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The Measurement and Analysis of Harmonics and Interharmonics in Output Waveforms of Frequency Inverter. Part II

Abstract

The paper discusses the measurement and analysis of the voltage and output power distortions of frequency inverter that supplies an induction motor. It covers basic information regarding frequency inverters and norms with definitions and descriptions of terms related to the measurement of harmonics and interharmonics. Moreover, it describes the problems that can occur while analyzing the signal when the inter-harmonics are present during the measurement. Exemplary results of measurements done with power quality analyzer in the laboratory have been presented.

Keywords: interharmonics, inverter, power quality analyzer, measurements.

1. Introduction

With the development of electronics new opportunities arose to multiple common facilities. A good example is an induction motor with its extremely simple structure, high efficiency and reliability, having one fundamental drawback - lack of a simple, ordinary possibility of speed regulation. Owing to the introducing of frequency inverters, that disadvantage has been eliminated and a simple rotational speed regulation of induction motors became possible. Unfortunately, a motor supplied by frequency inverter is a totally nonlinear unit degrading power quality by introducing of harmonics and interharmonics. Adding of nonlinear units to an electrical system always causes deterioration of power quality and generation of extra loss.

Power quality is evaluated in accordance with legal regulations – applicable norms determine admissible values of parameters that characterize power quality [1, 2] and others describe the methods of their measurement and analysis [3, 4]. For example the harmonics and interharmonics occur among these parameters-their presence in electrical system can cause a series of undesirable situations. An extended description of reasons of why harmonics and interharmonics appear and effects of their occurrence can be found in papers [5, 6], methods of location theirs sources describes the work [7]. The most frequent effects of harmonics and interharmonics occurrence are: thermal effects, distortions in control and security systems, energy overload, low-frequency oscillation in motor systems, disruptions in electronic devices operation or telecommunication interference [5, 6].

Problems with measurement of harmonics and interharmonics are discussed in most of works that regard the studies on power quality [8, 9, 10]. There is also a number of works devoted only to measu-rement and analysis of harmonics and interharmonics [11, 12, 13].

2. Lab Research Area

The area used for research comprises two electric machines: induction motor (AC approx. 2.2 kW) and servomotor (approx. 1.2 kW) of coupled and set in a joint bed. Servomotor is a load for the induction motor which is supplied with Commander SK frequency inverter. Commander SK performs control in the open loop of reverse coupling in accordance with a sensorless, actual field vector orientation enabling full torque and speed control by an automatic compensation of torque and lost motion [14]. The output signal is achieved by means of pulse width modulation method - PWM (Fig. 1).

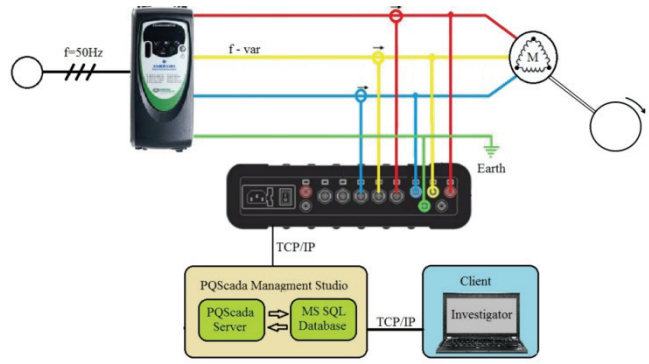

Fig. 1. Schematic of the measuring system

Thanks to the special construction of the research stand it is possible to perform measure-ments easily by using a power analyzer. Measurements were done with Elspec Blackbox G4500 device, microprocessor –controlled power quality analyzer class A. The device has 11 measurement channels enabling the measurement of voltages and currents in each phase according to the scenario chosen or defined by the user. In each period the voltage is sampled 1024 times which allows for analyzing up to 511 harmonic components. The current channels are sampled 256 times in a period, and the analysis of harmonics is possible up to as much as 127th component. Moreover, the device allows for the interharmonic analysis. The analyzer enables to register parameters of power quality with accordance to the EN 50160 and IEC 61000-4-15 norms [15]. Complete analysis of data gathered in the system PQScada can be executed using dedicated PQInvestigator software.

PQScada software enables view, control, analyze, and monitor multiple measurement devices simultaneously. Data is accurately time-synchronized within and across sites. The PQScada server is the heart of the data management and analysis system. The main task of the PQScada server is downloading, processing and storage of data [16].

