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Improvement of the process of conducting arc-free ferronickel melting in a six-electrode furnace

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Keywords: submerged-arc furnaces, ferronickel, arc-free mode, "triangle" on the electrodes, artificial "star", half-phase of a six-electrode electric furnace, zero-point offset voltage, harmonic.

Abstract – For three-phase six-electrode submerged-arc furnaces, a technical solution has been proposed that allows to determine the contour of an electrode with an arc discharge by analyzing the harmonic spectrum of offset voltage of zero point, created artificially. Researches carried out on an industrial six-electrode furnace which melts ferronickel, have confirmed the possibility of using the proposed method for monitoring and controlling the operating mode of the furnace.

INTRODUCTION

The Department of Electrical Engineering of the National Metallurgical Academy of Ukraine has accumulated many years of experience in studying of the parameters and operating modes of submerged-arc furnaces in Ukraine, Kazakhstan, Georgia, Russia. The object of study was the working space of electric furnaces which are smelting ferrosilicon, ferrosilicomanganese, ferromanganese, ferronickel, ferrochrome. The subject of research was: the structure of the working space, the temperature field, the distribution of electrical potentials in the volume of the working space of the furnace bath, the presence of an electric arc discharge and the size of the gas cavity in the area of the electrode end, the ratio between the powers of the electric arc and charge conductivity, and the charge current density.

The presence of an arc discharge (nonlinear element) in three-phase three-electrode submerged-arc furnaces was determined by the third harmonic of the voltage between the zero of the artificial star and the conducting hearth. According to the theory proposed by the author [1], in the presence of an electric arc in three phases, the neutral offset voltage will be presented in the form of the third harmonic in relation to the network frequency. During the research of three-phase three-electrode industrial furnaces, in which the secondary circuit is made according to the "triangle on the electrodes" scheme, the neutral of the energy sources was obtained by creating an artificial "star" from variable resistances (Fig. 1, 2). The voltage between the zero point of the artificial "star" and the conducting hearth of the furnace was the neutral offset voltage. In almost all furnaces that were studied, the harmonic composition of this voltage consisted not only of the third harmonic, but also had other components (Fig. 3). To eliminate the influence on the magnitude and shape of the neutral offset voltage of the mains voltage, which in this spectrum is represented by the first harmonic, were used a change of the resistance of the "rays" of the artificial "star" to obtain a "pure" third harmonic (Fig. 4, 5) and the actual value of the neutral offset voltage.

