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ANALYSIS OF THE INFLUENCE OF STATIC FREQUENCY CONVERTERS ON POWER QUALITY AND THE EFFECT OF USING ACTIVE FILTERS

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ABSTRACT

The assurance of the electric power quality and the monitoring of the level of disruptive emissions determine that the problems related to the limitation of electrical disturbances become one of the important concerns of the electrical energy specialists. The paper presents both the results of a laboratory study on how the frequency converters influence the level of voltage and current harmonics at the output of the converters, and the results and conclusions of the measurements that highlight the major improvement brought to the power quality indicators by equipping with an active filter the supply circuit of a high-power electric drive powered by a frequency converter. An important conclusion of the paper is that before making the decision to mount filters to limit the level of distortion, it is necessary to make a careful analysis of the solutions regarding the reduction of distortion even at the level of the disruptive equipment. Only if these measures are not enough, the solution of using active filters, although expensive, is very effective.

Keywords: power quality, frequency converter, active filter, data acquisition, total harmonic distortion, true RMS value

INTRODUCTION

The power quality represents a complex concept of estimating the electricity product expressed through a system of indicators that are determined by value for a point of the network and for a certain time interval. This set of indicators is important both for the energy user, ensuring the supply of consumers in good conditions, and for the energy supplier, supporting the good functioning of the energy systems.

The conditions currently imposed regarding the limitation of losses in the electrical network, the assurance of the electric power quality and the monitoring of the level of disruptive emissions determine that the problems related to the limitation of electrical disturbances become one of the important concerns of the electrical energy specialists. Currently, there are effective technical solutions for limiting the level of distortion to an accepted value by using specialized filtering equipment.

A high level of voltage and current harmonics can produce multiple faults in electrical installations, such as [1]:

- overloading and even failure of transformers and cables;
- overloading and failure of capacitor batteries;

- reduced efficiency of transformers and cables;
- overloading of electric motors.

The paper presents both an experimental study on how the static frequency converters (SFC) powering the induction motors influence the quality of the electricity transmitted to the final receiver, and the results and conclusions of the measurements that highlight the major improvement brought to the electricity quality indicators by equipping with an active filter the power supply circuit of an electric drive of significant power, powered by SFC.

EXPERIMENTS ON THE ELECTRIC DRIVE SYSTEM OF THE INDUCTION MOTOR FED WITH SFC

The experimental measurements were carried out on an electric drive system frequency converter - induction motor - working machine made in the Laboratory of Machines and Electric Drives from Petroleum-Gas University of Ploiești by using a data acquisition system with N114 DAQ board, aimed to:

- analysis of the three-phase voltage system produced by SFC;
- analysis of currents in the motor supply circuit.

Figure 1 shows the electrical scheme of the experimental drive system composed of:

- **S.F.C.** - frequency converter Lenze, type EVF 8245;
- **As. M.** - wound rotor three-phase induction motor (with nominal data 400V, star connection, 3kW, 920 rpm);
- **DC M.** – direct current machine with the role of an electromagnetic brake to obtain a load torque of various values;