Elspec Investigator is a client application that communicates, receives, and displays data from the PQScada Server system. This software allows, besides the review of events, the study of the different variables through graphs and the creation of automatic reports complying with a standard EN 50160. One of the important advantage of this system is that it is based on the Microsoft SQL Server [17].

The application allows for visualization and processing of data, as well as for creating discretionally tabulations.

3. Measurement Results

Measurements were performed in the lab research stand described above. Setting different values of output inverter frequency, the occurrence of harmonics and interharmonics in the output current and voltage of inverter was submitted for analysis. Measurements were done for frequencies 49.6 Hz; 53.7 Hz; 57.6 Hz; 61.6 Hz; 45.8 Hz; 42.5 Hz.

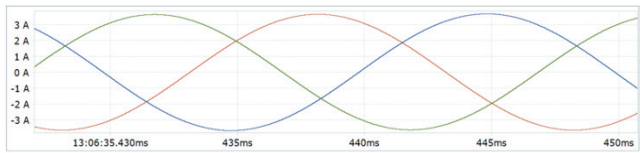

Fig. 2. Inverter output current waveform for *f*=49.7 Hz

Fig. 2-3 present the results of measurements and analyzes for the output inverter frequency equal to 49.7 Hz (system frequency). The current waveform is practically undeformed (Fig.2); it is proved by its spectrum (Fig.3), in which the amplitude of the highest harmonic constitutes around 0.11% of the fundamental harmonic.

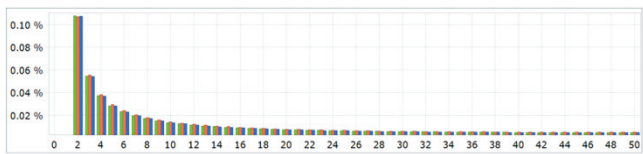

Fig. 3. Spectrum of higher harmonics of inverter output current for *f*=49.7 Hz

Voltage waveform (Fig. 4) features big distortions. In the signal spectrum achieved in accordance with the IEC 6100-4-7 norm [4] the dominant components are the fundamental harmonic, from the high ones it is the third harmonic; other components have insignificant values (Fig. 5). *THD* coefficient which was selected for the voltage waveform achieves the value of 24.5%. In the spectrum of interharmonics (Fig. 6.) the components that dominate are the first, second and third constituting respectively 5.9%, 3.5%; 2.3% of the fundamental harmonic component (13.5 V; 8 V; 6 V).

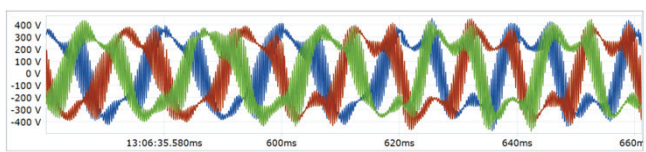

Fig. 4. Inverter output voltage waveform at *f*=49.7 Hz

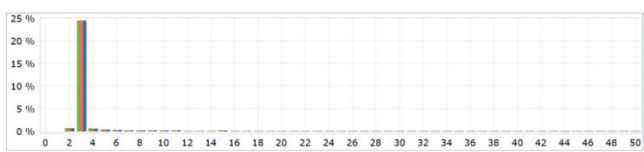

Fig. 5. Spectrum of higher harmonics of inverter output voltage, f=49.7 Hz

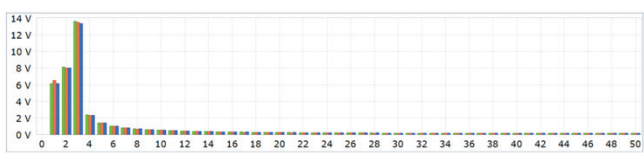

Fig. 6. Spectrum of voltage interharmonics for the output inverter, *f*=49.7 Hz

Analogous measurements and analyzes were conducted for the other frequencies studied. It has been found that regardless of the output frequency value of inverter the current wave distortion is extremely low so this value will be omitted in further parts of the study.

In case of 53.7 Hz frequency, in the spectrum achieved in accordance with the norm regulations (Fig. 7) practically only the first and third harmonic have an impact on the shape of voltage waveform (Fig. 8a.) show that its components are of high frequencies and amplitudes, and signal *THD* equals 18.1%. In case of this frequency, the second interharmonic has high value of 38 V (16.5%) and lower, but significant one are the first and third interharmonic having respectively values of 9. 8V (4.3%) and 14.7 V (6.4%) (Fig. 8b).