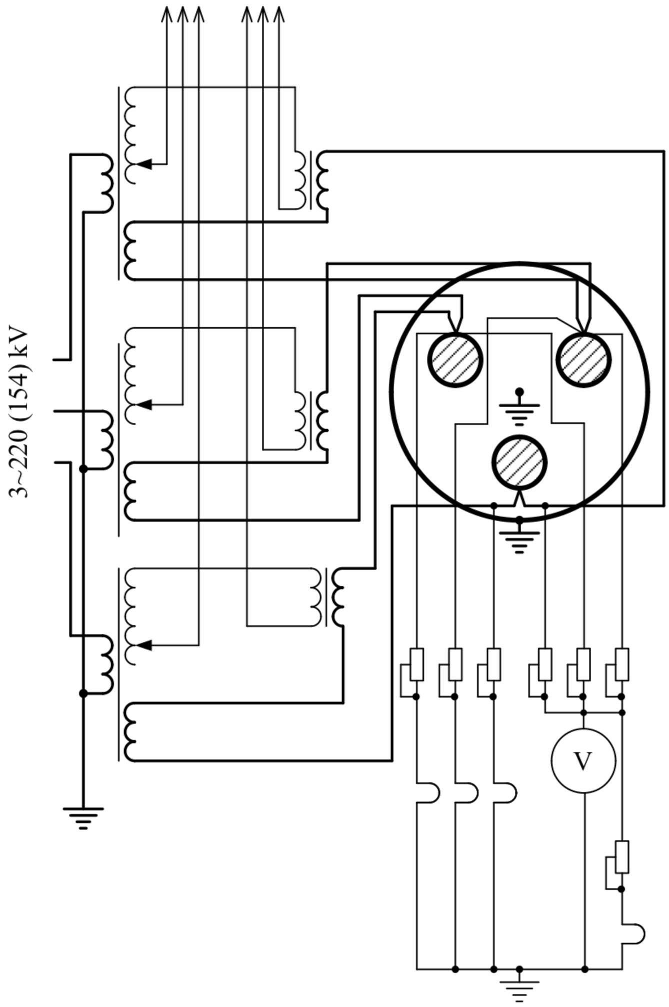


Figure 1: Measurement scheme for research of industrial furnaces with a secondary circuit "triangle on the electrodes".

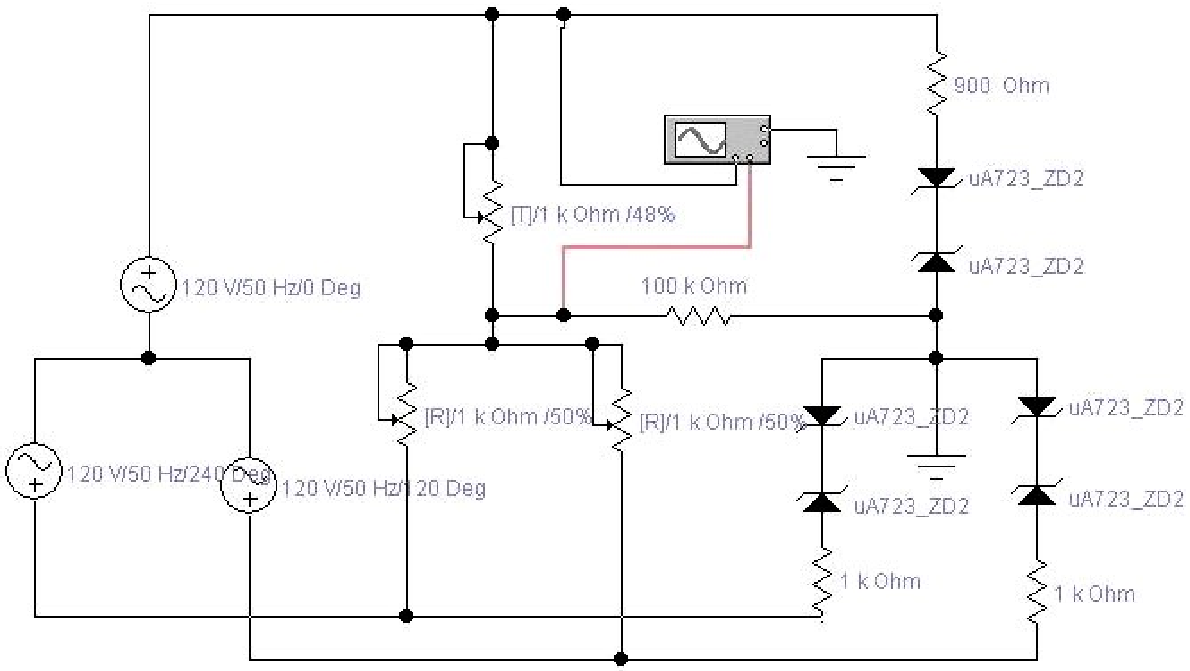


Figure 2: Scheme for modeling of the furnace circuit of a three-electrode furnace without compensation of the first harmonic of the zero-point offset voltage

