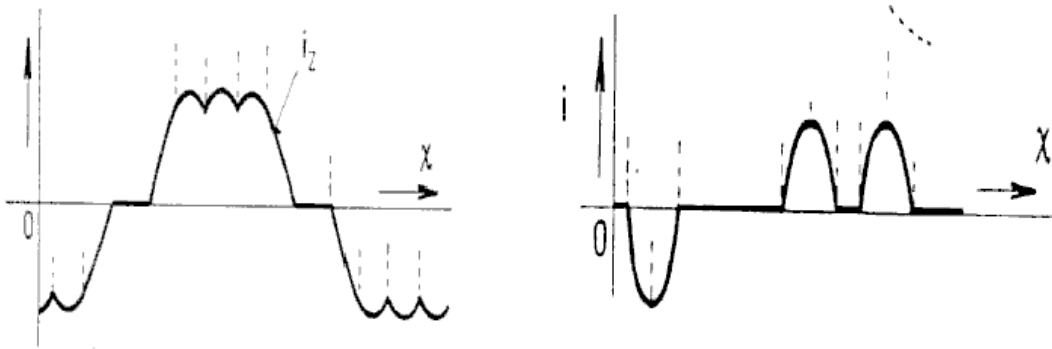


Fig. 4. Harmonics of single phase voltage converter for inductance load

### 3. THREE PHASE VOLTAGE CONVERTER

Three phase variation of voltage converter is usually done as a three multiple of single phase voltage converters (previous paragraph). Voltage converter load can be connected to the star or delta (Y, D). If there is a phase centre at the Y connection, three phase softstarter works as a parallel combination of three single phase softstarters and harmonic currents are equal to the values of single phase converters mentioned above.

At the three phase inductance load the active power is zero therefore first current harmonic delays  $\pi/2$  after voltage. Similar to 1phase variation, three phase converter works as a switch for interval  $0 < \alpha < \pi/2$ . In the interval  $\pi/2 < \alpha < \pi/3$  clock cycles with two and three switched thyristors alternate subsequently. The current is continuous. In the interval  $2\pi/3 < \alpha < 5\pi/6$  several clock cycles fall out and the current is interrupted. Examples of both current types are in the following figure 5.



**Fig. 5. Current and voltage waves of 3p voltage converter for inductance load and different delay angles**

The harmonic analysis is difficult, because basically there is a transition between continuous and interrupted current wave. In the first step is possible use well-known 1 over h rule. Curves of several harmonic currents dependence on delay angle for both limiting load types are displayed in the figures 6-7.