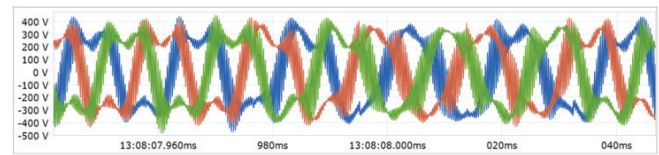

Fig. 7. Inverter output voltage waveform at *f*=53.7 Hz

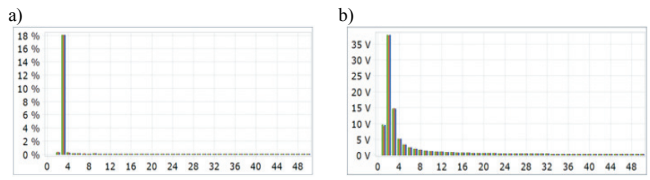

Fig. 8. Spectrum of harmonics (a) and spectrum of interharmonics (b) of inverter output voltage, *f*=53.7 Hz

A visual analysis of voltage waveform at the frequency of 57.5 Hz (Fig. 9) fails to allow for noticing significant differences when compared to the waveforms that have been analyzed above. However, the spectrum (Fig. 10a) achieved in accordance with the norm [4] contains more significant components. Among the higher harmonics, the first and fiftieth one have the value of about 41.4 V (18%) while the fortieth having around 20.7 V (9%), *THD* of the signal equals 27%. Similarly, the spectrum of interharmonics (Fig. 10b) contains higher spectrum of components when compared to the previously analyzed examples. Apart from the first component (10 V - 4.3%), second (37.5 V – 16.3%), third (17.5 V–7.6%) higher interharmonics appeared; the ones having significant values are: forty-eight (15 V – 6.5%), forty-ninth (15 V – 6.5% and fiftieth (38.5 V – 16.7%).

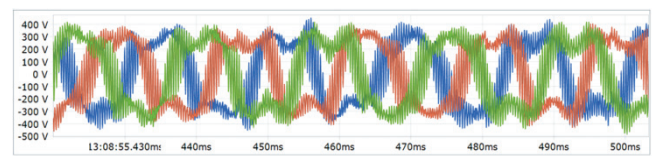

Fig. 9. Inverter output voltage waveform at *f*=57.5 Hz

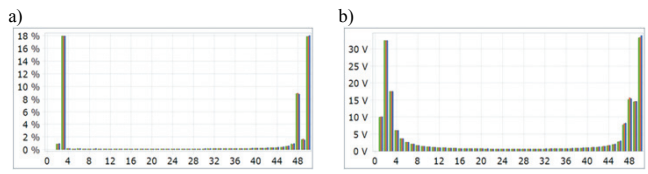

Fig. 10. Spectrum of harmonics (a) and spectrum of interharmonics (b) of inverter output voltage, *f*=57.5 Hz

Further studies were conducted for the inverter output frequency equal to 61.6 Hz. In the voltage waveform (Fig. 11) the third harmonic is significant, as approved by the harmonics spectrum (Fig. 12a). In the waveform, the occurrence of high frequency components is also visible, that are probably located outside the measurement display, determined by the norm [4], as they are absent in the spectrum. Additionally, it can be noticed that minor components appear nearby the forty-fifth to fiftieth harmonic that is visible in the signal spectrum (Fig. 12a). The spectrum of interharmonics (Fig. 12b), apart from the components first, second and third, contains components of very high values, from the forty-

fourth to fiftieth having values from around 15 V to as much as 60 V.

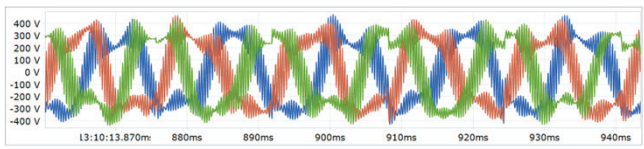

Fig. 11. Inverter output voltage waveform at *f*=61.6 Hz

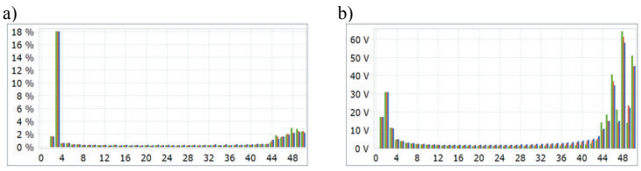

Fig. 12. Spectrum of harmonics (a) and spectrum of interharmonics (b) of inverter output voltage, *f*=61.6 Hz

Further studies were conducted for the frequency of 45.8 Hz. Voltage waveform (Fig. 13) features a significantly deformed sine wave with a significant occurrence of the third harmonic and harmonics of very high frequencies. On the spectrum of harmonics (Fig. 14a) we can notice that the third harmonic has a high value (20% - 46 V), while there are no other components visible. *THD* of the signal equals 20%. In the spectrum of interharmonics (Fig. 14b.) the dominant components are the first, second, third and fourth one respectively of values 8.5 V, 17 V, 36 V, 8 V.