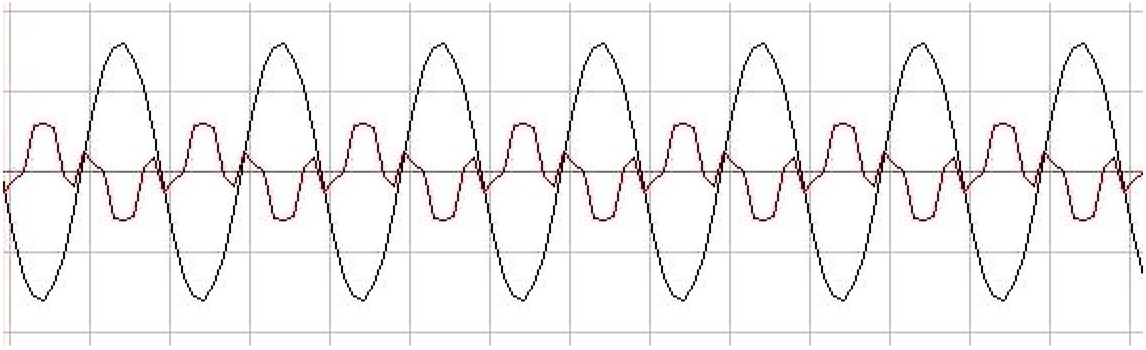


Figure 3: Waveform of zero-point offset voltage without first harmonic compensation

Further researches using computer simulation made it possible to establish the dependence of the phase shifts of the first harmonic of the zero point offset voltage and the reference phase voltage from the presence of arc discharges, which made it possible by maneuver of the furnace electrodes to obtain symmetry along a nonlinear element in the circuit [2].

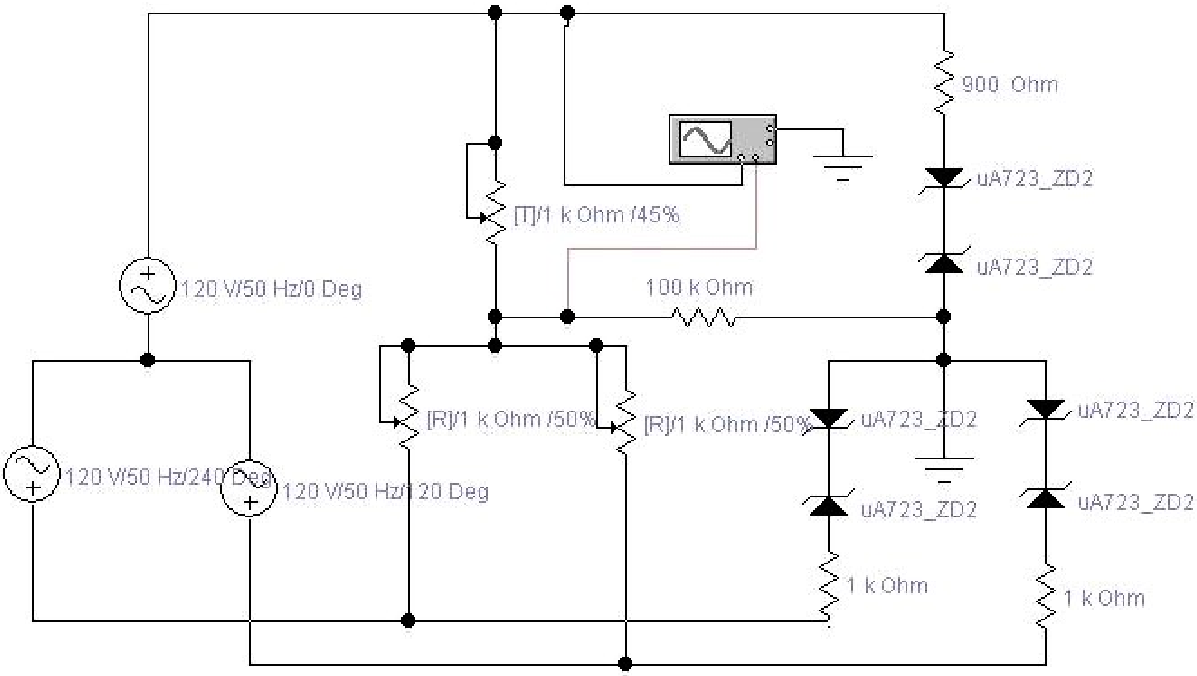


Figure 4: Scheme for modeling of the furnace circuit of a three-electrode furnace with compensation of the first harmonic of the zero-point offset voltage

