HARMONIC COMPONENTS OF ELECTRIC DRIVES WITH FREQUENCY CONTROL FOR CENTRIFUGAL MECHANISMS

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Abstract: *The paper deals with the problems in the operation of non-linear loads, causing distortions in the sinewaves of voltages and currents. There is currently increasing use of variable frequency drives (frequency inverters) that drive electric motors and are such loads. The experimental results cover multiple measurements of voltages and currents harmonic components and the calculated values of the total harmonic distortion coefficients of voltage and current for each of the phases, supplying different loads. An analysis of the results obtained has been done and specific conclusions have been pointed out on the basis of the measurements carried out.*

KEYWORDS: *MOTOR DRIVES, ELECTRIC MACHINES, INDUCTION MOTORS, FREQUENCY CONTROL, HARMONIC ANALYSIS, TOTAL HARMONIC DISTORTION*

1. Introduction

In the industry, the number of consumers with non-linear volt-amperage characteristics - electronic converters, static reactive power sources, electric arc furnaces, gas discharge light sources, battery chargers, electronic ballasts and LED light sources, and more, increases continuously. In the group of electronic converters are included - rectifiers, inverters, frequency converters, controllers of induction motors and voltage regulators. All these users consume non-sinusoidal current, resulting in distortion in the sinewaves of voltages and currents [1].

Current harmonics cause voltage drops in the resistances of the electrical circuits that overlap the sinewave of the supply voltage and deform its sinusoidal shape. This leads to a deterioration in the quality of the electrical energy supplied to consumers, which may cause problems in their operation [2, 3].

The supply of non-sinusoidal voltage to the electric motors leads to the movement of harmonic current in their windings [4, 5].

In order to efficiently use electrical energy, it is desirable to change the AC voltage to a constant frequency, to have a sinusoidal shape and a constant size. One of the main factors influencing the change of these characteristics are squirrel-cage induction motors, driving different mechanisms. In this sense, these electricity consumers are an important part of the energy system to undergo research to improve the electricity performance.

2. Technical considerations

There is currently increasing use of variable frequency drives (frequency inverters) that drive electric motors. The voltages and currents of the frequency inverters that power an electric motor are rich in harmonic frequency components [6].

Frequency drives of electric motors lead to increased harmonic distortions in power grids [4, 5, 6]. These distortions are individual. They depend on the mode of operation.

In a three-phase, four-wire power system, neutral (zero) wires can be severely affected by non-linear loads connected to single-phase 230 V circuits. Under normal conditions and a symmetrical linear load, the base 50 Hz portion of the phase currents is reset in the zero conductor. In a four-wire power system with single-phase non-linear loads, odd harmonics, with frequencies that are three times multiples of the fundamental frequency: third, ninth, fifteenth, etc. harmonics - they are not reset but summed up in the zero conductor. For systems with many single-phase non-linear loads, the current in the zero conductor may actually exceed the phase current. The result is excessive overheating. There are no current limit switches in the zero conductor. Greater zero wire current can also cause higher than normal output voltage drop.

Zero busbars and their offsets are dimensioned to carry out the full value of the rated phase current. They may be overloaded as a result of the conducting through the zero wires an additional sum of current harmonics with frequencies that are three times multiples of the fundamental frequency [7].

Meanwhile, IEC 61000-3-4 [1] sets the limit values for harmonic current components in low-voltage power electric distribution systems.

The term ‘frequency regulation’ has a dual meaning and use. In a broader sense, the term ‘frequency regulation’ has the meaning of ‘regulation by means of angular speed change’ without paying attention to the specific technical implementation. In a narrow sense, ‘frequency regulation’ refers to the above-mentioned basic way of varying the rotation by changing the frequency of the current.

With frequency inverter drive, it is possible to adjust the speed, torque, direction, start and stop of standard induction motors. The main advantages of this regulation are: significant opportunities for energy saving; extended life of mechanical equipment; reducing the starting current; higher starting torque; the ability to adjust the motor speed below and above the synchronous value. The frequency converter changes not only the frequency but also the voltage applied to the motor. This provides the required torque of the motor shaft without overheating and provides additional energy savings.