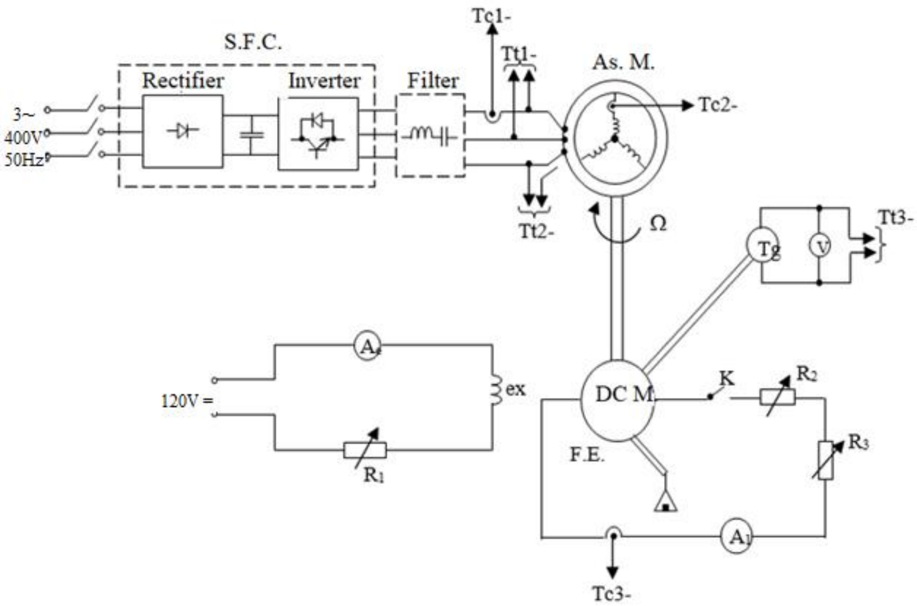


Figure 1. *The electrical scheme of the experimental drive system*

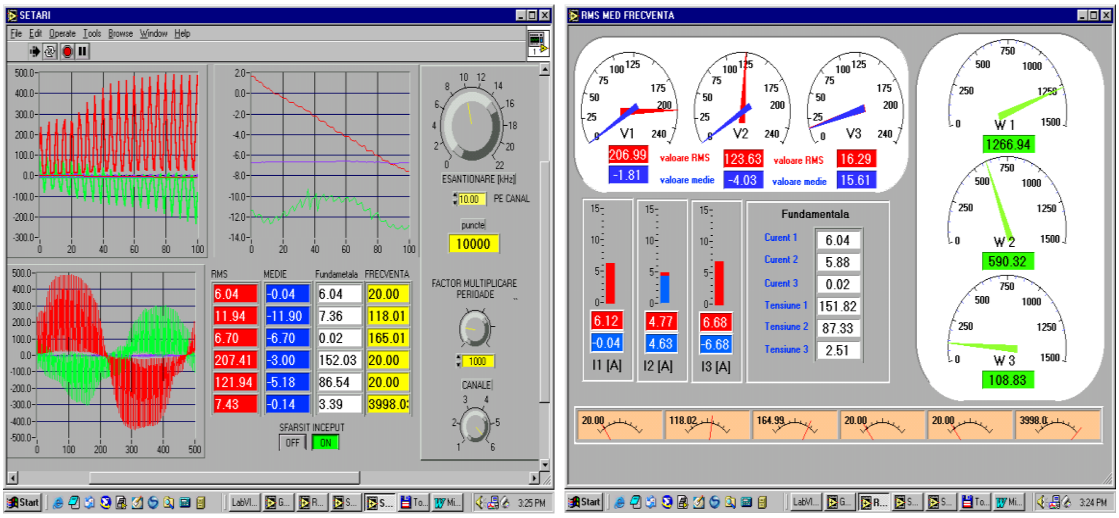
In order to carry out the actual measurements, a data acquisition system consisting of 3 voltage transducers (Tt1, Tt2, Tt3), 3 current transducers (Tc1, Tc2, Tc3) and a N114 type acquisition board was implemented and the schemes necessary for data processing and graphical presentation were created in the LabView environment [2].

The 6 acquired quantities are:

- the line voltage u_l and the phase voltage u_f at the SFC output;
- the motor speed, proportional to the u_{Tg} voltage at the electrical terminals of a tachogenerator;
- the stator current i_s and the rotor current i_r measured on a first phase of the induction motor;
- the load torque M_s, proportional to the rotor current of the d.c. machine with the role of an electromagnetic brake.

