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INVESTIGATION OF THE INFLUENCE OF VSD ON THE POWER DISTRIBUTION NETWORK

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ABSTRACT:
Nowadays power converters present commonly used devices. However they negatively influence power grid and fed devices as well. The main attention is given to uncontrolled rectifiers with capacitive load as an input part of indirect frequency converters (in common use for variable speed drives - VSD).This paper presents physical background of negative influences of power converters on power network with focus to the low frequency interference. Generation causes of non-characteristic harmonics and interharmonics are explored and discussed in detail. Extensive series of simulation are provided and compared with experimental results. This research offers missing background for standards covering low-frequency EMC.

KEYWORDS:
Harmonic Analysis, EMC, Harmonics, Fourier Series, Power Converters, VSD

1. INTRODUCTION

Nowadays a lot of attention is given to the negative effects of semiconductor devices on the distribution network from the electromagnetic compatibility point of view. As the power electronic converters find wide application in power systems, power quality is becoming a more important issue to consider. The operation of indirect frequency converters with IGTB (see Figure 1) brings a lot of advantages (possibility of new control methods of VSI, using new steering algorithms etc.), but it is often accompanied by some unfavourable effects (e.g. [2], [9]-[11]). The converter adversely influences the power distribution network due to non-sinusoidal taken current, fed motor by transient motor overvoltage and converter control circuits as well. 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 problems concerning characteristic harmonic currents of converters, their causes, negative effects in the power distribution network and ways to minimize them, are relatively well-known (e.g. [1],[2],[6]). There has been less attention paid to non-characteristic and interharmonic current components in practice and the literature (e.g. [2]-[5],[7],[8],[11]). These frequency components are transferred to the power grid, where they can cause distortion of supply voltage, disturbance of connected equipment (e.g. ripple control devices, compensation units), etc.

This paper looks mainly at the uncontrolled diode bridge rectifiers with capacitive load, which is employed as an input part of the indirect frequency converters for supplying voltage source inverters (in common use for variable speed drives).

According to standards the low-frequency interference is considered on a frequency range 2.5 kHz and the frequency components can be defined as follows:

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 f1 is the fundamental frequency of power system (50 Hz).

2. THREE PHASE UNCONTROLLED BRIDGE RECTIFIER

In the case of the indirect frequency converter with voltage source inverter (see Figure 1), we can divide the circuit into inverter part and rectifier part supplying capacitor in the DC Bus.

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

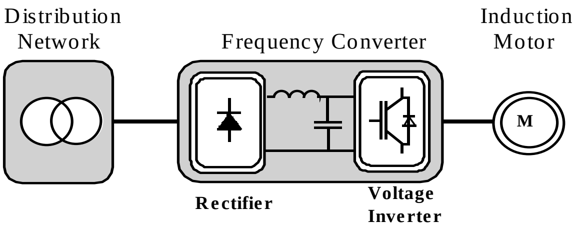

Figure 1. Block diagram of the variable speed drive (VSD) with frequency converter

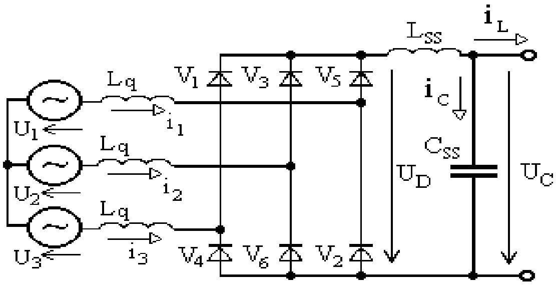

Figure 2. Three-phase bridge rectifier configuration

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

Amplitude Im is constituted that the area of both currents will be identical for the same parameter d (where d is a diode conduction time).