The capital costs of the water pumping stations are high, but the most expensive component is the electricity to drive the pumps. It is therefore important that pump units have to are highly efficient in providing proper maintenance.

Most of the existing pumping systems (of the order of 70%) are over-sized by designers by at least 20%. This reveals excellent retrofit capabilities with frequency inverters to equalize pump flow to the actual needs of the system as accurately as possible. In such cases it is very important to pick over the electrical characteristics of the motor and the inverter. Older inverters create significant harmonic distortions, resulting in additional heating of the motor windings.

3. Measurements results

The purpose of the measurements is to evaluate the operation of centrifugal mechanisms electric motors – a pump unit and a fan.

For the centrifugal pump loading, a method is used for placement (rotation) the revolving valve at different positions. In this way, different load of the electric motor is simulated in operating mode. And since a large number of such aggregates are found in practice, it is expedient to study and analyze them in working mode to assess their impact on the quality of electrical energy.

Measurements have been done with changes in the load on the electric motor with an fully open revolving valve, 2/3 open revolving valve, 1/3 open revolving valve and 1/4 open revovlving valve, changing the electrical values and indicators.

A centrifugal pump powered by a squirrel-cage induction motor type AO 052-4 with nominal technical data is used for this purpose: P_{RATED}=5.5 kW, U_{RATED} = 380 V, I_{RATED} = 14.2 A, n_{RATED} = 1440 min^{-1}, cosφ = 0.86. Three-phase frequency converter of the *ELDI* series with *U/f* and *Vector Control* is used to control the pump [8].

The centrifugal fan tested has an induction motor type AO 022/2, P_{RATED}=0.55 kW, U_{RATED}=380 V, I_{RATED}=1.4 A, n_{RATED}=2750 min^{-1}, cosφ=0.83. For rotation control, the same type of frequency converter used in the pump unit is used, but in this case it is of less power (P = 0.75 kW) and single-phase power supply $U_{HOM.}$ = 230 VAC.

The results have been obtained using a *METREL MI 2292* electrical energy quality analyzer [9]. In addition, centrifugal fan results obtained from a *VOLTCRAFT ENERGY LOGGER 4000* electrical meter have been also provided [10]. The measurements have been done in laboratories at the Technical University of Gabrovo.

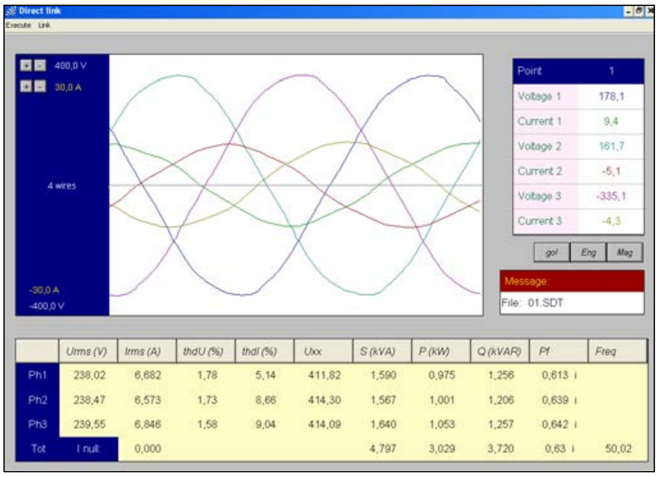

Fig. 1 *Voltage and current changes at fully open revolving valve of the centrifugal pump*

