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ENERGY EFFICIENT, MULTICRITERION INTELLIGENT CONTROL SYSTEM OF THE ELECTRICAL REGIMES OF ARC STEEL-MELTING FURNACE

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Summary. Hierarchical structure of a system of adaptive multicriterion control of a three-phase arc steel furnace electrical modes is proposed. Models of optimal control vector synthesis were developed. Adaptation of control is performed depending on technological stages, which are identified by neural network.

Keywords: arc steel-melting furnace, neural network, control system

1. INTRODUCTION

Contemporary state of metal production industry is characterized by continuous growth of part of steels melted in three-phase electric arc furnaces (EAF). These steel-melting installments are characterized by large steady-state power of furnace transformer up to 1 MV·A/ton. They are characterized by highly dynamic, nonlinear and non-symmetrical load. Also, arc furnaces functioning is accompanied by technological short circuits and unstable, discontinuous burning of arcs and it can lead to oscillations of arc power, which are commensurable with furnace transformer power. Moreover, furnace functioning leads to oscillations, nonlinear shape distortions and non-symmetry in power system voltage. Four important problems arose during exploiting of arc furnaces:
1. Ensuring maximum arc power during melting of solid charge.
2. Qualitative stabilization of arc power.
3. Minimization of specific power losses.
4. Limiting nonlinear and varying load impact on power system.

Mentioned problems significantly increased in high-power and high-impedance furnaces with arc voltages of 1000-1500 Volts and specific power of 1 MV·A/ton. In general, these problems are contradictory and can be solved only with toleration of some compromises.

Solution of mentioned task requires adequate improvements of melting technology, development of new efficient melting systems and also creation of hierarchical intelligent systems of adaptive optimal control and high-speed multi-circuit systems for electric regime coordinates control. Moreover, high arc current amplitude oscillations lead to vibrations and significant electrodynamic forces in the windings of electrical power equipment, which decreases its functional reliability and life time. This is mainly caused by the low dynamic accuracy of controlling the electrical-regime parameters because of the significant sluggishness of existing electromechanical (electrohydraulic) electrode-position control systems.

Nowadays, the part of electrical steels in the total steel output is increasing, the power of an electric furnaces is increasing, and, as the result, melting process is intensified [1,2]. Therefore, it is important to improve the electrical and technical efficiency of arc furnaces and the electromagnetic compatibility of the electrical-regime parameters with the power system parameters.

As for the technical and economic assessment, the optimum control of electric melting is known to be two to three times as efficient as the solutions intended for stabilizing electrical regime parameters [3]. Nevertheless, these problems should be solved jointly, since the qualitative stabilization of electrical-regime parameters at the level of synthesized optimum values additionally increases the control efficiency. Therefore, the main methods of increasing the electrical and technical efficiency of melting in arc steel furnaces are represented by developing control circuits and synthesis of optimal control methods. They are intended for minimization of dispersion of the electrical regime coordinates and stabilizing them at the level of synthesized optimum values.

2. ANALYSIS OF KNOWN SOLUTIONS

The functions of most existing EAF electrical-regime control systems (e.g., ARDG, ARDMT, RMM, and STU arc-power controllers) are mainly limited to the maintenance of a specified phase impedance, arc voltage, or arc current depending on the voltage of the secondary winding of a furnace transformer (FT). As noted above, high oscillations in the electrical-regime parameters, which are caused by the low dynamic accuracy of their control and the limited functional optimization abilities of the above mentioned controllers given do not allow one to substantially increase the efficiency of the EAF heat-regime control.

To improve the electromagnetic compatibility of the arc-furnace electrical operating conditions with the power system conditions, static filter-compensating devices are widely used in metallurgy, which should compensate for the negative effects of a furnace on the power system. Of course, such solutions are often required. But we believe that metallurgists should mainly obtain automatic and algorithmic solutions intended for the suppression of the causes of disturbances in their origin (in the power circuit of an arc furnace), i.e., solutions intended to anticipate the appearance of negative actions on the technical and economic indices of the furnace and the electromagnetic compatibility of the furnace electrical operating conditions with the power system conditions.