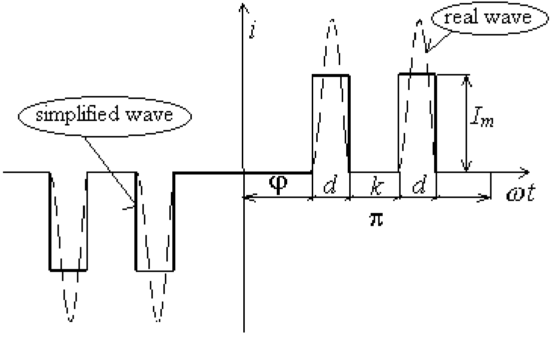

Figure 3. Real and simplified phase current wave

From the figure it is obvious that used simplification is rough in commensurate with the value of parameter d. The error of using simplification decreases with the 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 Figure 3 is symmetrical odd function, coefficients a_h are zero and we can only solve coefficients b_h:

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

After editing we will get:

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

For symmetrical power network is valid d+k=600 and relation (2) we can convert to:

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

The Back expression of current i by Fourier progression is:

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

For higher current harmonics amplitudes are valid:

$$I_h = \frac{1}{h} I_1 \cdot \frac{\sin\frac{hd}{2}}{\sin\frac{d}{2}} \qquad (5)$$

where (6)

$$I_1 = \frac{8I_{fm}}{\pi}\cdot\sin\frac{d}{2}\cdot\cos\frac{\pi}{6} = 2{,}205.I_{fm}.\sin\frac{d}{2}$$

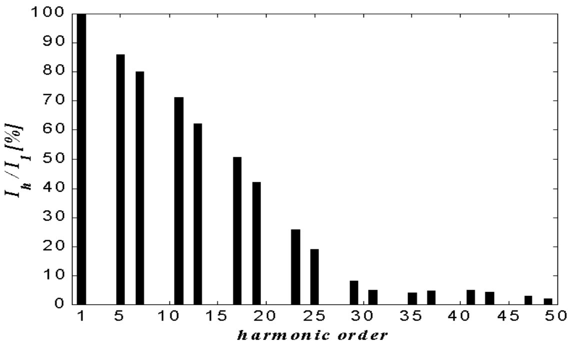

Figure 4. Frequency spectrum of ideal current wave

When we use the relation (4), we find out that only harmonics of a definite order (5., 7., 11., 13. etc.) will appear on a frequency spectrum (Figure 4). These harmonic orders are called characteristic harmonics and their amplitudes are solved by an equation (5).

3. NON-CHARACTERISTIC HARMONICS

Under real conditions, unbalanced power source - amplitude or phase non-symmetry, the considered problem becomes more complicated and we can find also non-characteristic components in the frequency spectrum. In contrast to characteristic harmonics for calculation amplitudes of non-characteristic harmonics we can not use equation (5) and we have to apply numerical Fourier analysis (DFT or FFT) for investigation of frequency spectrum of a taken current. Voltage and current circumstances at single phase voltage power source non-symmetry you can see in Figure 5.

Power source non-symmetry causes distortion of phase currents and drift of basic harmonic wave of phase current against phase voltage.

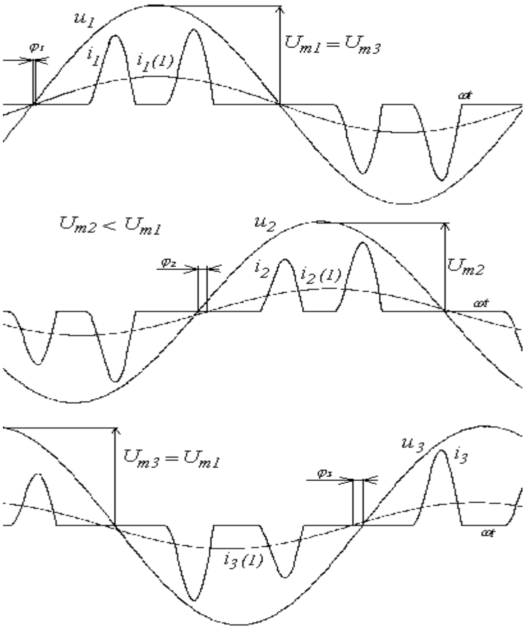

Figure 5. Voltage and current waveforms at single phase voltage source non-symmetry

The frequency spectrum of phase current from Figure 5 contains non-characteristic harmonics of an odd multiple of three only (Figure 6) and their amplitudes depend on the value of voltage source non-symmetry (Figures 7-8).

