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The system of arc lengths regulation of an electric arc furnace with a neuro-controller

Abstract. *The elaborated system of regulation of an arc lengths of an electric arc furnace with a neuro-controller and the obtained results of computer simulation of electric mode for the existing and proposed systems have shown improvement of dynamics indicators of regulating arc lengths as compared with a serial power controller – AFAR-T.*

Streszczenie. *Praca przedstawia system sterowania łukiem w piecu łukowym za pomocą sterownika neuronowego. Zbadano model komputerowy takiego urządzenia w Simulinku. Wyniki tych badań pokazały przewagę takiego rozwiązania w stosunku szeregowego sterownika AFART-T (**System regulacji długości łuku w elektrycznym piecu łukowym ze sterownikiem neuronowym**).*

Keywords: steel-melting arc furnace, neuro-controller, computer model, dynamics
Słowa kluczowe: piec łukowy, sterownik neuronowy, model komputerowy, dynamika

Introduction

Electric arc furnaces (EAF) have found a wide application in ferrous metallurgy for production of steel and precision alloys. Throughout melting the electric mode (EM) is characterized by instability and is accompanied by constant fluctuation of the arc power. The deviation of the EM from the rational (optimal) mode decreases the electro-technical efficiency indicator.

The existing systems of automatic regulation (ARS) of the electric mode (EM) (arc power regulators) of electric arc furnaces (EAF) do not fully satisfy modern strict regulations towards dynamic and static precision of keeping electric mode coordinates on the preset level, namely optimal values. These requirements are put forward by the problems of energy savings, its efficiency, electromagnetic compatibility of the EAF mode and electrical networks (power systems) as well as technological process and environmental issues.

The reason for unsatisfactory dynamic and static precision of ARS EAF is the existence of considerable non-linearity, dead zones and backlash in regulation system, object of control and in the mechanism of electrode displacement, as well as uninterrupted performance of coordinated (arcs lengths) and parameter disturbances, which possess occasional non-stationary nature. These factors, as well as certain lag effect of the existing ARS lead to considerable dispersion of EM coordinates, which negatively influences both technical and economic indicators of EAF [1].

Therefore the task of improving the existing ARS arcs (power) lengths is very important and topical. This article attempts to solve this task by implementing neuro-network controlling principles.

Proposed solutions

To improve dynamic indicators the authors propose the electro-mechanical system of regulating the arcs lengths with a neuro-controller Fig. 1. In this system the DC-motor, through the reducer, carries out the transition of the electrode, thus regulating arcs lengths and, consequently, voltage, current and arc power. Electric drive of electrodes displacement (EDED) is realized according to the scheme "thyristor transformer – DC-motor" with the forming negative feedback for current and the motor speed, and the electrode displacement mechanism (EDM) is the "pinion-rake" type. The kinematical scheme is close to being balanced. The moment of the static workload includes the reactive moment of friction, a short moment of the moving masses imbalance and a considerable dynamic moment. The regulation is executed according to the differential law of regulation:

$$U_{dif} = bU_a - a(I_{a.set} - I_a) \quad (1)$$

where: U_a, I_a – the average values of the arc voltage and current, $I_{a.set}$ – the set value of the arc current, a, b – stable coefficients which designate stable electrical mode.

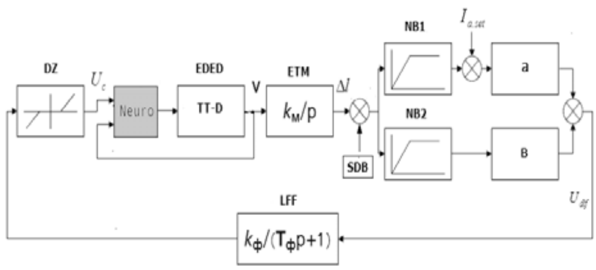

Fig.1. EAF power controller with a neuro-controller functional chart for one phase

The neuro-controller is activated at the thyristor transformer input of the electric drive electrode transition. It is constant and forms the regulation signal $U_c = f(U_{dif})$ [2].