The authors of [4] give an example of the realization of this direction in increasing the efficiency of controlling the EAF electrical conditions; they describe an EAF power system that includes a saturating reactor. In furnaces with such a power system and high impedance, metallurgists can increase the EAF transformer power via increasing the secondary voltage and can run a heat using long arcs. These solutions can decrease the arc-current dispersion, increase the arc stability, and decrease the short-circuit probability, all other things being equal.

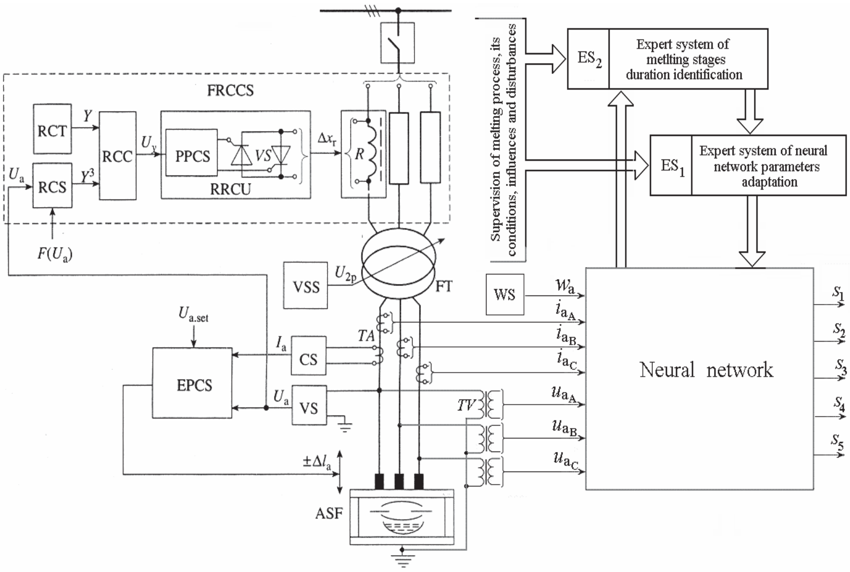

Fig. 1. Functional schematic diagram of the power and electrical-regime control system for an EAF with neural-network-based melting stages recognition: FRCCS is the regime coordinate control subsystem; RCS and RCT, regime coordinate set-point device and transducer, respectively; RCC, regime coordinate controller; RRCU, reactor-resistance control unit; PPCS, pulse-phase control system; *VS*, thyristor unit; *R*, reactor; EPCS, electrode-position control subsystem; CS and VS, current and phase-voltage sensors, respectively; FT, furnace transformer; and VSS, transformer voltage step switch; ES_1 and ES_2, expert systems.

However, when the method of controlling the reactor resistance proposed in [4] is used, a single type of artificial external characteristics (AECs) in a furnace, i.e., arc current-voltage characteristics ($I_a(U_a)$), is only realized. This type is represented by characteristics such that the arc currents are stabilized in the range of low and medium arc voltages (short and long arcs). The arc current is a controlled parameter in such furnace AECs at a given voltage step of a furnace transformer, and the arc current is specified by the bias current of the saturating reactor. This scheme restricts the functional possibilities of the system in the realization of various optimum strategies of controlling EAF regimes using partial criteria or generalized target functionals, which are formed with allowance for current heat conditions and current requirements for the technical and economic indices of an arc furnace. Moreover, the realization of this control requires a significant preset power of the saturating reactor, and the shape of the electric current during control is close to a rectangular shape. The fabrication of such a saturating reactor requires high-quality magnetic materials with oriented crystals.

3. TWO-CIRCUIT HIGH-SPEED CONTROL SYSTEM

To realize these directions in increasing the control efficiency, we propose a two-circuit coordinate-parameter hierarchical automatic control system (CS) for an EAF electrical regime with automatic neural network based identification of technologic stages (Fig. 1).

In this two-circuit system, regime coordinates, i.e., electrical regime coordinates such as the arc current, arc power, and furnace reactive power (which change according to their specific laws), are rapidly controlled and stabilized at a given level using the thyristor-assisted control of the resistance of a reactor located in the primary winding circuit of the furnace transformer. Conventional single-phase current-limiting nonsaturating reactors, which do not require special magnetic materials for their magnetic system, are used as the reactor in each furnace-power phase.

This CS of melting modes consists of two subsystems (control circuits), namely, an electrode position control subsystem (EPCS) and a furnace-regime coordinate-control subsystem (FRCCS). These systems operate simultaneously and independently and have isolated phases.