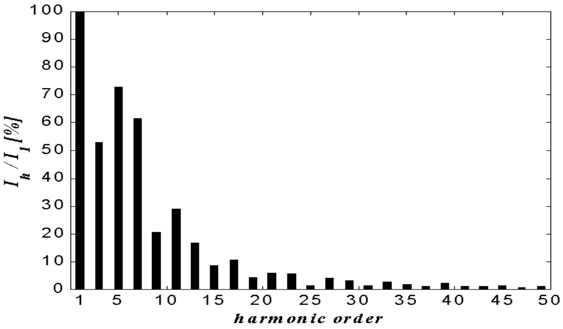

Figure 6. Frequency spectrum of taken phase current at 3% power source non-symmetry

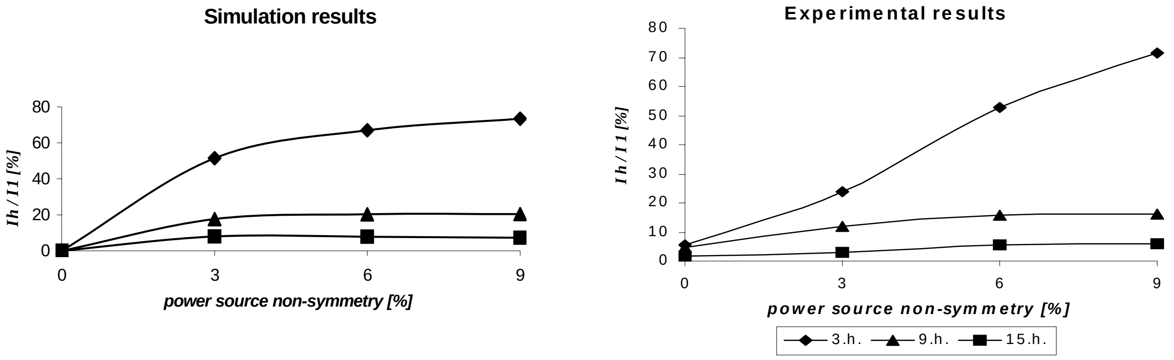

Figure 7. Non-characteristic harmonics in dependence of voltage power source non-symmetry

The value of non-characteristic harmonics increases with voltage non-symmetry and it results in low decrease of characteristic harmonics. A drop of dominant harmonics has influence on coefficient THDi (small decrease), but higher increasing of third harmonic causes a low rising of coefficient THDi

(Figure 8). In the following figures you can see a comparison of simulation and experimental results. The measurement of harmonic components was carried out according to the scheme in Figure 1 and has been measured by a frequency analyser.

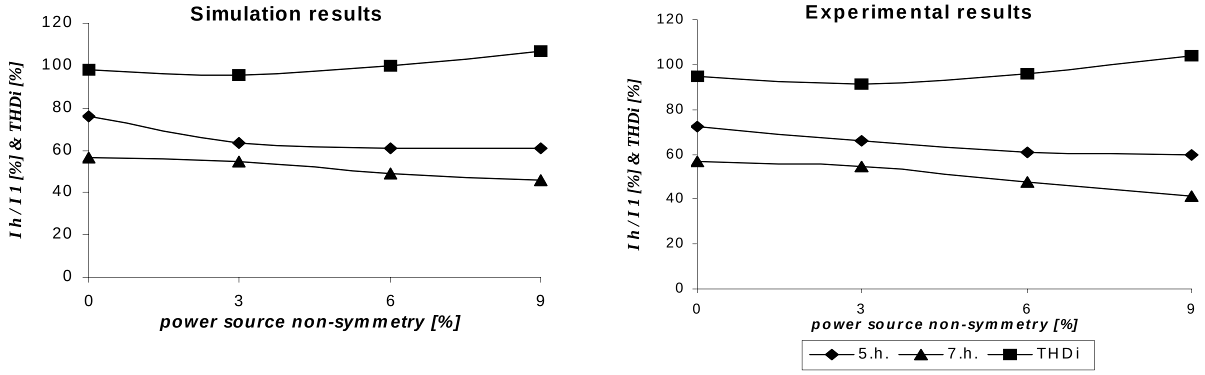

Figure 8. Characteristic harmonics and THDi in dependence of voltage source non-symmetry