LABVIEW DIAGRAMS OBTAINED BY DATA ACQUISITION

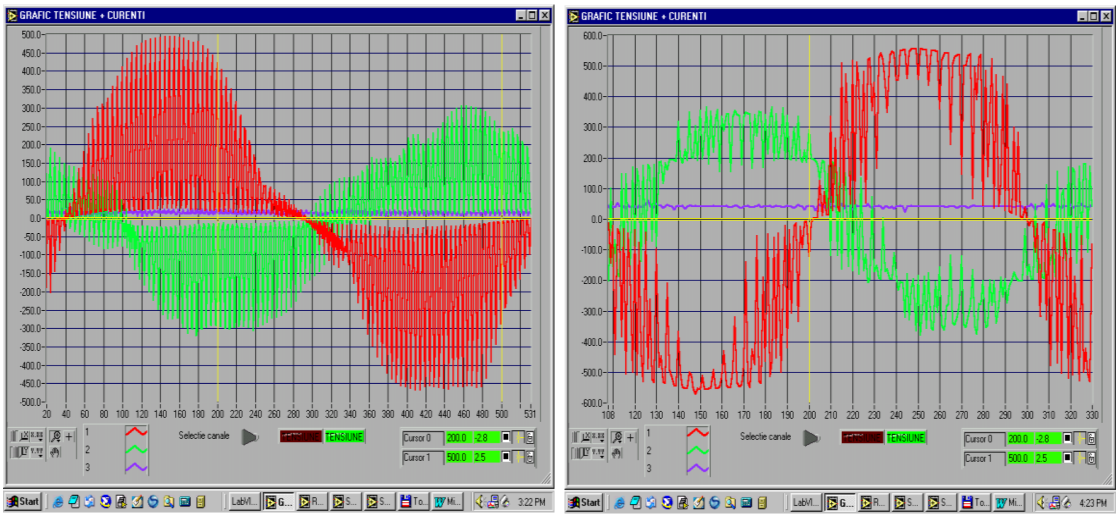
Measurements were made for the stationary operation of the electric drive system at 20, 30, 40, 50 and 75 Hz and at three different load torques M_{s0} = 0, M_{s1} = 7.64 Nm and M_{s2} = 15.28 Nm in turn. At each of the 15 measurements, made for a certain frequency and a certain torque, the obtained diagrams are shown in figures 2 and 3. The sampling frequency used in data acquisition is 10 kHz. Figure 2 shows, as an example, two diagrams obtained for a frequency of 20 Hz and a load torque M_{s2} = 15.28 Nm. Figure 2a shows the waveforms of the acquired voltages represented for 100 sampling points (10 ms), respectively 500 points (50 ms), the waveforms of the currents (on 100 sampling points), and in the diagram in figure 2b the true RMS value, the average value, the RMS value of the fundamental and the frequency for the acquired quantities are displayed.



a) b)

Figure 2. *LabView diagrams obtained for f =20Hz, M_{s2} =15.28 Nm*

Figure 3 compares the waveforms of the line voltage u_l (red colour), respectively the phase voltage u_f (green colour) obtained at the voltage frequency of 20 Hz, respectively 50 Hz, for load torque M_{s2}, similar diagrams corresponding to the other 13 cases studied being similar in form, but of course with different values.



a) b)

Figure 3. *LabView diagrams of u_l, u_f waves at M_{s2}=15.28 Nm: a) for f =20Hz, b) for f =50 Hz*

By analysing the voltage waveforms in figure 3 it can be observed that:

- they are strongly distorted compared to the sinusoidal form, showing an important deformation due to higher harmonics, the quantitative value of these distortions being indicated for the 15 distinct measurements in another paper by the author [2];
- the phase voltage variations follow the rectangular steps of values: -2U/3, -U/3, U/3 and 2U/3, whose theoretical reasoning is presented in the literature [3];
- the conduction - blocking intervals of the inverter arms, obtained by the PWM technique, can be distinguished [4].

ANALYSIS OF THE STATOR AND ROTOR CURRENTS OF THE INDUCTION MOTOR

From the Labview diagrams in figure 2 the following quantities were extracted in Table 1:

- the true RMS values of the stator and rotor currents, denoted I_s and I_r;
- the RMS values of the fundamental of the stator current $I_s^{(1)}$ in the 15 analyzed stationary regimes.

For the stator currents, the following quantities were calculated and entered in the table:

- *the deforming residue of the stator current*, defined by the RMS value of the harmonics [5]:

$$I_{sd} = \sqrt{{I_s}^2 - \left(I_s^{(1)}\right)^2} \tag{1}$$

- *the distortion coefficient of the stator current*, which indicates the share of the residue I_{sd} in the true RMS value of the stator current:

$$k_d^{I_s} = \frac{I_{sd}}{I_s} \tag{2}$$

- *the Total Harmonic Distorsion coefficient (THD)* of the stator current [6]:

$$THD^{I_s} = \frac{I_{sd}}{I_s^{(1)}} \quad (3)$$

Table 1 *Values related to i_s and i_r in stationary regimes obtained for various frequencies*