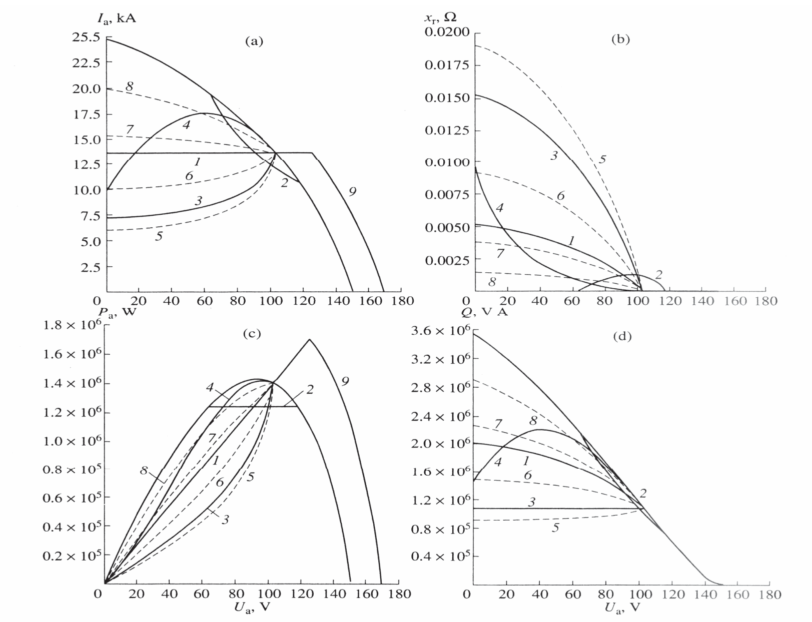

Fig. 2. Electrical characteristics of a DSP-6 arc steelmaking furnace with a two-circuit electrical-regime control system (the numerals on the curves are explained in the text).

The first subsystem is an ordinary electrode-position control system with an electromechanical or hydraulic actuator, which controls the change in the arc length $\pm\Delta l_a$. The control of the arc length is indirectly realized as a function of the current values of arc current I_a and voltage U_a, and the signals proportional to these values are generated at the output of an arc current or voltage sensor, respectively. An arc-voltage setting signal $U_{a.set}$, which is proportional to l_a, is the master control of this subsystem. If necessary, transformer voltage steps can be switched using VSS devices.

The FRCCS subsystem is intended for controlling a furnace-regime coordinate (electrical-regime parameter), such as the arc current, arc power, or furnace-reactive power.

A change in the reactor resistance Δx_r is the master control of this subsystem. In each phase, this change is controlled smoothly and continuously via shunting the reactor by a VS thyristor unit in a certain controlled segment of a powering voltage half-cycle. The segment time is determined by the phase of the output signal of a pulse-phase control system (PPCS), and this signal, in turn, forms as an autocorrelation function of the output signal U_y of a proportional-integral furnace regime coordinate controller (RCC). The input of this controller receives Y^3 signals from a set-point device and Y signals from the sensor of a certain controlled furnace-regime coordinate. In the general case, the setting signal Y^3 of this subsystem is a function of the arc voltage, which enters into the input of a furnace-regime coordinate set-point device (RCS). In particular, upon the stabilization of a regime coordinate, signal Y^3 is a constant, which determines the required level of regime-coordinate stabilization. In the general case, setting signal Y^3 is calculated in the RCS from a $Y^3 = F(U_a)$ relation, which is the setting action of this subsystem (this is especially effective for the realization of the adaptive multicriterion control of an EAF electrical-heat regime). Compared to the electromechanical EPCS subsystem, the speed of this subsystem is higher by an order of magnitude: its response time is 0.03-0.04 s. For the reactor resistance to be controlled with a thyristor, metallurgists developed solutions so that the distortion of the sinusoidal furnace-loading currents is minimal.

4. MELTING STAGES RECOGNTION SYSTEM

One of the prerequisites of guaranteed production of steels and alloys with desired physical and chemical properties and of high technological and economical efficiency during melting process is synthesis and implementation of two-circuit system control vector depending on technological melting stage. Therefore one of main problems is recognition of technological melting stages and moments of their changes.

