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POSSIBILITIES FOR DETERMINING THE INTERFERENCE BETWEEN A POWER SUPPLY NETWORK AND A CONVERTER FED DRIVE*

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Abstract: Measuring instruments, measurement methods, and an exemplary analysis of the impact of chosen operating stages of the converter drive on the power supply network have been presented. The measurements of electrical and mechanical parameters in drive systems used in industry are complex. The task is difficult due to the necessity of connecting a measuring instrument into electric circuits of an active facility with the use of only short non-operational periods of the device. However, a well-chosen model of a drive system allows the multivariate research of the impact of drive parameters and a control algorithm used on voltage and current harmonic content and performance of the system, and therefore on a simulation analysis of the impact of the drive on the power supply network.

Keywords: *power quality, converter drives, voltage and current measurements*

1. INTRODUCTION

The determination of the impact of a drive on the power supply network and possible determination of the impact of the network on the drive are complex and in some applications could be critical [1]. The complexity of the task results from the necessity of acquiring appropriately advanced measuring instruments and of employing methods of analysis concerning advanced drives. The methods of analysis should be based on appropriately advanced software that allows the simulation of the drive behavior in its key operating stages while taking into account all significant phenomena occurring in the drive. Measuring systems used should provide small measurement errors and a high measurement frequency. The high measurement frequency is especially relevant in the case of converter drives. It is also relevant to obtain measurements in a limited time, especially in industrial conditions.

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This article is dedicated to demonstrating measurement capabilities of the Institute of Electromechanical Systems and Industrial Electronics and the Faculty of Electrical Engineering, Automatic Control and Informatics of the Opole University of Technology. These capabilities, along with the software acquired, allow the multivariate analysis of the impact of the drive on the power supply network. The key to the multivariate analysis is to determine the parameters of the drive properly. In the case of this type of analysis, it is possible to determine the parameters of the drive using an off-line method. However, in converter drives, it is also necessary to exactly determine the algorithm used for controlling power electronic elements. The determination of the drive parameters and control algorithm allows a substantial reduction of the number of necessary measurements.

The measurement system was designed to meet high requirements in terms of the number of simultaneously measured channels (16 channels), the sampling (up to 1 MS/s sample and hold) and duration of a measurement. These also concern the aspects of security measures in the system for the range of voltages measured (up to 50 kV without capacitor voltage transformers) and currents (up to 2 kA). Additionally, all measurements were done in class A.

This article presents the analysis of the impact of a medium-power drive on the power supply network. A 20W39MX heating pump is powered by an SEE 355 ML type asynchronous motor, which is located in the drive. The paper is organized as follows: In Section 2, one of the measuring systems has been described, in Section 3, the model of the converter drive system has been analyzed and the method for its simulation briefly presented. In Section 4, the multivariate results of the analysis of the impact of the drive on the power supply network have been presented, Section 5 is a summary.

2. SYSTEM FOR MEASURING CONVERTER DRIVES

In the Institute of Electromechanical Systems and Industrial Electronics of the Opole University of Technology, a measuring system for measuring dynamic states in power supply networks and drive systems was developed. The modular measuring system is composed of [2]:

- National Instruments components, assembled on the NI PXIe-1062Q chassis, comprising two measuring cards with A/D NI PXI-6133 converters (sampling rate 2.5 MS/s synchronically in all 16 channels, 14-bit), an oscilloscope (digitizer) NI PXIe-5122 (100 MS/s in two channels, 14-bit), an NI PXI-7852R multifunction module with a FPGA XILINX Virtex-5 LX50 architecture, an NI PXIe-8130 controller (Fig. 1).
- a1 TB hard drive matrix, capable of real-time writing a data stream from 16 channels of the PXI-6133 cards at a rate of 400 kS/s.
- BNC 2120 shielded connector blocks which allow the measuring system to be connected by means of coaxial cables.

- An electronic visual display.
- Three-phase low- or medium-voltage dividers and appropriate medium-voltage fuses.
- The LEM current transducer (HOP2000-SB/SP1).
- The Phoenix Contract type MACX MCR-UI-UI-UP-NC isolating amplifier [3, 4] that allows the conversion of any automatic signal into any other signal and simultaneous retaining the isolation between the input and output of the signal.