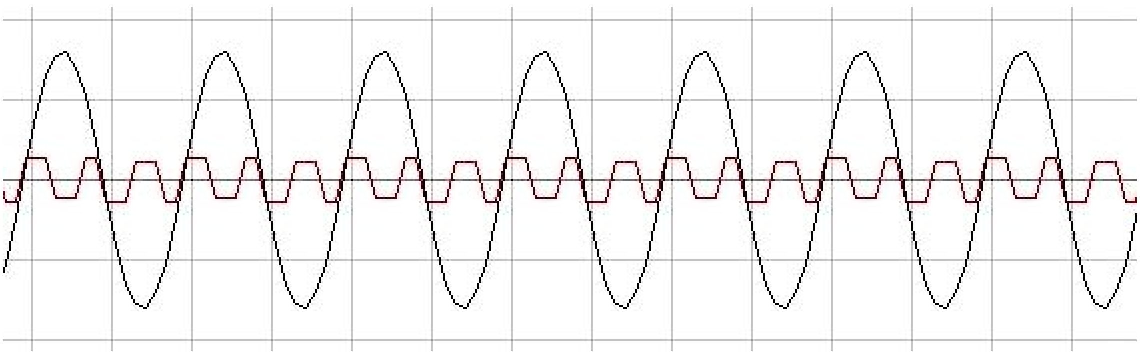


Figure 5: Waveform of the z-point offset voltage with first harmonic compensation

RESULTS AND DISCUSSION

In the operation of three-phase six-electrode (when the electric circuit of the phase is presented in the form of two half-phases with an electrode in each half-phase) ore-thermal electric furnaces with multi-slag processes of ore-reduction smelting (for example, obtaining ferronickel), one of the negative factors is the periodic formation of an electric arc discharge in the area of the electrode end, which significantly impairs the technological indicators (dust emission increases, nickel extraction decreases, exhaust gas temperature rises). In addition, there are a number of technological factors associated, for example, with the transition of silicon, chromium into the ferronickel, confirming the need to work in an arc-free mode.

Researches carried out on six-electrode industrial ore-thermal furnaces have shown that there is a close relationship between the physicochemical conditions under the paired electrodes. The change in electrical resistance under one electrode causes a change of the current in a circuit which consists of two electrodes. With the development of an arc discharge under one of the electrodes, a process of power redistribution occurs, which leads to the simultaneous movement of paired electrodes, although the disturbance took place only on one electrode. Such unjustified movements of the electrodes impair the structure of the melting space. These factors ultimately reduce the technical and economic performance of the furnace (specific power consumption, productivity). That is, for this type of furnaces and type of technological processes there is a need to promptly identify of the electrode under which an arc discharge occurs in order to take measures to eliminate it.

In this paper, a technical solution is considered that makes it possible to effectively control the appearance of an arc discharge in the sub-electrode space (nonlinear element in the circuit) of each of the six electrodes in submerged-arc furnaces from operational point of view.

As a result of carried researches, a scheme was drawn up for modeling of the furnace circuit of a six-electrode furnace, which made it possible to obtain the zero point offset voltage and control its third harmonic and other components. For this purpose, two three-phase systems were created in the electrical circuit of the six-electrode furnace, consisting of half-phases of odd and even electrodes. For each of these systems, an artificial symmetric "star" was created separately. The neutral offset voltage for each of the systems was measured between the star zero point and the conductive hearth (Fig. 6).

Figure 7 shows a waveform of the half-phase voltage and neutral displacement to study the possibility of determining the presence of an arc under the electrode of the second (reference) half-phase (Fig. 6). The coincidence of the initial phase angle of the curves of the half-phase voltage and neutral offset voltage indicates to the presence of an arc discharge under the electrode of the second half-phase. An advance of the neutral offset voltage by 120° relative to the reference indicates on the presence of an arc discharge under the electrode of the fourth (lagging) half-phase, and a 120° lag under the electrode of the sixth (leading) half-phase. The presence of arc discharges under the electrodes of odd half-phases is determined in a similar way.

