The determination of real phase parameters of rectangular six-electrode ore-smelting furnace of type RPZ-63.

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ABSTRACT

The influence of instantaneous current values of neighboring phases on the measured instantaneous values of "electrode – hearth" area in the rectangular six-electrode ore-smelting furnace of type RPZ-63 has been investigated. The trend of changing the coefficients of induction interaction from close phase to distant phase has been established. The correction method of measured instantaneous value of electrode voltage, considering the influence of instantaneous current values of neighboring phases for the furnace electrical mode control has been proposed.

1. INTRODUCTION

The advance level of computer technology introduction during manganese ferroalloys melting at PJSC Nikopol Ferroalloy Plant makes it possible to acquire the data package of alternate current and voltage instantaneous values with the required interrogation rate, the usage of which allows evaluating, in terms of quality and quantity, the processes that occur in the ore-thermal furnaces, when the alternate current flows through the "electrode – hearth" area, incorporating the non-linear arc resistance [1, 2].

When calculating the electrical characteristics of six-electrode ore-thermal furnaces of type RPZ-63 it is required to consider the features of electrode drop measurements [3].

In '90s, when implementing the information sub-system of automation process control system of six-electrode furnaces, special attention was paid to the input information reliability at PJSC Nikopol Ferroalloy Plant. The analysis of vector diagrams of the six-electrode furnaces currents and voltages demonstrated that measured voltage at "electrode – hearth" area incorporates uncontrolled EMF value of mutual induction induced by the currents of neighboring electrodes [3]. The authors [3] conducted researches of measured electrical parameters of the furnace in the course of power voltage and fixed electrode phases transposition. Based on the research results, it was concluded that currents of close and distant phases have induction effect on measured electrode voltage and the method of measured value correction using the induction interaction coefficients (K_{ii}) between the phases determined by sequential single-phase switch of the furnace transformers was proposed.

The deployment of the above described method for operation with instantaneous current and voltage values is constrained, since the measured effective values of electrode voltage being the derived value of harmonic analysis are corrected. As a consequence, non-linear nature of current and voltage curves are ignored.

2. EXPERIMENT

In order to develop the correction method of measured instantaneous electrode voltage value error considering the influence of instantaneous current values of neighboring phases, the researchers were conducted at the furnace of type RPZ-63 that melts ferrosilicon manganese (Fig. 2.1). The measurements were made with one operating phase with sequential simultaneous disconnection of furnace transformers of the other two phases ("A" - electrodes 1, 2; "B" - electrodes 3, 4; "C" - electrodes 5, 6).

Fig. 2.2 illustrates the curves of "C" phase current, which operates in the single-phase mode and non-operating phase electrode voltages induced by it. The value of phase displacement angle of voltage towards current is typical for electrical circuits with resistance including reactive and active components.

As can be seen from the above, the voltage on electrode "3" induced by "C" operating phase, when "A" and "B" phases (u_{3iiC}) are non-operative, is equal to:

$$u_{3iiC}(t) = i_C(t) \cdot R_{3iiC} + 2\pi \cdot f \cdot X_{3iiC} \frac{di_C(t)}{dt} \qquad (2.1)$$

where: i_C is C phase current, R_{3iiC}, X_{3iiC} are active and reactive components of induction interaction coefficients K_{3iiC}.

When "A" phase is operating:

$$u_{3iiA}(t) = i_A(t) \cdot R_{3iiA} + 2\pi \cdot f \cdot X_{3iiA} \frac{di_A(t)}{dt} \quad (2.2)$$

where: i_A is A phase current, R_{3iiA} ,X_{3iiA} are active and reactive components of K_{3iiA}.