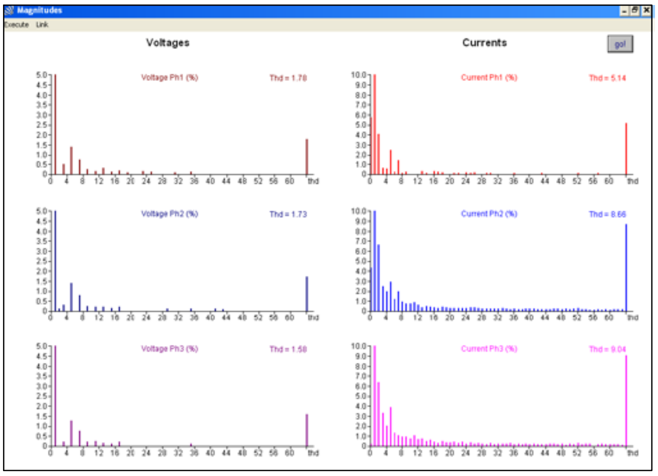

Fig. 2 *Observed harmonics at fully open revolving valve of the centrifugal pump*

4. Analysis of the results obtained for the centrifugal pump unit

The results obtained clearly show that a different load on the pump unit and the induction motor, respectively, changes some of its electrical characteristics. This results in a change in the power factor - PF, which has values in the range of 0.6 to 0.75 with a pronounced inductive character of the load.

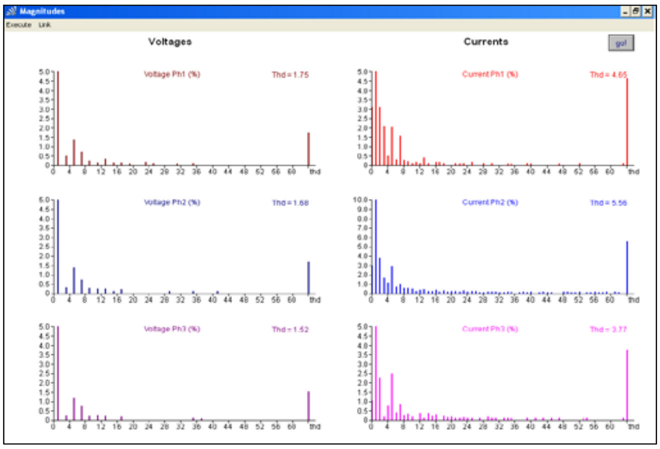

Fig. 3 *Observed harmonics at 1/3 open revolving valve of the centrifugal pump*

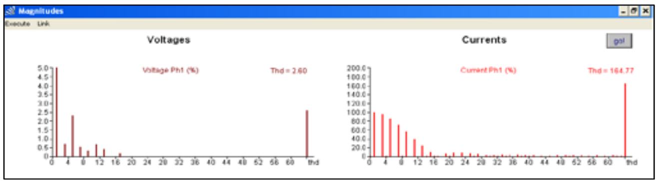

Fig. 4 *Observed harmonics for centrifugal fan at frequency of 50 Hz*

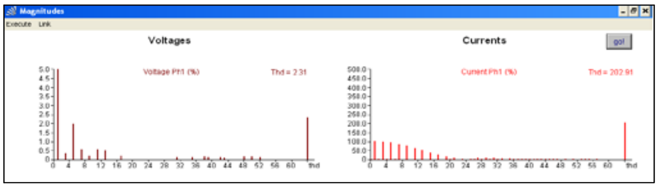

Fig. 5 *Observed harmonics for centrifugal fan at frequency of 30 Hz*

These values are typical of the squirrel-cage induction motors because they do not always work at a nominal load, largely due to the resistance of the drive mechanism. This leads to different values of the electrical energy quality indicators.

The results for the higher harmonics show that they are very pronounced with the serial number - 3, 5 and 7, they reach 9.04% for the current - THD_I and are too small for the voltage - THD_U = 1.50÷1.76. Nevertheless, the values of the higher harmonics are within the limits set in the ordinances, with the phase voltages and currents not altering their sinusoidal shape unacceptably.

