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INVESTIGATION THE ELECTRICAL POWER QUALITY OF A METALS MELTING ELECTRIC INDUCTION FURNACE

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Abstract: *The paper analyses electric power quality of a steel melting electric induction furnace. The measurements have been made in the second of the furnace transformer, on the LV line. The values of currents, voltages and its harmonics are recorded by three-phase power quality analyser MI 2885 Master Q4. The conclusions of experimental results of electric power quality of the investigated induction furnace are drawed.*

Keywords: *steel melting electric inductance furnace, electric power quality, harmonics.*

INTRODUCTION

The energy efficiency of electrical installations is a current topic which is related to the rational use of energy resources. The electric power quality affects energy efficiency and it is a factor in the maintenance of electrical systems and equipment (Belgaum Foundry Cluster, Gönen, T., 2014. Stefanov, St., V. Ruseva, 2010).

Most of the industrial sites in accordance with the principle of operation of the elements and systems used change the parameters of electricity reducing its quality. Such sites are the metallurgical ones in which melting and casting of metals is performed. The main equipment for the implementation of these processes are electric furnaces. They are different types but induction ones are with very good characteristics. The principle of operation is based on the thermal action of induced vortex currents in the metal that melts (Iagar, A. et al., 2009). Electronic converters are used to increase the frequency of the low voltage supply - for example 430 Hz, 1 kHz, 2.5 kHz and others. Electronic frequency converters are a source of changes in the parameters of electricity and its quality is an important factor for efficient, reliable and safe operation of systems (Kermeli, K. et al. 2016, Rajalakshmi, D. et al. 2019).

The consumption of electricity from an electric induction furnace for melting metals has been studied (Koev, K., Sv. Grigorov 2021). The amount of energy consumed during the year is large and this is a prerequisite for studying the impact of the operation of the facility on the power grid.

The purpose of the study is to conduct a preliminary measurement and analysis of some indicators of the quality of electrical energy of an electric induction furnace for melting steel.

EXPOSURE

Characteristics of The Studied Object

The electric induction furnace is without a steel core. The required temperature for melting the steel is about 1600 ° C and the mass of the molten metal can be up to 600 kg. The system has a power of 400 kW and it is supplied with a three-phase alternating (AC) voltage of 380 V. It is rectified by a rectifier, filtered and converted back to alternating current by a thyristor current inverter. The frequency of the AC voltage thus obtained is 1 kHz which is significantly higher than the mains voltage frequency of 50 Hz. The high frequency voltage supplies the induction furnace. Its coil is made of a tubular wire through which water circulates to ensure the required temperature.

Measuring Equipment and Measurement Methodology

A three-phase electricity power analyzer MÍ 2885 Master Q4 manufactured by Metrel, Slovenia (MI 2885 Master Q4, Metrel, 2021) has been used. The company is world proven in the production of this type of measuring equipment. The device measures all quantities in three-phase or single-phase networks, as well as indicators for the quality of electricity.

The device is developed in accordance with Standards of Safety EN 61010-1 and of Electromagnetic Compatibility EN 61326. The measurements are performed in compliance with the requirements of the Standards EN 50160, IEC / EN 6100Q-4-15, IEC / EN 61000-4-30 Class S, IEC / EN 61000-4-7 Class I, IEC / EN 61557-12 and IEEE 1459. The analyzer can measure various quantities, such as active, reactive and apparent power; power factor PF; cos φ; the values of linear and phase currents and voltages; harmonics and interharmonics of current and voltage up to number 50.

The accuracy of the analyzer when measuring phase and line voltages is ± 0.1% of the nominal value. The accuracy of the current inputs to which the four current measuring transducers (Rogovski winding) with a range of 3 ... 6000 A are connected, is ± 1.5%, and the accuracy of the transducers is ± 1%. The records of measurements are saved in a microSD card, the memory of which can be up to 32 GB. The analyzer can be connected to a computer via the RS 232 serial interface. Other connection options are via USB and Ethernet outputs. The recorded data is read and analyzed on a computer using a special PowerView software product.

The parameters of the electric energy are measured in a distribution system of 0.4 kV at the terminal supplying the induction furnace. The measurement is performed within a short period during the steel melting process.