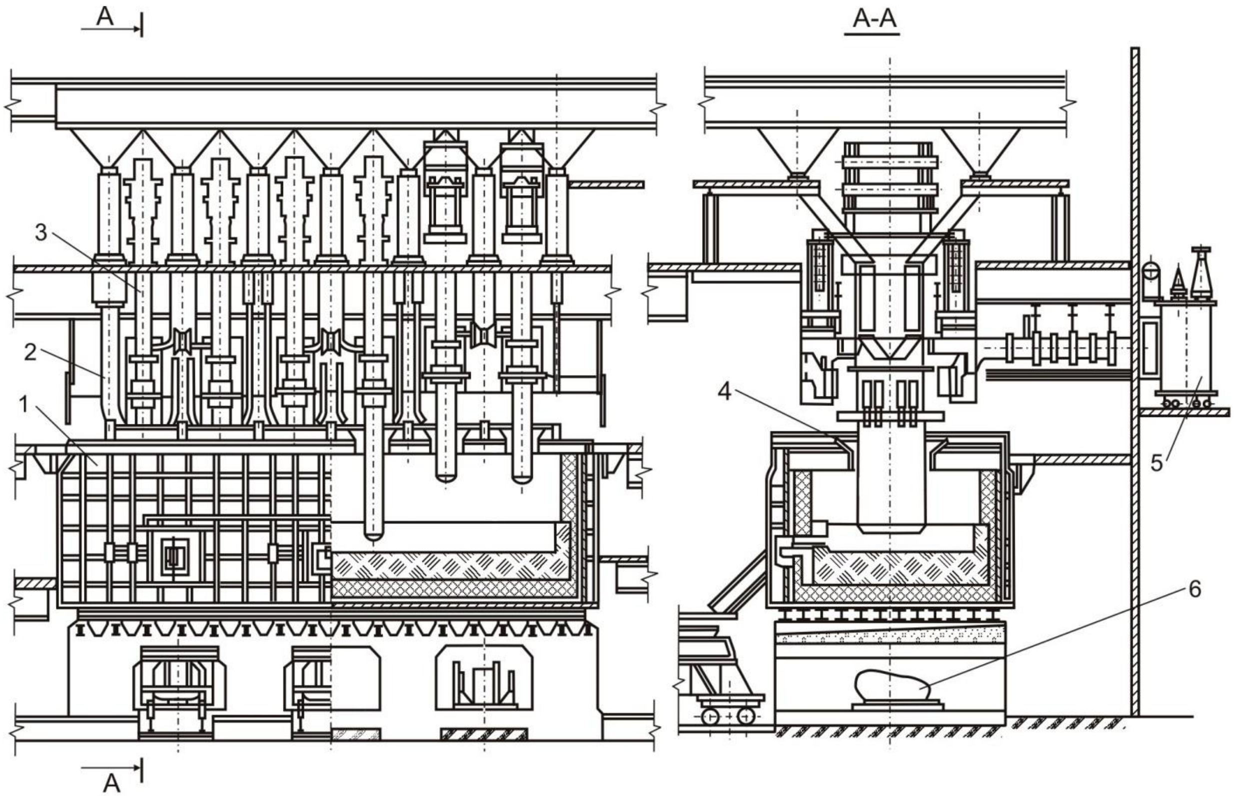

Figure 2.1: Closed six-electrode rectangular electric furnace of type RPZ-63:
1 - bath, 2 – charging pipes, 3 – electrode holder, 4 – charging hoppers, 5 - transformer, 6 – hoists for ladle cars rolling down.

In case of three-phase closing, the measured voltage on the 3rd electrode is as follows:

$$u_{3ii}(t) = i_B(t) \cdot R_3 + L_3 \frac{di_B(t)}{dt} + u_{3iiA}(t) + u_{3iiC}(t) \quad (2.3)$$

where: R_3 is active resistance of near-electrode space of the electrode; L_3 is induction of near-electrode space of the electrode 3; i_B is B phase current.

Consequently, in order to obtain the corrected (actual) instantaneous value of electrode 3 voltage ($u_3(t)$) it is necessary to subtract the voltages induced by "A" and "C" phases current from the measured value:

$$u_3(t) = u_{3ii}(t) - u_{3iiA}(t) - u_{3iiC}(t) \quad (2.4)$$

In order to determine K_{3iiA} the instantaneous phase current values and electrode voltages of non-operating phases, measured in the mode of single-phase closing and calculated by FFT (fast Fourier transformation) method, induced as a result of its induction interaction, were used:

$$i_C(t) = I_{mC1} \sin(\omega t + \varphi_{iC1}) + ...I_{mCn} \sin(\omega t \cdot n + \varphi_{iCn}) \quad (2.5)$$

$$u_{3iiC}(t) = U_{m3iiC1} \cdot \sin(\omega t + \varphi_{u3iiC1}) + ...U_{m3iiCi} \sin(\omega t \cdot n + \varphi_{u3iiCi}) \quad (2.6)$$