Fig. 1. Measuring set in a portable box

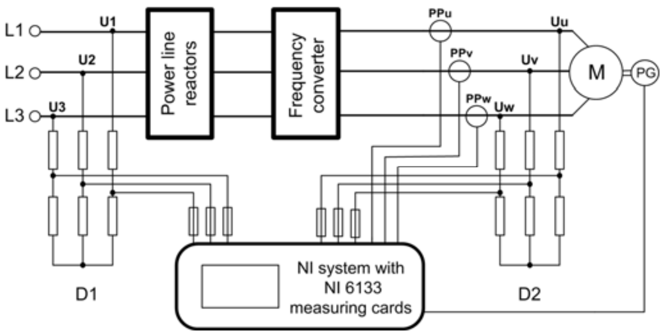

Fig. 2. Schema of the measuring system: PPu, PPv, PPw – Rogowski coils, PG – encoder

In addition, the software was capable of using the system abilities to collect data in real time. The reliability of the program is relevant here. It should allow reliable measurements in industrial conditions where it is often possible to take only a one-off measurement.

The measuring instrument was applied in configuration shown in Fig. 2. The scheme of the measuring system consists of an asynchronous motor of the SEE 355 ML type with the power of 315 kW driving a 20W39MX heating pump with the rated capacity *Q* of 550 m^3/h. The motor was powered by the VLT6400 Danfoss frequency converter. The device (Fig. 1) was tested in hard conditions, i.e. in the immediate vicinity of strong interference fields generated by high-power inverters (Fig. 3).

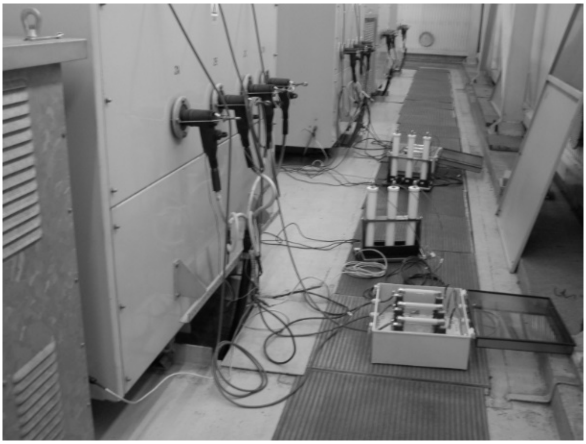

Fig. 3. Dividers with fuses incorporated in the drive circuits

An example of the result of measurements obtained by means of the measuring system visualized using a TDMS viewer is shown in Fig. 4.

Fig. 4. Example of the visualization of a part of the recorded waveforms in an electric drive

Data recording for measurements of converter drives in real time is only possible using the binary code (TDMS files), even when the type RAID hard disk matrix is used. In order to use these data in external programs, they have to be converted to ASCII, however. The size of measurement files often exceeds several GB, thus their handling is time-consuming.

3. MODEL OF THE ANALYSED CONVERTER DRIVE SYSTEM

The model used in the research includes the power track of a three-phase bridge rectifier and its commutations. Besides, the model contains the whole structure of the converter part of the drive. This allows consideration of all commutations between transistors and diodes inside the rectifier [5]. The monoharmonic model [6] of the asynchronous motor and the model of the system controlling the rectifier by means of the scalar control V/f = const were used [6, 7].

The calculations were made by a formalized variable structure method. The parameters resulting from the real characteristics of the pump were used to simulate the load. This allows the effective modelling of commutations inside the rectifier and energy losses resulting from these commutations. Considering the complex model is important because in the frequency converter, the voltage across the capacitor in the intermediate circuit changes. The change of this voltage depends on the rectifier and the amount of energy consumed by the inverter [5].

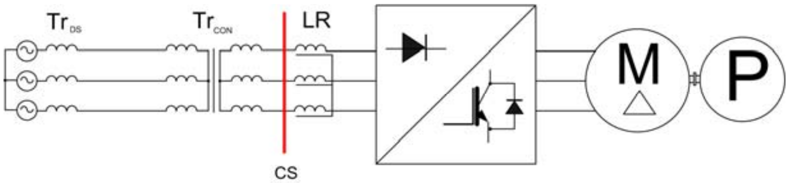

Fig. 5. Model of the drive and power supply network with a marked cross section (CS), Tr_{DS} – distribution transformer, Tr_{CON} – converter transformer, and LR – line reactors

The following simplifying assumptions were adopted for the construction of the mathematical model of a squirrel-cage asynchronous motor: the whole symmetry of the construction of the stator and rotor, the continuous distribution of the phase windings in the stator and rotor circuit, even air gap, the division of the magnetic flux into the main and the leakage, the linearity of the magnetic circuit, the sinusoidal distribution of the magnetic field in the air gap, and no changes in the distribution of the magnetic field with the saturation of ferromagnetic materials. Rotor parameters were viewed from the stator.