Most efficient approach to technological stages recognition under conditions of insufficient information about technological process and its stochastic fluctuations is recognition based on neural networks principles. For implementation of such approach, three-layer neural-network- based expert system is included into control system. It is used for recognition of melting stages S_1, S_2, …, S_5 (Fig.1). Input information of the neural network is vector of instantaneous values of arc voltages u_{aA}, u_{aB}, u_{aC}, currents i_{aA}, i_{aB}, i_{aC} and consumed on current stage active energy w_a [5,6]. Informative parameters of mentioned electrical mode coordinates time dependencies are averaged values on stationarity intervals of their canonical harmonics (they are calculated using FFT method). Also, power spectrums of voltages U_a and currents I_a in informative frequency range are taken into account. They are calculated using the fast wavelet transform technique. Dispersion, correlation coefficient and total harmonic distortions (THD) coefficients of currents and voltages are used too. Algorithm of operative calculation of mentioned parameters integral values is implemented using microprocessor device. Optimal parameters of three-layer neural network used for melting stages recognition were obtained, training and testing performed. Industrial testing of network was performed on arc furnace DSP-3. This neural network forms the first level of melting stages recognition hierarchical system.

On the second level there is expert system ES_1, which serves for adaptive optimization of neural network variable coefficients (coefficients of synaptic relations). This expert system is of production type, in other words is it based on “instructive knowledge” – in form of production rules “If … Then …” This expert system, basing on expert knowledge and operative input information, performs discrete parametric optimization of neural network to parameters of furnace charge. It loads from database synthesized matrix of synaptic relations, which corresponds to current type, density and stowing of hard charge, changes transfer constant of active energy measuring channel proportionally to the weight and temperature of loaded charge. Knowledge base of expert system is assembled from formalized technical specialists' experience.

On the third, highest level of hierarchy expert system ES_2 is used, which processes expert knowledge from exact analysis of melting stages changes. If identification error is greater then certain threshold, ES_2 initializes procedure of learning (adjusting) to slowly varying conditions of melting process: current state of furnace cladding, power supply parameters, external temperature, etc.

Developed expert hierarchical neural-network-based system for melting stages recognition naturally combines advantages of neural networks and expert systems. Neural networks have capability of operative parametrical adaptation and expert systems make it possible to relatively simple identify moments of adaptation algorithms start.

This ensures small error of melting stage change moments identification. Error didn't exceed 5% during experiment melting in DSP-3 furnace.

5. ELECTRICAL CHARACTERISTICS OF A TWO-CIRCUIT CS

Fig. 2a shows the natural and artificial external characteristics of a DSP-6 arc furnace in the first step of the furnace transformer. Artificial external $I_a(U_a)$ characteristics *7*, *2*, and *3* are formed by the two-circuit coordinate-parameter control system upon the stabilization of the arc current, arc power, and furnace reactive power in the zone of short and medium arc lengths. Fig. 2b shows the corresponding reactor resistance $x_r(U_a)$ curves for characteristics *1*, *2*, and *3*. Fig. 2c and 2d show the artificial characteristics of the arc power ($P_a(U_a)$) and furnace reactive power ($Q(U_a)$) corresponding to characteristics *1*, *2*, and *3*. For the artificial furnace characteristics corresponding to characteristics *1* and *2*, we obtained the following $x_r(U_a)$ dependences for controlling the reactor resistance:

$$x_{\mathrm{r}}^{I}(U_{\mathrm{a}}) = \frac{\sqrt{U_{2\mathrm{p}}^{2} - U_{\mathrm{a}}^{2} - 2rU_{\mathrm{a}}I_{\mathrm{as}} - r^{2}I_{\mathrm{as}}^{2}}}{I_{\mathrm{as}}} - x\,;$$

$$x_{\mathrm{r}}^{P}(U_{\mathrm{a}}) = \frac{\sqrt{U_{\mathrm{a}}^{2} - (U_{2\mathrm{p}}^{2} - U_{\mathrm{a}}^{2} - 2rP_{\mathrm{as}}) - r^{2}P_{\mathrm{as}}^{2}}}{P_{\mathrm{as}}} - x\,;$$

where:

- U_{2p} – secondary-phase voltage of the electric-furnace transformer,
- r, x – active and reactive current-lead resistances, respectively,
- I_{as}, P_{as} – levels of arc-current stabilization and arc-power stabilization, respectively.