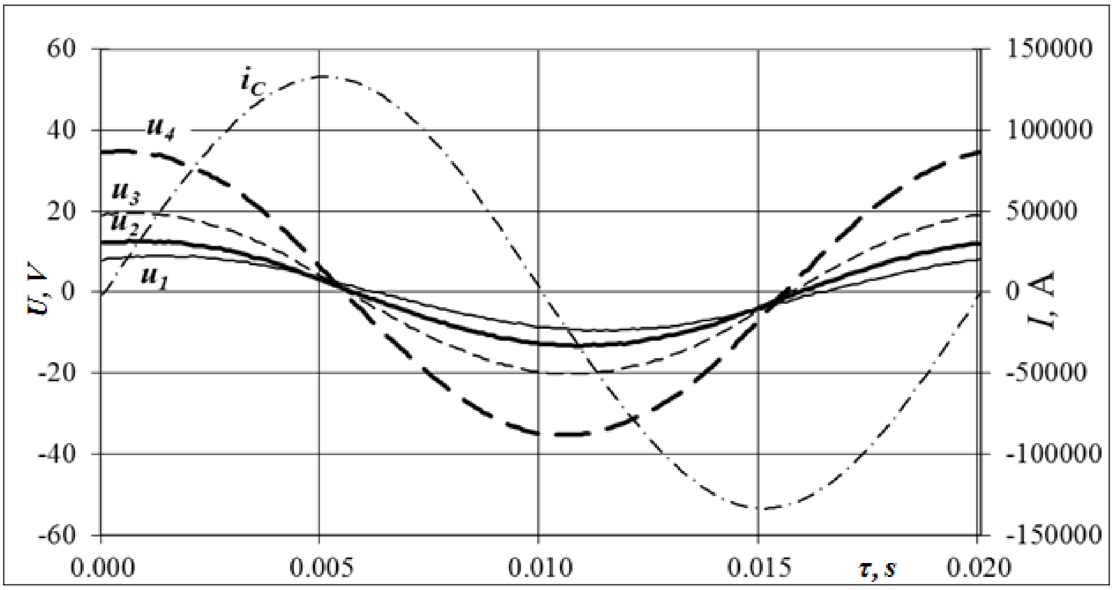

Figure 2.2: Curves of operating phase current "C" - $\boldsymbol{i_C}$ (_ . _) and electrode voltages of non-operating phases induced by it: (___) $\boldsymbol{u_1}$ is electrode 1; (___) $\boldsymbol{u_2}$ is electrode 2; (_ _ _) $\boldsymbol{u_3}$ is electrode 3; (_ _) $\boldsymbol{u_4}$ is electrode 4, of six-electrode ore-thermal electric furnace.

The induction interaction coefficients are determined for each harmonic constituent and equal to the relation of peak stresses $U_{m3ивCm}$ to the operating phase current I_{mCn}. $K_{ив}$ for values of the first harmonic of current i_C and voltage u_{3iiC} is equal to:

$$K_{3ивC1} = \frac{U_{m3ивC1}}{I_{m3C1}} \qquad (2.7)$$

Active component K_{ii} is as follows:

$$R_{3ивC} = K_{3ивC1} \cdot \cos(\varphi_{iC1} - \varphi_{u3ивC1}) \quad (2.8)$$

Reactive component K_{ii} is as follows:

$$X_{3ивC} = K_{3ивC1} \cdot \sin(\varphi_{iC1} - \varphi_{u3ивC1}) \quad (2.9)$$

For other harmonic constituents and electrodes K_{ii}, R_{ii}, X_{ii} are located similarly.