3.1. FORMALISED VARIABLE STRUCTURE METHOD

The algorithm follows a method of mesh analysis [8] and starts its operation for a system of differential equations which define all branches in the drive (network):

$$\mathbf{u}_B = \frac{d}{dt}\left(\mathbf{L}_B \mathbf{j}_B\right) + \mathbf{R}_B \mathbf{j}_B + \mathbf{v}_B \tag{1}$$

and a set defining the conducting stages of the power electronic components in the drive:

$$\sigma_{LB} = \{S_1, S_2, ..., S_n\} \tag{2}$$

where: $\mathbf{u}_B$ is the vector of branch voltages, $\mathbf{j}_B$ is the vector of branch currents, $\mathbf{L}_B$ is the inductance matrix, $\mathbf{R}_B$ is the resistance matrix, $\mathbf{v}_B$ is the equivalent vector of voltage sources. The branch equations are transformed by means of matrices **P** (transformation) and **D** (decomposition). This is obtained by means of $\mathbf{DPu}_B = \mathbf{0}$, thus creating closed loops, and $\mathbf{j_B} = \mathbf{P}^T\mathbf{D}^T\mathbf{i}_L$ by eliminating all elements which do not form the current state variables from the vector of branch currents. By applying the above substitutions, the final form of the state differential equations is obtained:

$$\begin{gathered}\mathbf{DPu}_B = \frac{d}{dt}\mathbf{DPL}_B\mathbf{P}^T\mathbf{D}^T\mathbf{i}_L + \mathbf{DPR}_B\mathbf{P}^T\mathbf{D}^T + \mathbf{DPv}_B \\ \mathbf{DPu}_B = \mathbf{0}, \quad \mathbf{DPL}_B\mathbf{P}^T\mathbf{D}^T = \mathbf{L}_L, \quad \mathbf{DPR}_B\mathbf{P}^T\mathbf{D}^T = \mathbf{R}_L, \quad \mathbf{DPv}_B = \mathbf{v}_L\end{gathered} \tag{3}$$

The automatic method for calculating branch voltages has been described in [8].

4. ANALYSIS OF THE IMPACT OF THE DRIVE ON THE POWER SUPPLY NETWORK

The methodology of the mathematical analysis of the impact of the drive on the power network is based on strategy presented in Fig. 6.

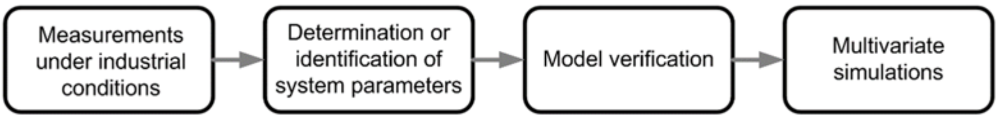

Fig. 6. Methodology of the measurements and mathematical analysis [5]

The total harmonic distortion (*THD*) was used in order to assess the impact of the system on the power supply network [9], whereas the calculated performance of the converter part of the drive system was used to carry out the economic assessment. The assessment was carried out for a variable value of the power line reactor parameters before the rectifier and for a variable load of the motor, which was achieved by a change in the modulation frequency in the inverter.

Based on the measured waveforms of the voltages and currents at the input and output of the rectifiers and the harmonic spectra, the performance of the converter part of the drive and the total harmonic distortion (*THD*) in the voltages and currents were calculated (Table 1, where f_s =3.5 kHz, η is the efficiency of the frequency converter).

The total harmonic distortion (*THD*) is defined as follows:

$$THD_U = \frac{1}{U_1}\sqrt{\sum_{n=2}^{40} U_n^2} \times 100\%, \quad THD_I = \frac{1}{I_1}\sqrt{\sum_{n=2}^{40} I_n^2} \times 100\% \tag{4}$$

Table 1. Selected parameters regarding the quality of operation of the drive

Power supply	THD_I [%]	THD_U [%]	η
Measurement			
Rectifier	60.24	6.60	0.977
Motor	6.02	8.48	
Model			
Rectifier	57.84	6.07	0.987
Motor	5.56	7.89	