The problem of coordinate stabilization during regime optimization is a partial problem. In the general case, the proposed two-circuit CS can realize other $I_a(U_a)$ AECs, e.g., those of type *4* (Fig. 2) or similar to the family of dashed curves *5*,*6*,*7* and *8*. For these and related AECs, we obtained models for the calculation of the corresponding reactor resistances $x_r^{Y}(U_a)$.

In the general case, we take into account a synthesized $x_r(U_a)$ dependence and calculate the artificial external characteristics of a furnace using the expression

$$I_a(U_a) = \frac{-U_a r + \sqrt{(rU_a)^2 + (r^2 + (x + x_r(U_a))^2)(U_{2p}^2 - U_a^2)}}{r^2 + (x + x_r(U_a))^2}. \quad (1)$$

In particular, AECs of types *1*,*3*,*5*,*6*,*7*, or *8* (Fig. 2) are calculated from (1) via multiplying a forming coefficient γ from the basic regulation law $x_r(U_a) = \gamma\, x_r^b\,(U_a)$. The basic regulation law is taken to be a $x_r(U_a)$ law corresponding to characteristics *1* or *3*. We assumed that the basic regulation law corresponds to characteristic *3*, i.e., $x_r(U_a) = x_r^Q(U_a) = x_r^b(U_a)$, where γ = 1. When substituting $x_r(U_a) = \gamma\, x_r^b\,(U_a)$ into (1) and changing the values of γ in the range from 0 to 1.25, we calculate the family of characteristics *8*, *7*, *1*, *6*, *3*, and *5* located between the natural external furnace characteristic (γ = 0) and AECs of type *5* (γ = 1.25).

When AECs are formed via adjusting the reactor resistance, the arc power $P_a(U_a)$ decreases with respect to the power for the natural characteristic ($x_r(U_a) = 0$). To compensate for this decrease and to increase (if necessary) the average arc power, it is sufficient to increase the secondary voltage of the furnace transformer (Fig. 2, characteristic 9) by 10-30%, which corresponds to modern trends in the intensification of the regimes of high-impedance long-arc furnaces [1,2].

In the general case, the control vector $\vec{x}\,(U_{2p}, U_{a\cdot set}, \gamma_1, \gamma_2, ...)$ contains the secondary voltage of the furnace transformer U_{2p}; the arc-voltage setting $U_{a\cdot set}$ of the electrode-position controller; and the coefficients γ_1, γ_2, ... of an analytical expression for the AECs of the arc furnace (which are variable parameters for optimum control synthesis).

6. OPTIMAL CONTROL SYNTHESIS MODELS FOR CS

We now determine the family of particular optimum criteria and compose a control target functional for the entire system in order to perform the operative synthesis of the optimum control of an EAF electrical regime according to current (technological, industrial, energetic, etc.) external conditions and the required technical and economic indices.

One of the versions of the mathematical optimization model is a multicriterion multiparametric optimization based on the set of alternative Pareto's optimum solutions,

$$\Phi(\vec{x}) = \Phi(Q_1(\vec{x}), Q_2(\vec{x}), ..., Q_s(\vec{x})) = \sum_{i=1}^{s} \lambda_i Q_i(\vec{x}) \Rightarrow \min,$$

where:

$Q_1(\vec{x}), Q_2(\vec{x}), ..., Q_s(\vec{x})$ – partial criteria;

λ_i – their weight coefficients.

This functional determines a control target and, along with the vector $\vec{x}$ of variable setting system actions and the description of its variation range $\vec{x} \in D$, forms a mathematical model for decision making in the problem of the optimum multicriterion control strategy.

One of the challenges in increasing the level of the electromagnetic compatibility is the synthesis of optimum control based on an indirect criterion, namely, the sum of the dispersions of the normalized arc current $D^*_{I_\mathrm{a}}(U_\mathrm{a.set}, \gamma)$ and the furnace reactive power $D^*_Q(U_\mathrm{a.set}, \gamma)$. The extremum of this criterion corresponds to the minimum of the dispersion of the network voltage fluctuational component,

$$D^*(U_\mathrm{a.set}, \gamma) = \lambda_{I_\mathrm{a}} D^*_{I_\mathrm{a}}(U_\mathrm{a.set}, \gamma) + \lambda_Q D^*_Q(U_\mathrm{a.set}, \gamma) \Rightarrow \min, \qquad (2)$$

where:

λ_{I_a} , λ_Q – weight coefficients of the $D^*_{I_\mathrm{a}}$, D^*_Q dispersions, respectively.