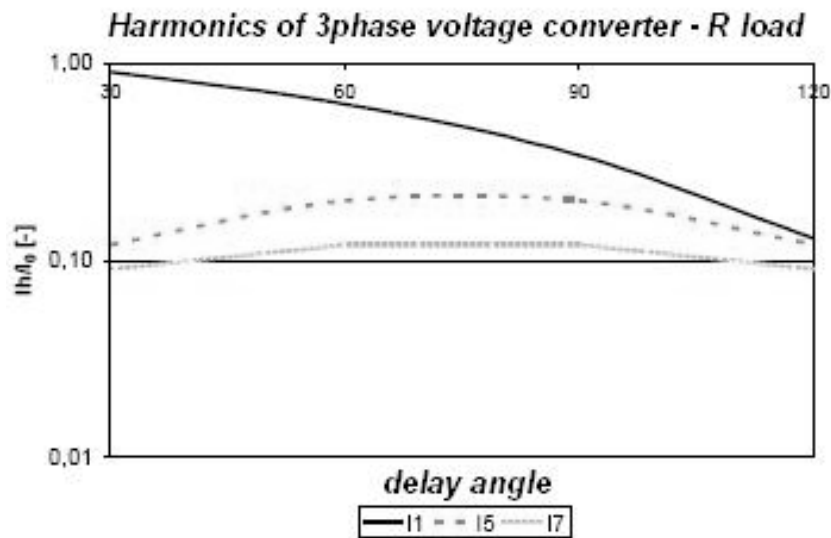


Fig. 6. Harmonics of three phase voltage converter for resistance load

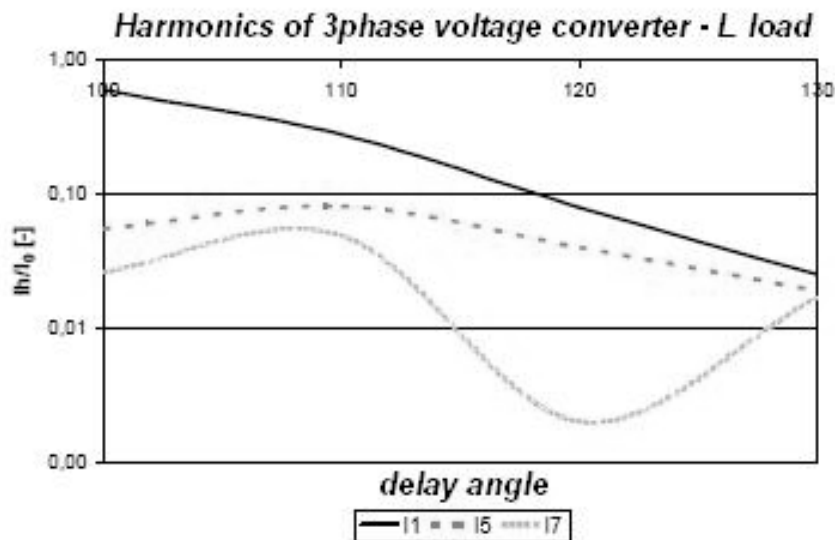


Fig. 7. Harmonics of three phase voltage converter for inductance load

Mentioned waveforms and simulation results of single phase and three phase softstarter (voltage converter) were calculated under permanent condition for constant delay angle. Unfortunately during start-up state with softstarter the situation for harmonic analysis calculation is getting more difficult in fact of the changing of delay angle and engine load type (typical character load is R, L,  $U_i$ ). For all devices we have to take attention not only to harmonics (characteristic and non-characteristic), but also additional frequency components

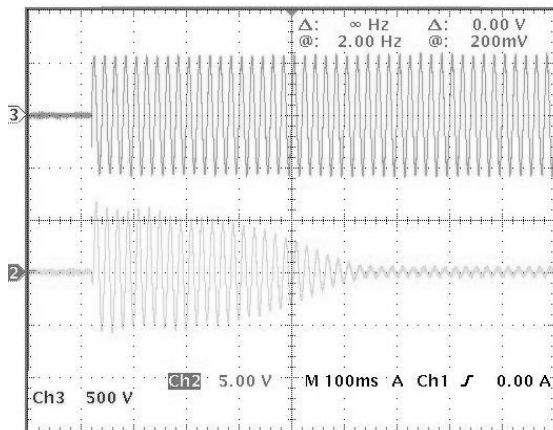
called interharmonics occur in the frequency spectrum of phase taken current according to dynamic changes during start-up process.

## 4. MEASURING OF SOFTSTARTERS

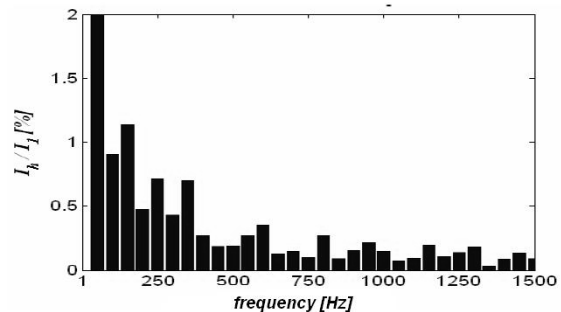
Measuring results of softstarters with asynchronous machine are presented in Fig. 8 - 11. The aim of the measuring was find out start-up current value of machine with direct connection and through softstarter to power grid.

### 4.1. Machine Measuring without Softstarter

The figure 8 shows classical current waveform (lower waveform) at direct connection to power grid and the amplitude of the phase current achieving value almost 31 A (ratio of current Hall sensor is 25 A/5 V) and start-up time is 480ms. Power grid voltage wave is in the upper half of figure 8. For comparison with the case of start up with softstarter the Fourier analysis of taken phase current was made. Results of harmonic analysis for direct connection of AC machine is shown in figure 9.



**Fig. 8. Current and voltage waves 3phase direct connection AC motor to power grid (up – power grid voltage, down - current)**



**Fig. 9. Appropriate frequency spectrum**

## 4.2. Machine Measuring with Softstarter

Additional measuring was made with softstarter and appropriate waveforms start up process of AC machine can be seen in the Fig. 10. From the picture it is evident that softstarter positively reduce start-up currents on value 22 A, but also increase start-up time to 750 ms. However on other hand harmonic components are higher than the case of direct connection.