3. RESULTS

Table 3.1 shows the dependence of active and reactive components K_{ii} on "C" operating phase current for the first harmonic, which implies that the quantities of active and inductive components K_{ii} do not depend practically on the current values and are determined by location of electrodes towards operating phase. The shorter the distance between the electrode and neighboring phase is, the higher value of X_{II} and R_{II} is, and the degree of current effect on the measured voltages of neighboring phases is higher. The developed correction method of measured instantaneous electrode voltage value error, considering the influence of instantaneous current values of neighboring phases, makes it possible, during each single-phase furnace closure, to find X_{II} and R_{II} for instantaneous non-operating phases electrode drop.

Table 3.1

Parameter		I_C	R_{1iiC1}	R_{2iiC1}	R_{3iiC1}	R_{4iiC1}	X_{1iiC1}	X_{2iiC1}	X_{3iiC1}	X_{4iiC1}
UOM		kA	Mohm	Mohm	Mohm	Mohm	Mohm	Mohm	Mohm	Mohm
Value	1	63.8	0.048	0.049	0.056	0.081	0.067	0.090	0.130	0.238
	2	65.7	0.048	0.049	0.055	0.081	0.067	0.090	0.130	0.237
	3	74.8	0.046	0.046	0.053	0.078	0.066	0.089	0.129	0.234
	4	82.9	0.045	0.046	0.053	0.078	0.069	0.092	0.132	0.239
	5	87.6	0.045	0.046	0.053	0.077	0.068	0.091	0.131	0.238

4. DISCUSSIONS

As part of automatic electric mode control system (AEMCS) of six-electrode furnace on ferrosilicon manganese melting [4], the model, which was based on the correction method of measured instantaneous electrode voltage value error, considering the influence of instantaneous current values of neighboring phases, was developed and implemented. The model implementation makes it possible to obtain, automatically on a real time basis, the real values of amplitudes and phase displacement angles of harmonic components of electrode voltages involved in determining the active resistance, power and other electric characteristics of near-electrode space employed in the industrial process management.

Figures 4.1 and 4.2 illustrate the results of the model operation efficiency checking. During the furnace operation in the three-phase mode, the calculation of real voltage (Fig. 4.1) and active resistance (Fig. 4.2) values of near-electrode space using instantaneous values of voltage drop directly measured at "electrode – hearth" of conducting hearth and real (corrected) values. After that, in order to exclude the effect of neighboring phases current on electrodes 3, 4 drop (phase "B"), without changing their position, the phases "A" and "C" were deactivated. The same calculation was made using the instantaneous values of voltage drops directly measured on the electrodes 3, 4 of phase "B".

It follows from the analysis results shown in Fig. 4.2 that resistance values of the third and the fourth electrodes determined during the single-phase furnace operation mode (no influence of neighboring phases) are almost the same as the resistance determined based on the real voltage values. As a result of direct voltage measurements, the values of active resistance of the electrodes 3 - 4 become mirror representation of electrode resistance values determined during operation of single phase "B" – greater resistance becomes less one and vice versa.