Waves of quantities in Figures 7-8 are displayed for definite circuit configuration (Lq, L_{SS}, C_{SS}, diode voltage drop etc.). It is obvious that a change of these circuit parameters influences phase currents and consequently values of harmonics. Dependence of non-characteristic and characteristic harmonics on circuit parameters L_{SS} and C_{SS} is shown on Figures 9-10.

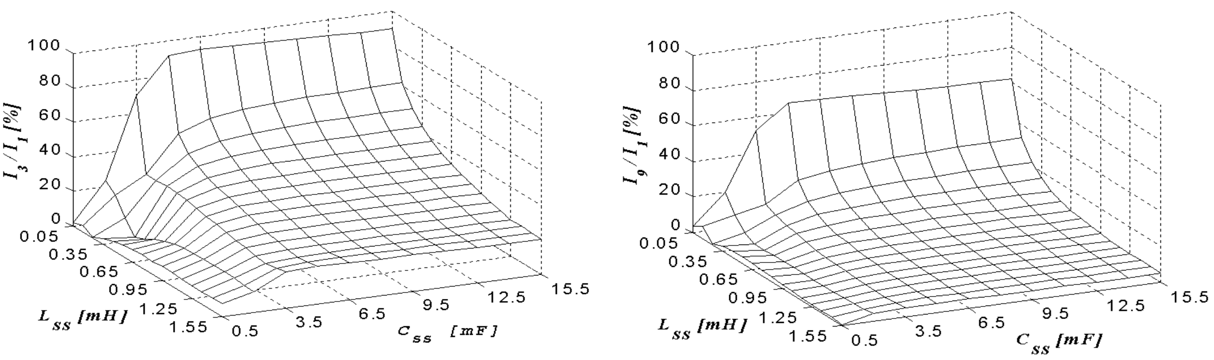

Figure 9. Non-characteristic harmonics in dependence of parameters L_{SS} and C_{SS}

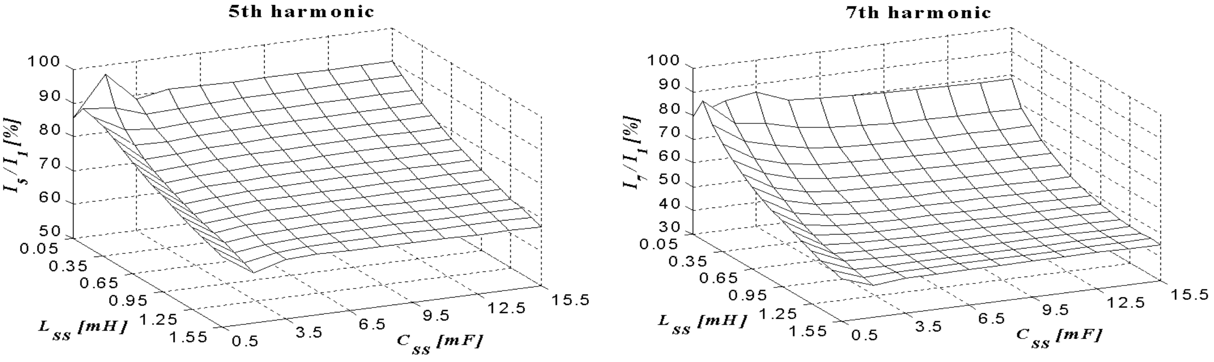

Figure 10. Characteristic harmonics in dependence of parameters L_{SS} and C_{SS}

4. INTERHARMONICS

Except characteristic and non-characteristic harmonics discussed in the previous paragraph, we can also find interharmonic components in frequency spectrum of consumed current (see Figure 11). The interharmonics occur as a consequence of dynamic changes of circuit parameters (power supply voltage dips, load variation, control interventions (machine start-up, speed reversal transient - generally feedback controller impact, etc.). The interharmonic current magnitudes are relatively small in comparison with characteristic and non-characteristic harmonic components, but they may impact the proper function of neighbouring appliances (e.g. interference of ripple control and tuned filters).