f	M_s	I_s	$I_s^{(1)}$	$I_s^{(1)}/I_s$	I_{sd}	k_d^{Is}	THD^{Is}	I_r
Hz	-	A	A	-	A	-	-	A
20	M_{s0}	6.54	6.48	0.99	0.88	0.13	0.14	1.37
	M_{s1}	6.18	6.18	1	0	0	0	6.18
	M_{s2}	6.12	6.04	0.99	0.98	0.16	0.16	4.77
30	M_{s0}	6.73	6.73	1	0	0	0	0.47
	M_{s1}	6.59	6.54	1	0.81	0.12	0.12	2.14
	M_{s2}	6.56	6.50	0.99	0.88	0.13	0.14	6.89
40	M_{s0}	6.93	6.65	0.98	1.5	0.21	0.22	1.6
	M_{s1}	6.78	6.61	0.98	1.51	0.22	0.23	5.01
	M_{s2}	6.84	6.64	0.97	1.64	0.24	0.25	8.44
50	M_{s0}	6.03	5.53	0.92	2.4	0.4	0.43	0.48
	M_{s1}	6.09	5.44	0.91	2.74	0.44	0.50	5.49
	M_{s2}	6.39	5.87	0.92	2.52	0.39	0.43	7.44
75	M_{s0}	3.26	2.85	0.87	1.58	0.49	0.56	0.8
	M_{s1}	3.69	3.17	1	1.89	0.51	0.60	3.17
	M_{s2}	4.37	3.82	0.87	2.12	0.50	0.56	13.11

From the analysis of the values presented in Table 1 and by comparing them with the k_d and *THD* values of the line and phase voltages obtained in the same experiments and presented and analysed in [2] it is observed that:

- the values of the k_d^{Is} and THD^{Is} coefficients are relatively small (especially at frequency values below 40 Hz), which means that the waveforms of the stator currents are much closer to the sinusoid than the waveforms of the line and phase voltages;
- all THD^{Is} values exceed the 5% limit, under which a waveform can be assimilated to a sinusoid [1]. Even when $I_s^{(1)}/I_s$ = 99% (for f = 20 Hz), THD^{Is}= 14% and is cannot be considered sinusoidal;
- the distortions of the stator currents are at the same level at f = ct., even if the load torque changes (takes the values 0, M_{s1}, M_{s2}).

- the values of the rotor current i_{ra} at idle are very small and, therefore, in this regime, the stator current is approximately equal to the magnetizing current of the machine, a fact theoretically demonstrated [7].

THE EFFECT OF USING ACTIVE FILTERS ON THE POWER QUALITY

One of the current effective solutions for limiting harmonic currents, starting from the analysis in the frequency domain of the shape of the distorted electric current curves, is the use of passive or active filters. Active filters, also called active harmonic conditioners (AHC), perform real-time correction of the shape of the distorted current curves, a quality that became possible with the increase in the computing speed of computer systems. Active filters are static power converters that can perform various functions, depending on either their control mode (current or voltage) or their connection mode (series or parallel). Although the costs of these filters are still relatively high (2 to 3 times the cost of an equivalent passive filter), their efficiency makes them more and more popular in industrial applications.

The monitoring of the distorted electrical quantities in the electrical power supply nodes of the disturbing receivers is carried out in order to [8]:

- establish the level of distortion in the analyzed point and compare it with the allowed values;
- detect the sources of disturbances in the form of harmonics or interharmonics;
- establish solutions for limiting the level of distortion in the analyzed point (modifications of the working regime or possibly the introduction of harmonic filters);
- validate the solutions adopted to limit distortions.

In order to highlight the efficiency of the use of active filters, the monitoring of the electrical energy parameters was carried out in the energy supply node of a high-power frequency converter VLT 5000, used to supply a 450 kW motor-compressor drive. The paper also presents the results of monitoring the parameters and their analysis, highlighting the importance of using active filters, which although expensive is very effective.

Figure 4 shows the results of the measurements (performed for one hour with the Fluke 434 energy analyzer), both in the case of supplying the SFC from the electrical network without an absorbing filter (graphs on the left), and in the case of supplying with an active compensating filter (graphs on the right). The graphs of the variation of the true RMS values of the phase voltage, the line current and the neutral current, respectively, are presented. It is observed that the voltage is maintained at the value of 227V, although the compressor load was much higher during the measurement with the filter in the circuit (the current being 500A, compared to 175A in the case of the measurement without the filter).