5. Analysis of the results obtained for the centrifugal fan

Since the frequency control is fed by single phase, the results are only considered for the first phase *Ph1*. The measurements carryied out show that the frequency influence on the shape of the current is the most influential. With lowering the frequency and the motor speed respectively, some electrical performance changes. The odd harmonics of the current are highly pronounced (3, 5, 7, 9, 11, 13, 15, 17, 19, 21), the overall harmonic distortion reaches very high values at the lowest frequency of the supply voltage (*f*=20 Hz): THD_I = 219.05%. The power factor *PF* is also very low: *PF* = 0.4, with the predominant capacitive character of the load. This is largely due to power capacitors in frequency control that have high capacity and lack of filters at the input of the converter. Because of the low power, the frequency control does not affect the shape of the voltage curve and its harmonic composition.

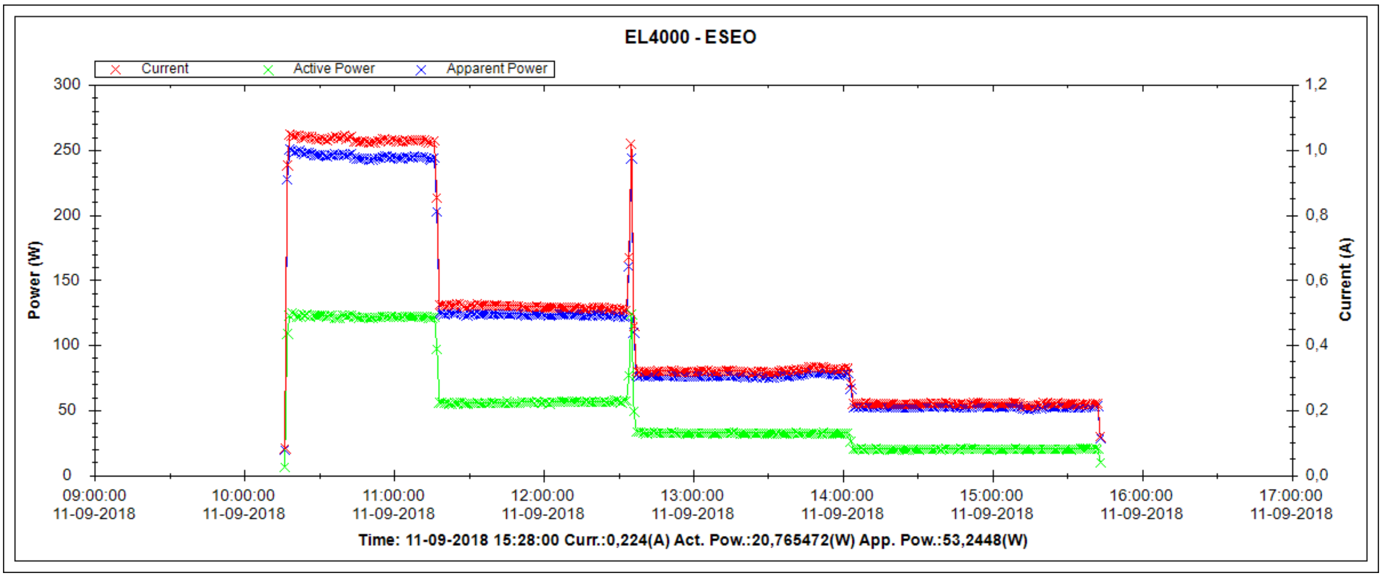

Fig. 6 *Loading diagram of centrifugal fan for different power supply frequencies*

6. Conclusions

The results obtained could be of great practical importance when considering to start and possibly implement the frequency control of induction motors for centrifugal equipment. There is more and more talk about the benefits (and deficiencies) of electric motors frequency control. Optional solutions implemented using a frequency converter can be successfully applied in laboratory exercises. It can practically examine the possibilities of the autonomous voltage inverter in order to acquaint and work with the students with a frequency regulator. The autonomous inverter provides great possibilities for exploring its co-operating with an squirrel-cage induction motor. This is a great advantage as most of the electric drives in the world are based on an induction motor controlled by frequency inverter.

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