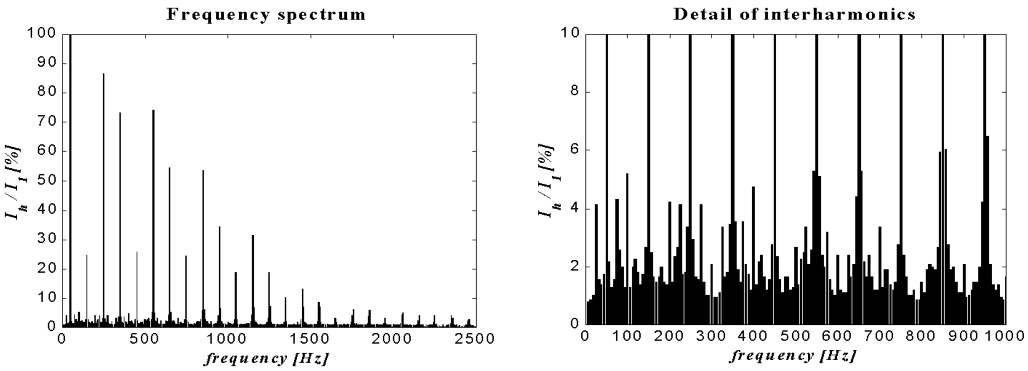

Figure 11. Measured frequency spectrum of phase current

At first, the impact of single phase voltage change on the interharmonics is explored. In case of single phase voltage change, we will change the amplitude of the second phase (Figure 12) and appropriate frequency spectrum is in Figure 13. Size of voltage change ΔU has a major influence on the interharmonics and it is determined in percent of phase voltage amplitude within the calculation window.

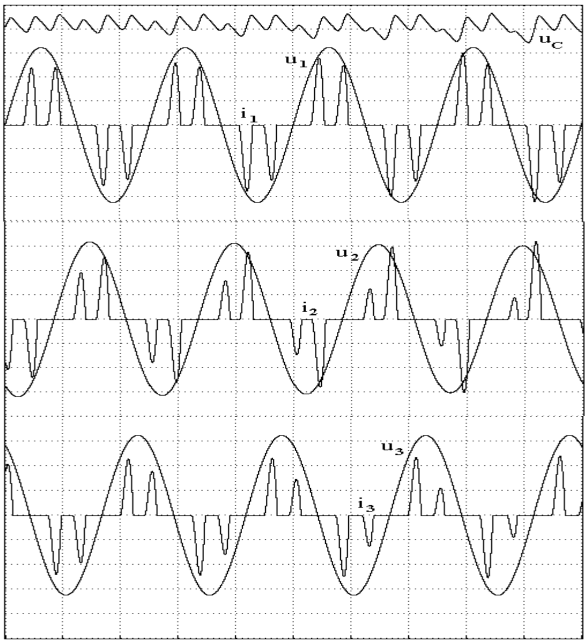

Figure 12. Voltage and current waveforms under single phase voltage source change (ΔU = 8.8 % ≅ 29 V)