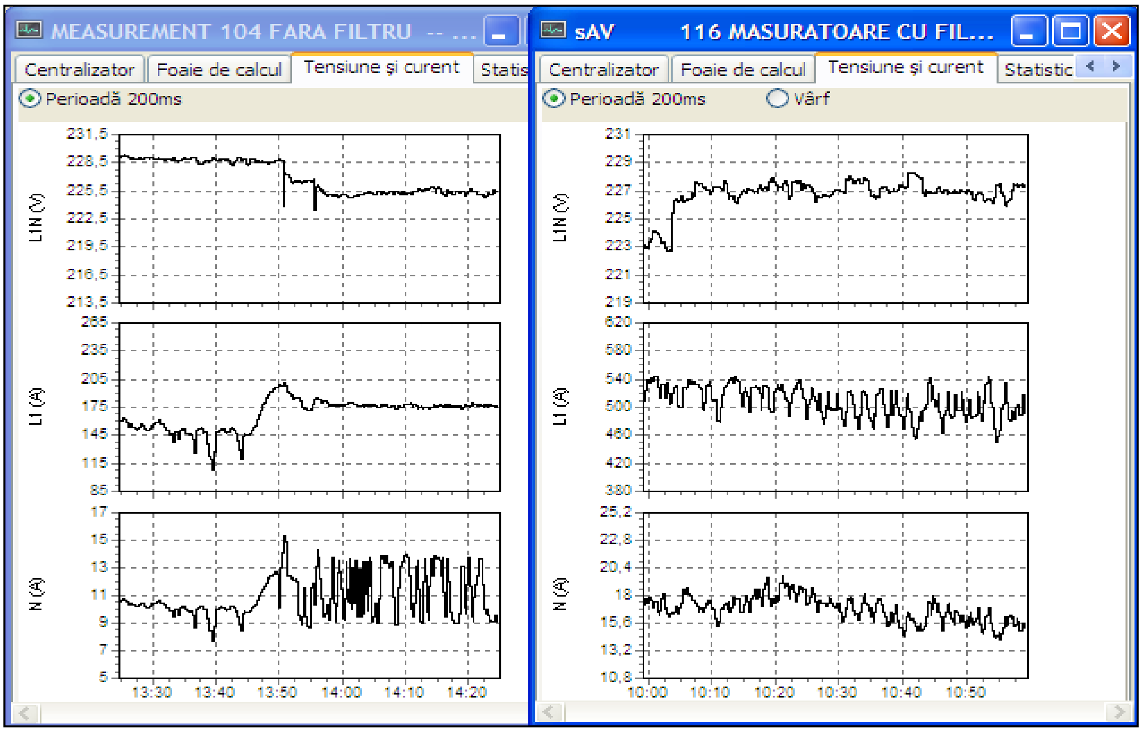


Figure 4. *Graphs of phase voltage, line and neutral current in circuits with or without active filter*

A major difference could be observed between the distortions introduced into the electrical network in the two cases. Thus, at the absorbed current, THD = 41.2% for the circuit without a filter, compared to THD = 3.1% in the case of the circuit with an active filter.

CONCLUSIONS

The increase in the share of power electronic equipment in electrical installations produces significant influences on the quality indicators of electricity, especially regarding the distortion of voltage and current waves.

Following the experimental measurements carried out on the voltage and currents of a three-phase induction motor electric drive system, the level of distortion coefficients at the output of the frequency converters was highlighted, but the effect of the use of this equipment is important especially for the level of power quality indicators downstream from the connection of these electronic equipment.

Currently, there are effective technical solutions for limiting the level of distortion to an accepted value by using specialized filtering equipment. The paper presents the major improvement brought to the power quality indicators by equipping the supply circuit of a significant power electric drive, powered by SFC, with an active filter.

However, before making the decision to mount filters to limit the level of distortion, it is necessary to make a careful analysis of the solutions regarding the reduction of distortion even at the level of the disruptive equipment. Only if these measures are not effective or the costs are too high, it is necessary to adopt the solution of using filters. The use of a certain filter requires a careful analysis of the efficiency of all types of filters, for the concrete problem to be solved and for the actual configuration of the industrial electrical network.

The filters used in the electrical network can ensure the limitation of some of the disturbances introduced into the network by consumers. The main aspects that can be solved with the help of filters are [4]:

- elimination of resonances in the electrical network;
- limiting losses in the supplier's network but also in the industrial network by limiting the circulation of harmonic currents;
- improving the power factor of disruptive consumers.

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