Electricity Quality Research

Of particular interest when analyzing the electric power quality in systems with semiconductor converters is the non-sinusoidality of currents and voltages (Gönen, T „2014. lagar, A. et al., 2009, Rajalakshmi, D. et al. 2019).

Figure 1 shows the changes of the phase voltages in the three phases of the four-wire power supply network (LI, L2, L3, N) during the melting of the steel in the induction furnace. The graphics for the three phases are almost the same - the differences are very small and most likely due to changes in the parameters of the electrical circuits. The shape of the voltages is similar to the sinusoidal one, but periodic distortions are noted with different amplitude for a large part of each half-period of the phase voltages. They are due to the operation of the electronic converters of the furnace supply system. The magnitude of the distortions are the smallest (about 3 V) in the range of maximum values of phase voltages.

The voltage change of the neutral conductor UN is presented, which is in a very small range (-0.1 ... 0.1) V. The shape of the voltage can be considered as packets of triangular impulses with steep fronts and short duration, which appear during operation of the electronic converters of the furnace supply system.

The graphics of the currents in the three phases (Fig. 2) differ much more from the sinusoidal shape compared to the graphics of the voltages (Fig. 1).

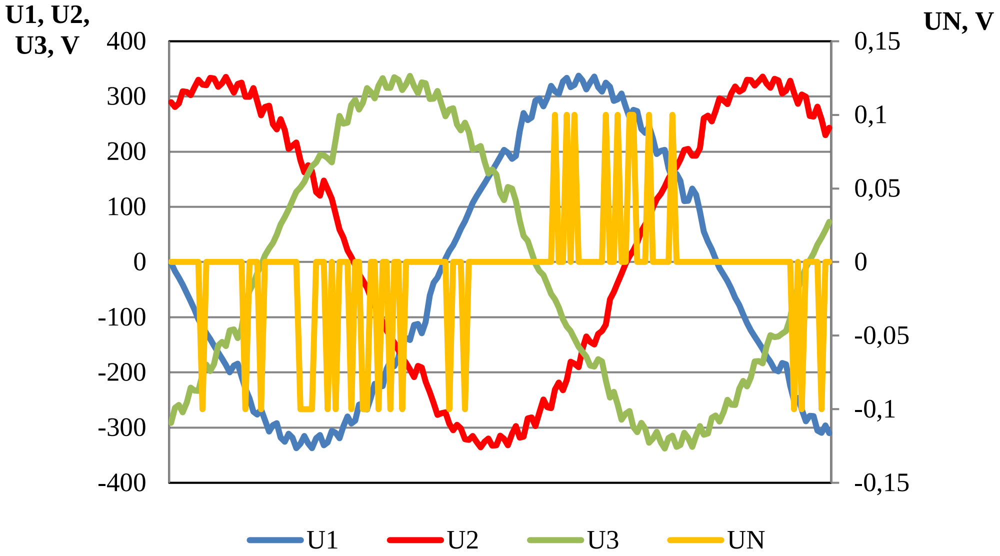

Fig.1. Changes in the shape of the voltages in the individual phase conductors Ul, U2, U3 and in the neutral conductor UN of the supply network.

The rectangular shape of the currents is typical which is due to the type of inverter used - of current. This type of converter is characterized by a constant value of current during each half-period. In this case the value of the current is not constant, but it changes periodically in the range of maximum values (the plateau of rectangular impulses). The largest range of distortions is about 50 A. The distortions of currents as well as of voltages are due to the operation of electronic converters.