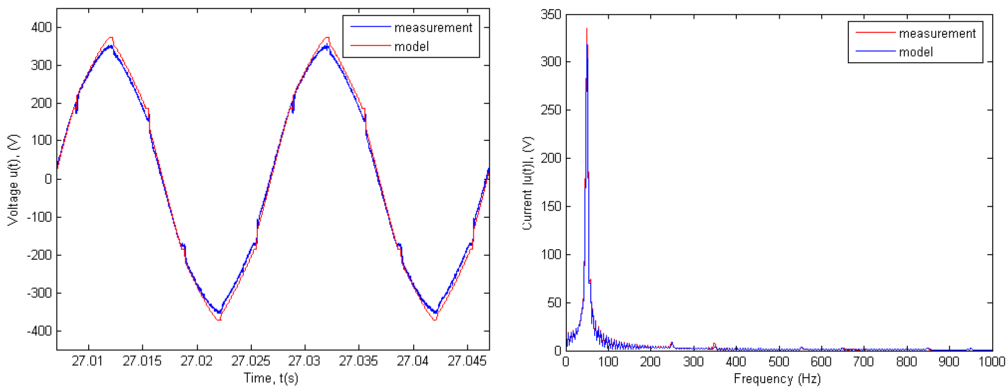

Fig. 7. Fragments of the voltage waveform (u_{L1}) at the input of the converter (left), and the voltage spectrum (u_{L1}) at the output of the converter (right)

The analyses of the results of measurement and of simulation allowed exact determination of the relevant parameters of the operation quality and the performance of the drive system. The results of measurement and those of the simulation are in fair agreement. The use of the proposed model of frequency converter makes possible calculating the efficiency of the converter part of the drive with a high probability.

The correspondence is clearly shown by the comparison of the waveforms of the voltages and currents at the input of the drive system of the frequency converter (Figs. 7 and 8) and the comparison of the currents that power the motor (Fig. 9). Such a high correspondence allows a reliable determination of the voltage and current spectra at the frequency converter power supply and the current spectrum at the motor power supply, thus determining the impact of the frequency converter on the power supply network and the motor.

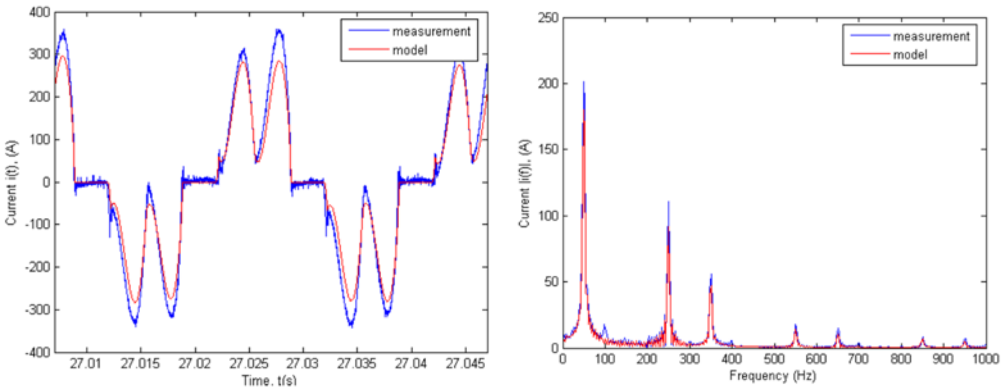

Fig. 8. Fragments of the current waveform (i_{L1}) at the input of the converter (left), and the current spectrum (i_{L1}) at the input of the converter (right)

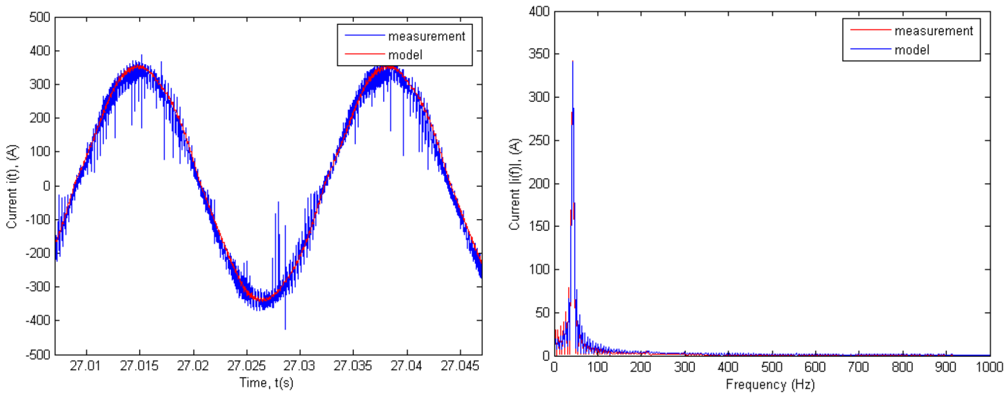

Fig. 9. Fragments of the current waveform (i_{L1}) at the output of the converter (left), and the current spectrum (i_{L1}) at the output of the converter (right)

The results obtained allow the analysis of the impact of the drive to be extended. Due to high concurrence achieved, it is possible to carry out this extended analysis based merely on the simulation results. Figure 10 shows the impact of the variable load of the frequency converter resulting from a variable rotational speed of the heating pump on the voltage and current waveforms at the frequency converter power supply. This impact was analyzed in the cross section between the power supply network and the power line reactors.