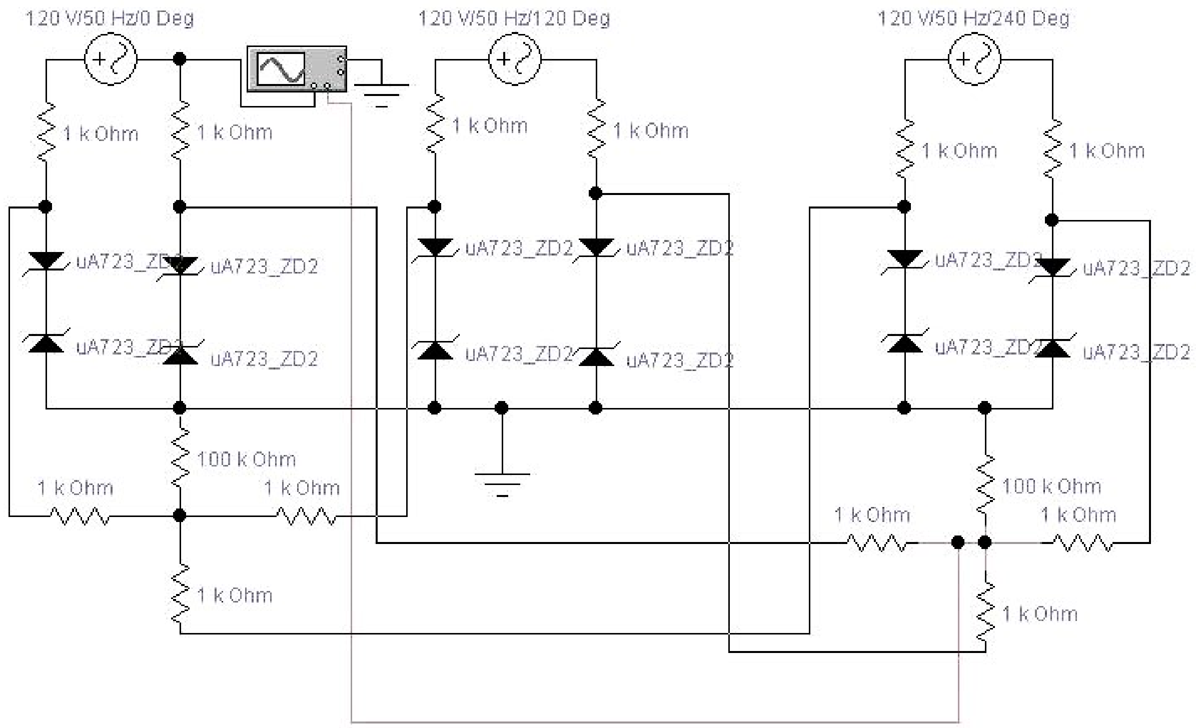


Figure 6: Scheme for modeling of the furnace circuit of a six-electrode furnace

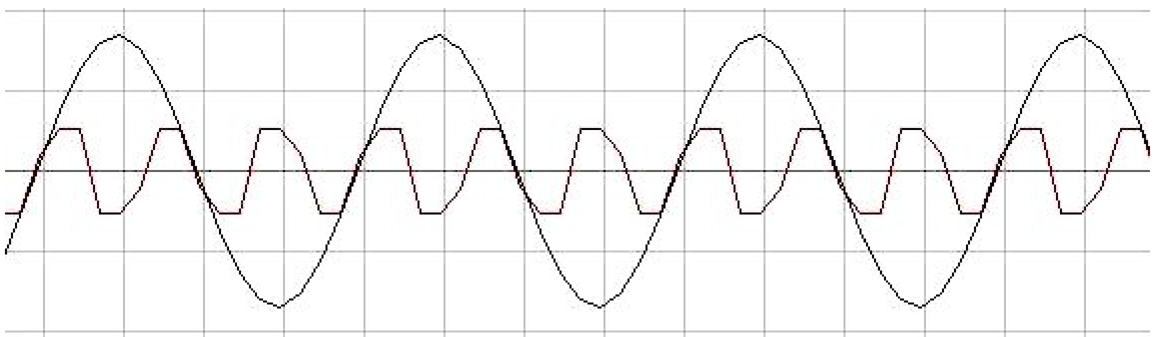
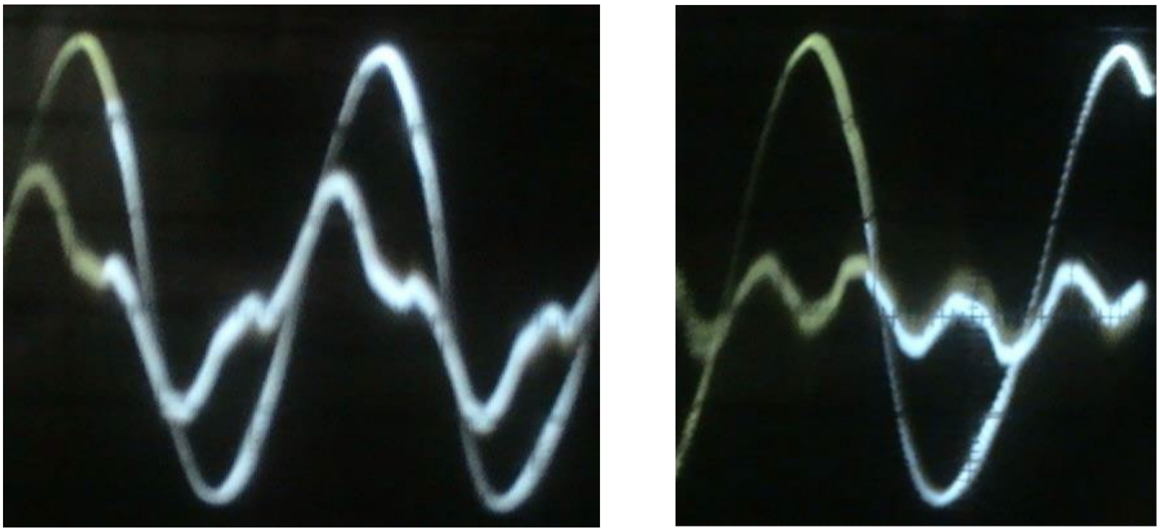


Figure 7: Waveform of the zero point offset voltage for a system of even half-phases of a six-electrode furnace (simulating an arc discharge under the second electrode)

The adequacy of the model was tested on an operating six-electrode industrial furnace during FeNi smelting. The above mentioned measurement scheme (Fig. 6) with the ability to control the shape of the voltage waveform of the artificial neutral and the voltage of the half-phase with an electronic oscilloscope. Technological personnel, by moving the electrodes, created conditions in the bath under which an electric arc occurred under each of the six electrodes. The simulation results were fully confirmed during the experiment. As an example, Fig. 8 shows the oscillogram fragments of the half-phase voltages and neutral displacement of a three-phase system of even electrodes of a six-electrode industrial furnace.



a) b)

Figure 8. Voltage oscillograms (half-phase and neutral bias) of a three-phase system of even electrodes of a six-electrode ferro-nickel furnace (average power 38 MW, transformer power 3 × 16,7 MW A) a) - unbalanced mode (arc discharge under the second electrode); b) - symmetrical mode (arc discharge under all even electrodes).

CONCLUSIONS

Analysis of the harmonic composition of the shape of the neutral offset voltage curve, created by using an artificial symmetric star, made it possible to obtain a number of information (dependencies) that can be used in control algorithms.

The proposed method for monitoring the presence of electric arcs under the electrodes can be used to control ore-thermal furnaces both independently and as an addition to the already used systems for monitoring and controlling the electric mode of six-electrode furnaces [3].

The proposed measuring scheme was tested on operation industrial six-electrode furnace of the Pobuzhsky Ferronickel Plant. During the melting, arcs were artificially created under the electrodes. Wherein:
1) the presence of an arc discharge was confirmed by the appearance of the third harmonic of the zero point offset voltage;
2) phase shifts of the first harmonic unambiguously indicated to the electrode with an arc discharge.

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