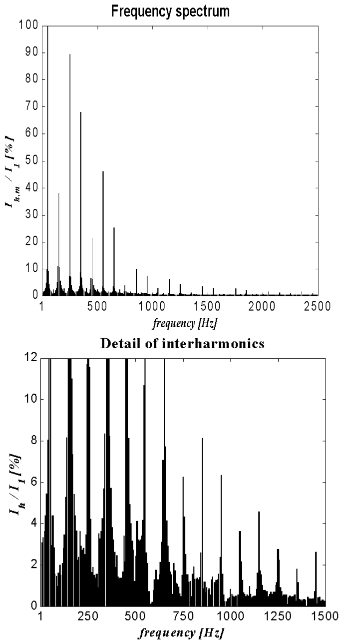

Figure13. Interharmonics under ΔU = 8.8 % ≅ 29 V

Due to single phase voltage change, current waveforms are heavily distorted that appears at frequency spectrum of interharmonics. Also the DC bus voltage is distorted - bigger ripple and lower pulsation (from six pulses it floats to four pulses). For higher ΔU, high distortion of phase currents changes the classical double pulse waveform of phase current changes to a single pulse waveform (Figure 12 – second phase).

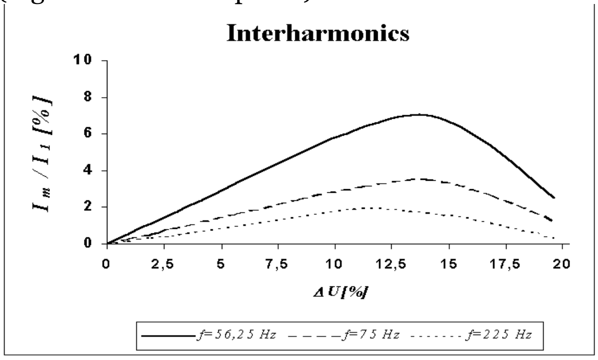

Figure 14. Dependence of interharmonics on voltage decrease under single phase voltage change

This pulse change of phase current has a good influence on interharmonic components and they decrease with increasing ΔU. On the other hand it has an unfavourable effect on harmonic components, mainly on the third non-characteristic harmonic (as can be seen on Figure 13), which essentially increases.

In case of three phase voltage change, we will change the amplitudes of all three phases of the power source.

Figure 15 illustrates the dependence of interharmonic currents on three phase voltage change.

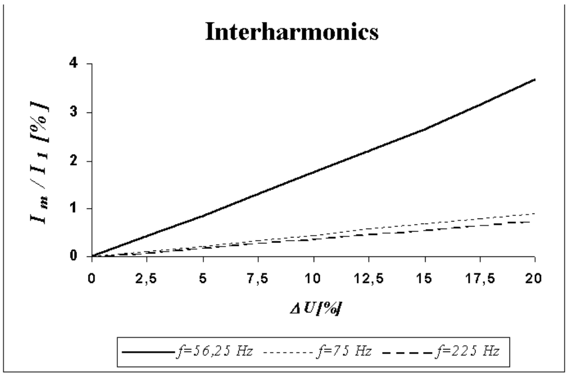

Figure 15. Dependence of interharmonics on voltage decrease at three phase voltage change

The graph in Figure 15 presents the increase of interharmonic currents with higher ΔU (almost proportional dependence according to the three phase symmetrical change).

5. CONCLUSION

This paper described the behaviour of the three phase uncontrolled bridge rectifier from the Electromagnetic Compatibility (EMC) point of view with respect to low-frequency interference. The first issue of this paper is non-characteristic harmonics. These frequency components arise due to an unbalanced condition in the power grid (such as unbalanced voltage). The second important part of this contribution focused on the interhamonics. The interharmonics occur as a consequence of dynamic changes of circuit parameters (power supply voltage dips, load variation, control interventions (machine start-up, speed reversal transient) - generally feedback controller impact).

In the real power systems the waveforms of consumed currents are always affected by combinations of many influences. It is not easy to distinguish, which effect causes an increase of each individual non-characteristic harmonic and interharmonic component. Consequently power source non-symmetry and other influences were considered separately.

The paper presented the physical and mathematical background of both non-characteristic harmonics and interharmonics. Generation causes were explored and discussed in detail. Major factors affecting the consumed current (Unbalanced Power Source, DC Bus CSS and LSS, dynamic changes) were described. Extensive series of simulation were provided and compared with experimental results. The measurement difficulties were discussed (measurements were performed in compliance with actual standards).

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