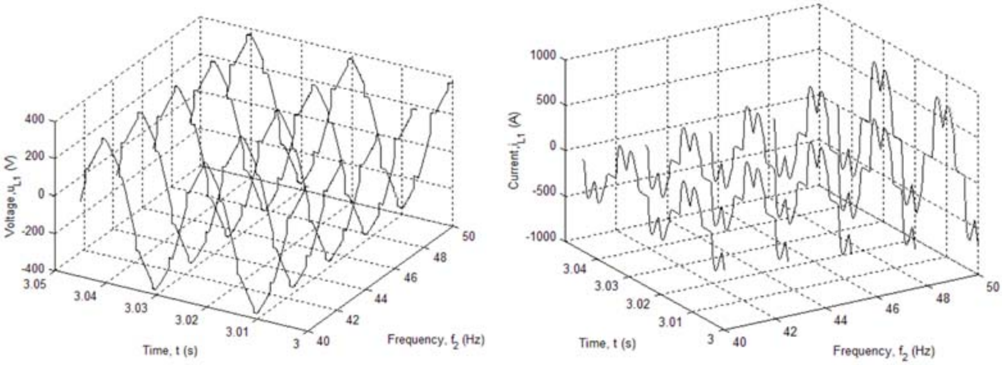

Fig. 10. Parts of the voltage u_{L1} (left) and current u_{L1} (right) waveforms in the cross section

The number values for this cross section are presented in Table 2. Numbers 0–1 in the table It is clearly shown that the value of the THD_I factor decreases as a result of the increasing load, whereas the value of the THD_U factor increases. Table 2 shows that this trend does not depend on the values of the parameters of the power line reactors used. It is also clearly shown that the increase in resistance and electrical reactance of the power line reactor has an effect on the reduction of harmonic content.

Table 2. Average values of THD_U and THD_I [%]
with respect to the line reactor parameters in the cross section (Fig. 5)

No.[a]	f_2 = 40 Hz		f_2 = 42.5 Hz		f_2 = 45 Hz		f_2 = 47.5 Hz		f_2 = 50 Hz	
	THD_U	THD_I	THD_U	THD_I	THD_U	THD_I	THD_U	THD_I	THD_U	THD_I
0	7.39	39.41	8.07	36.67	8.84	34.37	9.75	32.55	10.68	31.09
1	7.09	37.51	7.75	34.98	8.48	32.89	9.34	31.15	10.22	29.73
2	6.86	35.97	7.49	33.60	8.19	31.65	8.99	29.89	9.86	28.51
3	6.69	34.48	7.26	32.42	7.96	30.49	8.74	28.85	9.53	27.41
4	6.49	33.47	7.06	31.37	7.73	29.44	8.47	27.84	9.23	26.38

[a]Numbers 0–4 correspond to: 0 – L = 0 mH, R = 0 mΩ, 1 – L = 0.016 mH, R = 0.56 mΩ, 2 – L = 0.032 mH, R = 1.23 mΩ, 3 – L = 0.048 mH, R = 2.29 mΩ, 1 mean L – 0.064 mH, R = 3.59 mΩ.

5. CONCLUSIONS

The paper presents the methodology enabling the analysis of the impact of the converter drive on the power supply network as well as the impact of the network on the drive to be performed [4, 5, 8]. The key points in such an analysis are: the use of an appropriate measuring system that is chosen in terms of possibilities, the ability to take precise measurements, correct determination of drive parameters, simulation reflecting normal behavior of a system, determination of quality of operation parameters relevant due to the impact of the drive on the power supply network, and arriving at the right conclusions after the analysis. The comparison of the results of measurement with the results of drive simulation indicates that there is high correspondence between these waveforms, both in reference to the voltages and currents powering the frequency converter and the currents powering the motor. This is validated by the applied methodology, which allows the multivariate analysis of the impact of the converter drive on the power supply network and the possibility of analyzing the impact of the network on the drive.

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