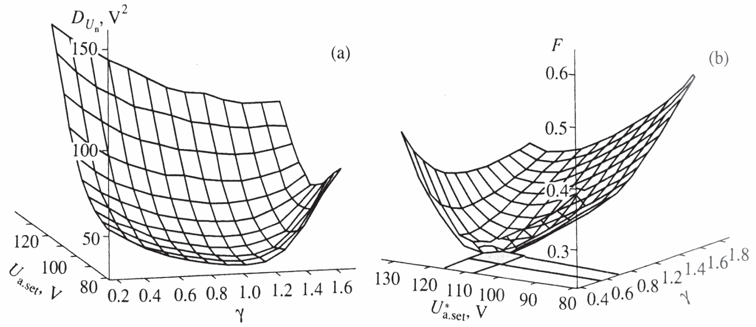

Fig. 3. Dependences of (a) the network-voltage dispersion and (b) the value of functional (3) on the setting actions of the two-circuit electrical-regime control system of a DSP-6 furnace.

Fig. 3a shows the dependence of the network voltage dispersion D_{U_a} on the variable setting actions of the system, namely, the EPCS arc-voltage setting and the AEC forming coefficient γ, which is obtained when the DSP-6 furnace regime is controlled by functional (2). The coordinates of its minimum determine the optimum setting actions $U^*_\mathrm{a.set}$ and γ^* of the two-circuit system when the electrical regime of the arc furnace is controlled by functional (2).

Another approach is the optimum-compromise control using the criterion of the maximum electric-power efficiency. This approach is effective due to the modern conditions of deficient and expensive electric power and the tendency toward intensifying a heat via an increase in the furnace transformer specific power (i.e., an increase in the secondary voltage of the transformer). This control can be synthesized using, e.g., the generalized additive functional

$$\begin{aligned}\Phi(U_\mathrm{a.set}, \gamma) = 0.28(1 - \overline{P}^*_\mathrm{a}(U_\mathrm{a.set}, \gamma) + 0.24\overline{P}^*_\mathrm{ep}(U_\mathrm{a.set}, \gamma) \\ + 0.21 D^*_{I_\mathrm{a}}(U_\mathrm{a.set}, \gamma) + 0.27\overline{W}^*(U_\mathrm{a.set}, \gamma)) \Rightarrow \min\end{aligned} . \qquad (3)$$

Fig. 3b shows the surface of this functional, and its extremum coordinates $U^*_\mathrm{a.set}$, γ^* correspond to the setting actions of the system when the optimum control is realized according to the maximum efficiency of using electric power.