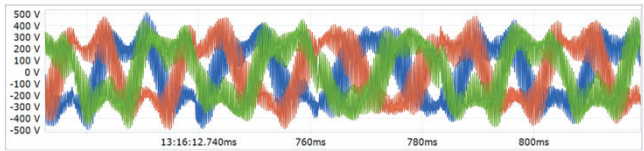

Fig. 13. Inverter output voltage waveform at *f*=45.8 Hz

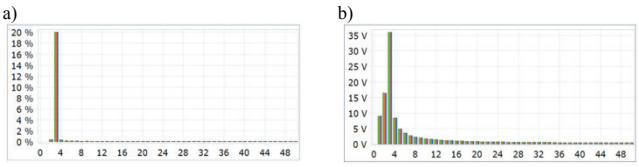

Fig. 14. Spectrum of harmonics (a) and spectrum of interharmonics (b) of inverter output voltage, *f*=45.8 Hz

The last frequency that has been studied was the 42.5 Hz frequency. Voltage waveform (Fig. 15) is similar to the waveforms at different frequencies; however a greater blur can be observed. It probably indicates a greater influence of components that have high frequencies. In the spectrum of signal (Fig. 16a) limited in accordance with the norm [4] up to 40 components, a dominant one is the third and the one of low value is the fourth component. *THD* of voltage equals 21%. The spectrum of interharmonics (Fig. 16b) shows that a greater impact on the current waveform has the first, second, third and fourth component respectively of values 7 V, 17 V, 35 V, 16 V.

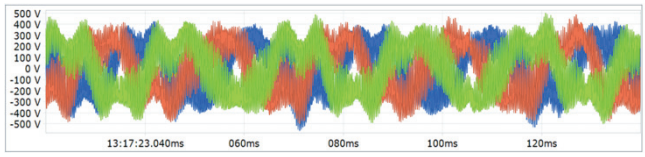

Fig. 15. Inverter output voltage waveform at *f*=42.5 Hz

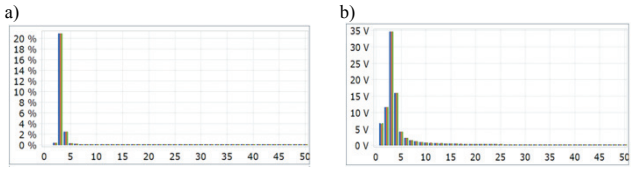

Fig. 16. Spectrum of harmonics (a) and spectrum of interharmonics (b) of inverter output voltage, *f*=42.5 Hz

4. Conclusions and Observations

The paper discussed the studies of the character of waveforms for output voltages and currents of frequency inverter that supplies the induction motor, for six various frequencies. Having conducted the studies, the following conclusions have been formulated:

- Output currents of inverter that supplies induction motor are practically undeformed;
- Output voltages of inverter are significantly deformed, *THD* is higher than 20% in each case;
- In the spectrum of voltage harmonics, the third component is definitely the most dominant, other components in most cases are insignificantly low. In the upper parts, away from the frequency of 50 Hz the occurrence of the components from the top range of analyzed frequencies can be observed (according to the norm [4] the analysis covers 40 harmonics);
- In the bottom parts, away from the frequency of 50 Hz voltage, waveforms become more blurred which indicates a greater influence of components with very high frequencies. In the spectrum, these frequencies are not visible as they are probably higher than the ones mentioned in the norm, and thus they are excluded from the analysis;
- In the spectrum of interhamonics, the first, second and third one always has high values. In the upper parts, away from the frequency of 50 Hz, it can be observed that very big components from the top range of the analyzed frequencies appear (in accordance with the norm [4] the analysis covers 40 harmonics);

Analysis of deformation waveforms of electrical frequently limited to harmonic analysis and *THD* to the 50th harmonic (standard [4]), interharmonics analysis are carried out less frequently. Examples presented in work shows clearly that such an approach can be a source of large errors.

5. References

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