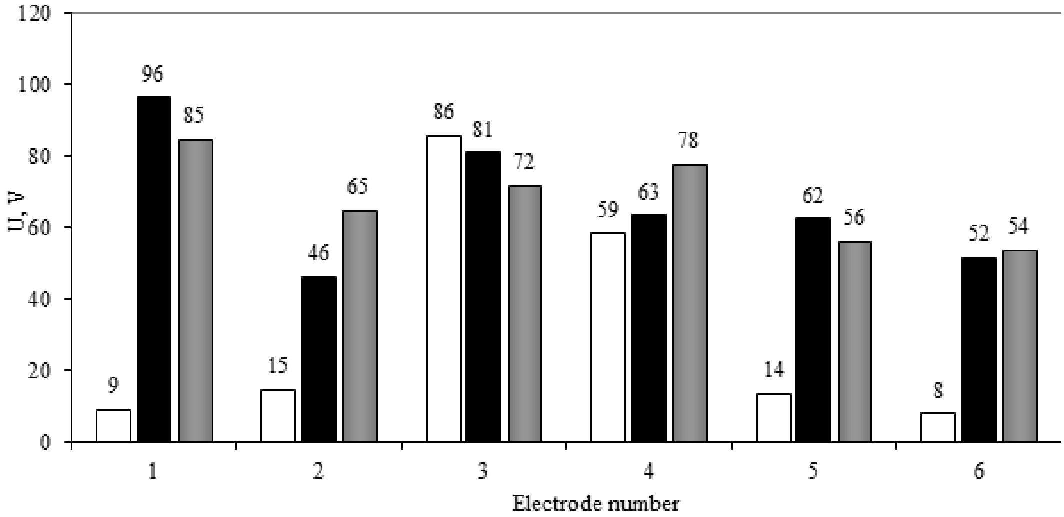

Figure 4.1: Values of real electrode voltage values of six-electrode ore-thermal electric furnace: □ **-** during operation of single phase "B" without effect of neighboring phases current; during three-phase closing: ▩ **-** without correction; ■ **-** corrected.

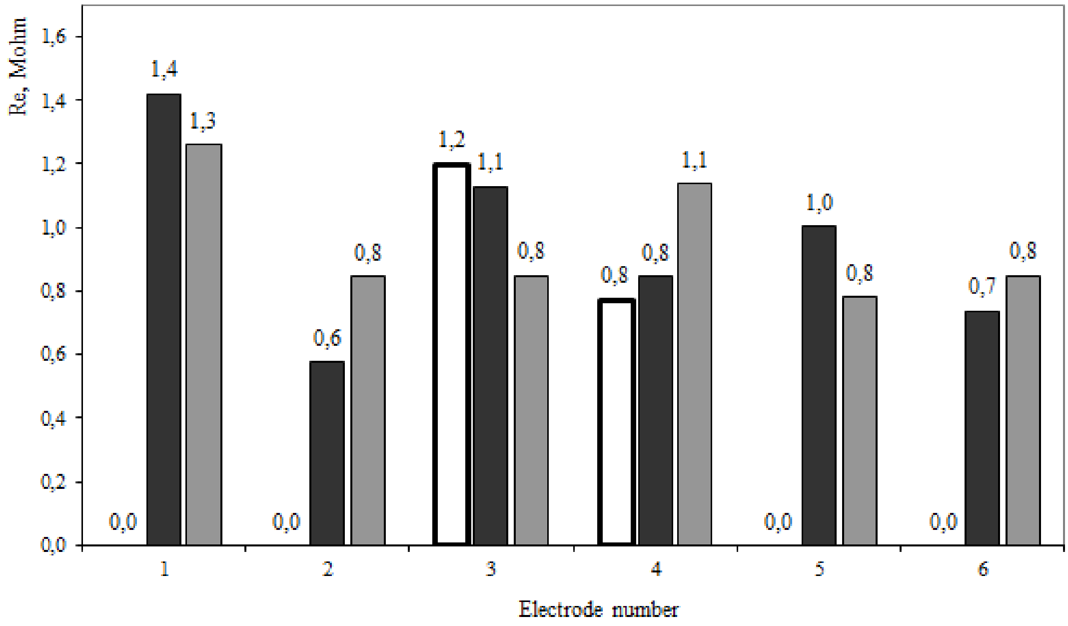

Figure 4.2: Values of calculated active resistance of near-electrode space of six-electrode ore-thermal electric furnace: □ - during operation of single phase "B", without effect of neighboring phases current; during three-phase closing: ▩ - without correction; ■ - corrected.

SUMMARY

It is shown that degree of current influence on measured voltages of neighboring phases does not depend on its value and is determined by electrodes location towards operating phase. The shorter the distance between the electrode and neighboring phase is, the higher value of X_{II} and R_{II} is, and the degree of current effect on the measured voltages of neighboring phases is higher.

The model developed based on the correction method of measured instantaneous electrode voltage value error considering the influence of instantaneous current values of neighboring phases makes it possible to obtain the real values of amplitudes and phase displacement angles of harmonic components of electrode voltages involved in determining the active resistance, power and other electric characteristics of near-electrode space employed in the operative industrial process management.

The deployment of the developed model as part of automatic electric mode control system of six-electrode ore-thermal electric furnace allowed optimizing the technical-and-economic parameters.

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