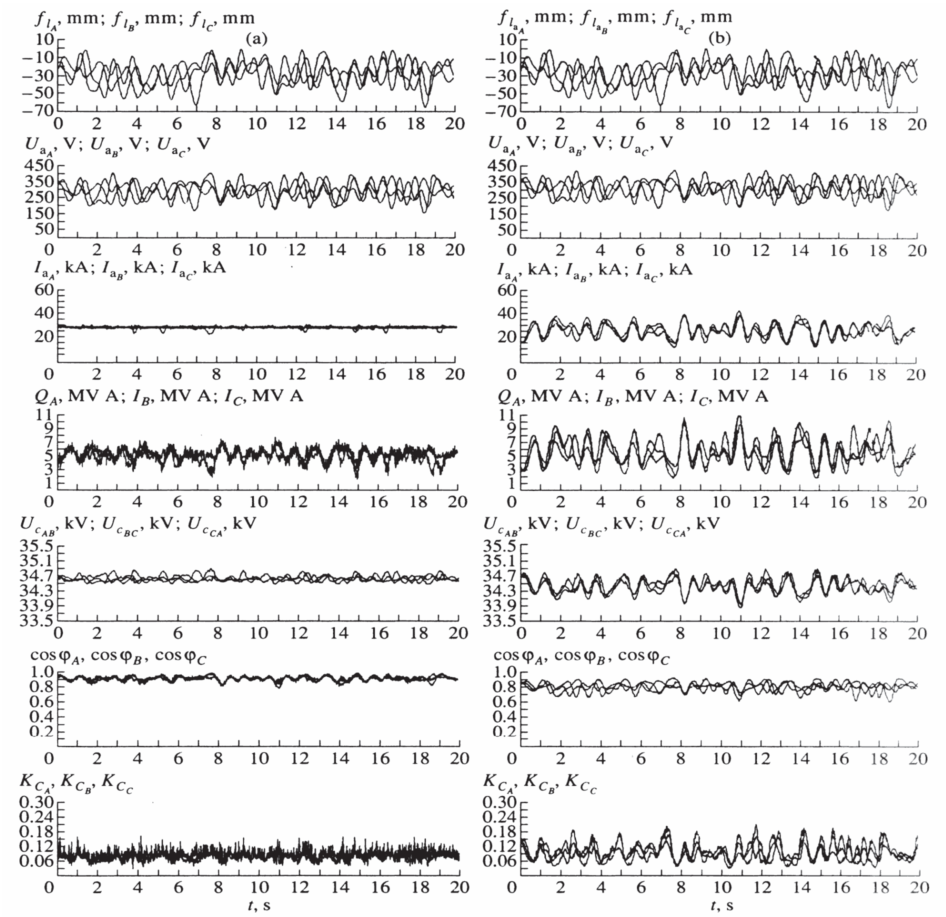

Fig. 4. Diagrams for DSP-50 electrical-regime coordinates at the stage of well melting for the operation of (a) the two-level CS and (b) an ARDG controller.

Control synthesis based on the formation of arc-furnace AECs of type *4* in Fig. 2 is an effective approach to optimizing furnace regimes according to the criterion of the maximum electric-power efficiency. A positive specific feature of characteristics of this type for this criterion is a minimum decrease in the arc power for medium-length arcs (in the range of rational furnace regimes) and an effective decrease in the power of the electric loss and the reactive furnace power for short arcs (for operational short circuits and similar regimes). As a result, the specific electric power consumption decreases, the reactive power consumption decreases, and the electric efficiency of an arc furnace increases.

We designed a hierarchic two-level system for the optimum control of the consumption regimes of the arc-furnace reactive power in order to substantially increase the electrical and technical efficiency of heat control and to improve the electromagnetic compatibility of arc-furnace regimes and power-network regimes. As an FRCCS, the lower level uses a high-speed subsystem for optimum reactive furnace power stabilization, which is optimized using criterion (2). In the general case, the upper level employs a static thyristor reactive power compensator. However, our results demonstrate that, for low- and medium-power furnaces, the upper level can contain only a capacitor bank to compensate for the constant component of the reactive power, i.e., to increase the power coefficient to the required level. This increase is necessary to decrease the electrical losses in the furnace power circuit and the energy system. This is possible owing to the fact that the use of the optimum stabilization of the reactive furnace power in the lower level of the subsystem minimizes the fluctuational component of the reactive furnace power to a level at which network voltage oscillations, which are estimated from the flicker dose, do not exceed the normative values.

Table 1. Integrated indices for ARDG controller and proposed CS.

Index	Two-level CS	ARDG controller
$\overline{U}_{\mathrm{a}}$,V	299.4	313.0
$\overline{I}_{\mathrm{a}}$, kA	29.1	27.3
$D_{I_{\mathrm{a}}}$, kA^2	0.939	35.4
$\overline{P}_{\mathrm{a}}$, MW	7.05	6.73
$\overline{U}_{\mathrm{n}}$, kV	34.67	34.46
$D_{U_{\mathrm{n}}}$, $\times 10^3$ V^2	7.27	37.58
$\overline{I}_{\mathrm{n}}$, A	330.2	353.1
$\overline{Q}_{\mathrm{c}}$, MVA	5.26	5.61
D_Q , MVA^2	859	3354
$\overline{\cos(\varphi)}$	0.914	0.80
$\overline{K}_{\mathrm{n}_{I_{\mathrm{n}}}}$	0.0835	0.0971
δU_{n} , %	0.947	1.542
F	0.0379	0.220

The efficiency of the designed CS structures and the proposed strategies of the multicriterion control of the electrical regimes of the heat were tested using a digital instantaneous-coordinate model for the power system and the two-circuit control system for arc-furnace electrical-regime coordinates. We studied furnaces of various capacities at various heat stages. To adequately simulate electrical regimes at various stages, we used random arc-length fluctuations, whose statistical characteristics (in particular, a spectral perturbation density function along an arc) corresponded to the real characteristics of these fluctuations at a certain heat stage in an arc furnace.