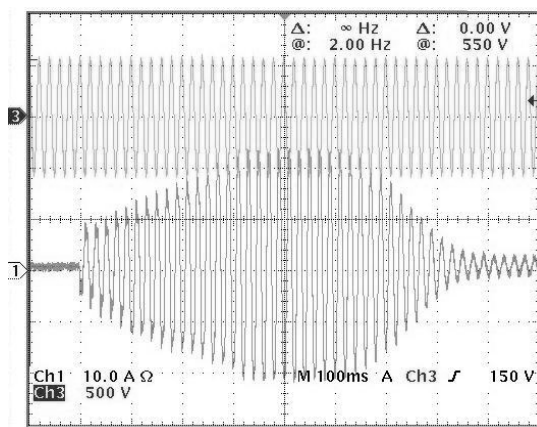


Fig. 10. Current and voltage waves 3phase connection AC motor to power grid via softstarter (up – power grid voltage, down - current)

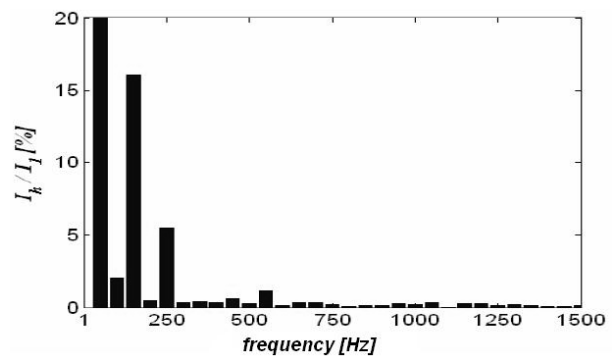


Fig. 11. Appropriate frequency spectrum

## 4.3. Comparison of the Measuring

TABLE 4-1  
Comparison of absolute and percentage values of measured harmonic currents

Harmonic order [h]	Without Softstarter		With Softstarter	
	I <sub>h</sub> [A]	I <sub>h</sub> /I <sub>1</sub> [%]	I <sub>h</sub> [A]	I <sub>h</sub> /I <sub>1</sub> [%]
1.	27	100	11.8	100
2.	0.23	0.85	0.24	2.1
3.	0.32	1.2	1.9	16.1
4.	0.12	0.45	0.12	1
5.	0.19	0.72	0.65	5.5

In the tab. 4-1 current sizes in the absolute and percentage values are displayed for harmonic orders 1 - 5 (50 - 250 Hz). Current values are sorted by AC machine connection to the grid – without softstarter (middle column) and through the softstarter (right column).

From the tab. 4-1 it is evident, that harmonic currents taken by softstarter are higher in comparison with prime connection to the grid (without softstarter).



## 5. CONCLUSION

---

Mounting and using of softstarters in industry has a big warranty. Using of softstarters can easily reduce start-up currents very effectively. However on other side softstarter produce wide range of frequency components in the spectrum of phase taken current and they can create dangerous overvoltages on the higher frequencies. Because start-up process is running under transient condition it is difficult to locate and measure these frequency components.

### Acknowledgement

This work has been made within the research project of Ministry of Industry and Trade of Czech Republic MPO ČR FT-TA2/035.

## LITERATURE

1. Kůs, V.: Non-characteristic harmonics and interharmonics of semiconductor converters. Conference CIRED 2004. Tabor. Czech Republic.
2. Kůs, V.: Low frequency interference. West Bohemia University hand-book 2003. Plzen. Czech Republic.
3. Arrillaga, J.: Power System Harmonic Analysis. John Wiley & Sons, New York, 1997
4. Bauta, M., Grötzbach, M., "Noncharacteristic Line Harmonics of AC/DC Converters with High DC Current Ripple," In: 8th IEEE-ICHQP, Athens, Proc. Vol. II, pp. 755-760, 1998.
5. Drábek, P., Kůs, V.: "Unfavourable Effects of Frequency Converters on Power Distribution Network." In: Power Electronics, Intelligent Motion, Power Quality (PCIM) 2002. Nuremberg, Germany. 2002, pp. 51-56.
6. Drábek, P.: "Analyses of interharmonic currents of semiconductor converters. [PhD thesis]. Plzen: West Bohemia University in Plzen, 2004. 143 p.
7. Kloss, A.: Stromrichter-Netzurückwirkungen in Theorie und Praxis. AT Verlag Aarau, Stuttgart 1981.
8. Vaculíková, P.: „Electromagnetic Compatibility of Electromagnetic Systems.” GRADA Publishing, Praha, 1998 (in Czech)

*Manuscript submitted 09.02.2009*

***Reviewed by Krzysztof Kluszczyński***

ZABURZENIA NISKIEJ CZĘSTOTLIWOŚCI  
URZĄDZEŃ ŁAGODNEGO STARTU  
W SIECIACH ENERGETYCZNYCH

V. KUS, P. DRABEK

**STRESZCZENIE** *Nowoczesne przekształtniki półprzewodnikowe pobierają z sieci energetycznej (SE) prądy o znacznych wartościach, powodując powstawanie w tych sieciach podharmonicznych i harmonicznym, niedozwolone w SE. Do szczególnej grupy często używanych przekształtników zalicza się także tak zwane softstartery (urządzenia łagodnego rozruchu). Ich głównym celem jest zmniejszenie prądu rozruchu, którego wpływ na SE zwykle nie jest monitorowany i nie są stosowane urządzenia zabezpieczające.*