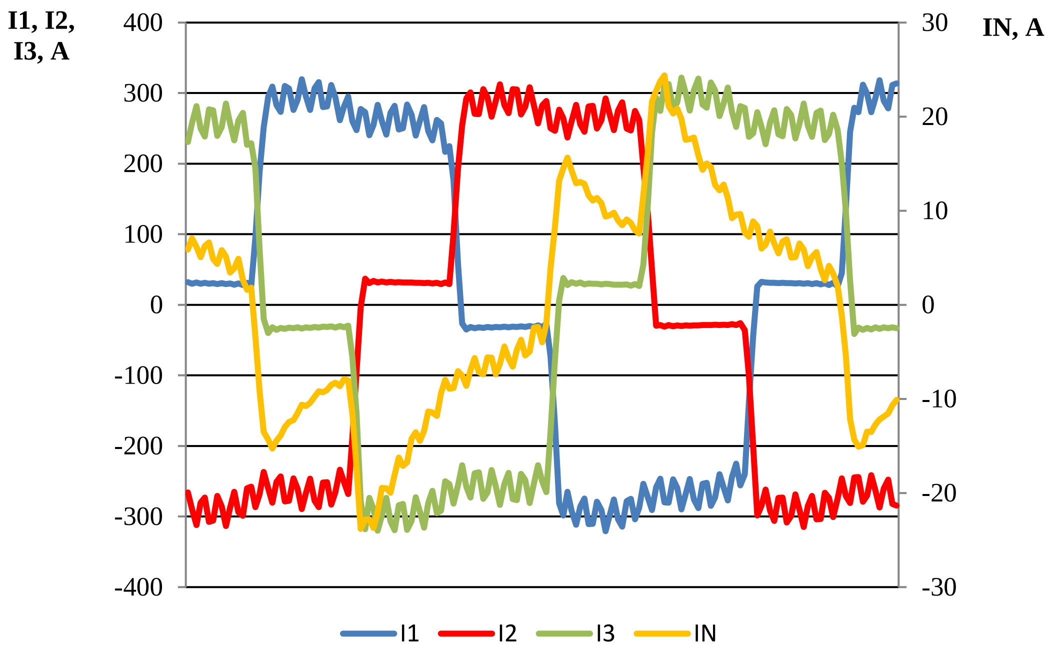

Fig. 2. Changes in the shape of the current in the individual phase conductors II, I2, I3 and the neutral conductor IN of the supply network.

The change in current in the neutral conductor 1N differs significantly from that of the voltage (Fig. 1), and the amplitude is much larger - about 48 A. Small periodic changes are observed in the form of the current similar to those in the region of maximum values of currents in the phase conductors. The reason is the same as in the graphics of other currents and voltages - the operation of electronic converters.

The deformation of the current and voltage curves compared to the sinusoidal shape (Fig. 1, Fig. 2) is estimated by the coefficients of non-sinusoidal voltage THD_U (Total Harmonics Distortion of Voltage) and by current THD_I (Total Harmonics Distortion of Current) in accordance with (BDS EN 50160: 2010 / A3: 2020). The values of the indicated coefficients are determined by the formulas:

$$\mathbf{THD_U} = \frac{\sqrt{\sum_{i=2}^{50} U_i^2}}{\mathbf{U_1}}.\mathbf{100}, \%; \quad (1)$$

$$\mathbf{THD_I} = \frac{\sqrt{\sum_{i=2}^{50} I_i^2}}{\mathbf{I_1}}.\mathbf{100}, \%, \quad (2)$$

where Ui (Ii) is the effective (RMS) value of the i-th voltage (current) harmonic;
U_1 (I_1) - the effective (RMS) value of the first voltage (current) harmonic.

The used electricity analyzer MI 2885 Master Q4 measures the harmonics up to 50th and presents the values of the non-sinusoidal coefficients in absolute units and in percentages relative to the main harmonic (first) (Table 1).

Table 1. Values of the non-sinusoidal coefficients by voltage THD_U and by current THD_I for each phase L1, L2 and L3

№	Coefficients	Phases of the supply network		
		L1	L2	L3
1	THD_U, %	4,2	4,1	4,2
2	THD_U, V	9,5	9,4	9,6
3	THD_I, %	27,1	28,3	28,1
4	THD_I, A	58,5	59,9	60,2

The maximal values of the harmonics of current and voltage in the first phase of the supply network are graphically presented in Fig. 3. The relative values to the fundamental harmonic are shown. It is not presented in order the amplitude values of the harmonics to be better seen and to be compared.

The largest amplitude values are of the second (h_2) harmonics of voltage and current, respectively 2.0% and 20.6%.