As an example, Fig. 4 shows the calculated diagrams for the working parameters of a DSP-50 arc furnace and its power network at the stage of well melting for the reactive power consumption regime determined by the designed two-level CS during the operation of an ARDG standard electrohydraulic arc-power controller. For each phase, these diagrams show a perturbation variation along the arc length $f_{l_a}(t)$ at this stage of heat, the arc voltage $U_a(t)$, the arc current $I_a(t)$, the furnace reactive power $Q(t)$, the voltage across the power-network busbars $U_n(t)$, the power factor $\cos\varphi(t)$, and the current harmonicity perturbation coefficient $K_h(U_a)$. The table gives the integrated indices (mathematical expectations, dispersions) that illustrate the operation efficiency of these systems and are obtained by the statistical processing of the results shown in Fig. 4. In these experiments, the arc voltage was $U_{a.set}$ = 313 V, and an ARDG arc-power controller was used. As a result of the calculations, the nominal arc current is $I_a = I_{a.n}$ = 27.3 kA, and the arc power is $P_a = P_{a.n}$ = 6.73 MW at a secondary voltage of 407 V. For the two-level CS, the secondary transformer voltage was increased by 10%, and the artificial external furnace characteristic was synthesized by functional (2) under conditions of a network voltage dispersion minimum. This minimum corresponds to the following optimum values: γ^* = 0.75 and $U_{a.set}$ = 299 V.

The calculated integrated indices demonstrate that all of the indices are significantly improved when the two-level CS is used instead of an ARDG-type arc-power controller. For example, the arc-current dispersion decreases by 30-40 times, and the flicker dose F decreases by a factor of five to six. The loading current harmonic distortions coefficient decreases by 14-15%; the power factor increases by 14-15%; the arc power increases by 4-5%; and the deviation of the voltage across furnace busbars from the nominal voltage decreases by 1.4-1.6%.

7. CONCLUSIONS

The use of a high-speed subsystem that controls the resistance of a reactor involved in the power circuit of the primary winding of a furnace transformer in the structure of a proposed two-circuit CS allows one to realize the multicriterion optimum control of an EAF electrical regime. This control provides a substantial increase in the electrical and technical efficiency of arc-furnace regimes and improves the indices of the electromagnetic compatibility of the furnace and its power system.

The proposed two-circuit CS can be used to run heats at the minimum number of switchings of a furnace transformer, which decreases the heat time and increases the reliability of the furnace power supply. Variable setting actions for the realization of the multi-criterion optimum control in this case, i.e., at U_{2p}= const, are only represented by a preset arc voltage $U_{a.set}$ and an $I_a(U_a)$ AEC relation for an arc furnace.

The substantial induced decrease in the amplitude and dispersion of the arc-current and furnace reactive power oscillations decreases the flicker dose by a factor of five to six and decreases the electrodynamic forces in the elements of the electric power facilities and their mechanical vibrations. As a result, the reliability of this equipment increases.

Efficiency of optimal control strategies implementation increased due to their synchronization with changes of melting stages, which are identified by hierarchical neural-network based control system.

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ENERGOOSZCZĘDNY, WIELOKRYTERIALNY UKŁAD INTELIGENTNY DO STEROWANIA ELEKTRYCZNYMI STANAMI PRACY PIECA ŁUKOWEGO DO TOPIENIA STALI

Streszczenie

W artykule zaproponowano hierarchiczną strukturę układu adaptacyjnego do wielokryterialnego sterowania stanami pracy trójfazowego pieca łukowego do topienia stali. Opracowano modele syntezy optymalnego wektora sterowania. Adaptacja sterowania dokonuje się w zależnośći od stadiów technologicznych topienia stali, które są identyfikowane za pomocą sieci neuronowej.

Słowa kluczowe: piec łukowy do topienia stali, sieć neuronowa, układ sterowania