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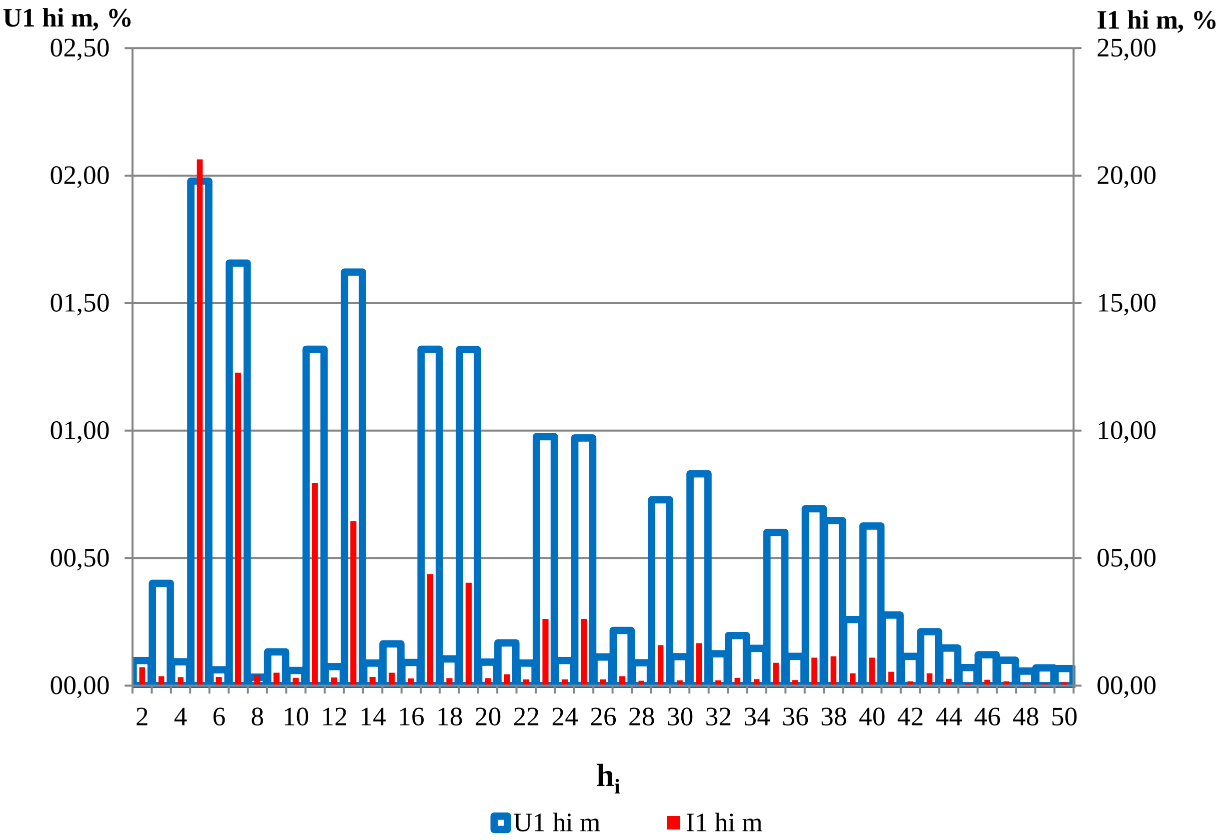

Fig. 3 .Values (%) of the amplitudes of the harmonics of voltage (U1 hi m) and of current (I1 hi m) in the first phase of the supply network.

According to (BDS EN 50160: 2010 / A3: 2020) the THD_I values should not exceed 8%. The results presented in Table 1 are about 3.5 times greater than required. Therefore the condition for THD_I values is not met.

CONCLUSIONS

Studies have been conducted on the electric power quality in an electrical installation supplying an electric induction furnace for melting steel. The magnitudes of currents and voltages and their harmonic components are measured.

It was found that the values of the non-sinusoidal voltage coefficients THD_U for each of the three phases are from 4.07% (L2) to 4.19% (L3). The values of the non-sinusoidal current coefficients THD_I for each of the three phases are from 27.11% (L1) to 28.31% (L2).

The amplitude values of the current harmonics 5, 7, 11 and 13 are large, and for the other harmonics up to 50th their values do not exceed 5%.

Longer studies are needed to give a more accurate and complete picture of the quality of electricity in the system in question, in order to offer solutions to increase the efficiency of the respective site.

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