Research Results

The design of the neuron-regulator included the stage of identification of the controlling object and the stage of regulation law synthesis. To identify the object of control model on the base of neuro-network the digital Simulink-model of the electric drive and mechanism of electrode transfer have been elaborated.

For the neuron network (NN) the following parameters have been set: a hidden layer, the number of neurons in the hidden layer S = 8, the number of delay elements on the neuro-network input N_i = 3 and the number of delay elements on the neuro-network output N_j = 3.

The size of the learning module comprised N_B = 10000, and time discretion comprised Δt = 0.01 sec. The NN input vectors were represented as numerical array in the double format, which corresponds to group data presentation. Data arrays were supplied to the input of the created Simulink-model of the controlling object to obtain reaction on the input data. The Simulink-model of the controlling object was presented to the neuro-controller for training with the purpose of reproducing its modes. According to the monitoring results of the digital model of the controlling object the training data sets were formed for neuro-network training which was carried out with the use of the trainlm function in correspondence with Levenberg-Marquardt algorithm. The synthesis of the neuro-controller was carried out by means of activation of NARMA-L2 Controller block from the Simulink library.[3].

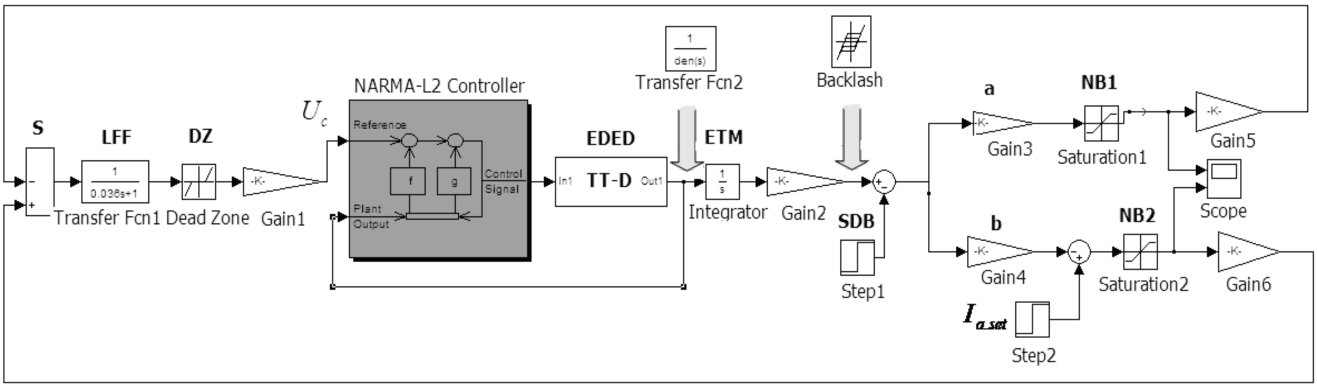

Fig.2. Structural chart of the ARS digital model of EAF-200 arcs lengths

Non-linear block NB1 reproduces the linearized in the working mode external characteristic of the furnace $I_a(l_a)$.

The gap in the model is represented by the static characteristic of the arc $U_a = g \times \psi(I_a)$ where g – is conductivity of the arc column, which was reproduced in the non-linear block NB2.

The electrode displacement mechanism (EDM) was supplied by a single and double array link. At the output of the summarizer S the difference signal was formed U_{dif}.

The low frequency filter (LFF) reproduced lag effect of the controlling signal formation and along with the element “dead zone” (DZ) and summarizer S supplied the model of formation block to the difference signal U_{dif}. The simulation disturbances block (SDB) formed time dependencies of the determined and occasional disturbances, according to the arc length $l_{dis}(t)$, for study of ARS modes at various stages of the steelmaking process[4]. The frequency and amplitude disturbances characteristics according to the arc length $l_{dis}(t)$ corresponded with the real ones which exist in the arc intervals at various stages of electric arc steelmaking.

The working efficiency of the designed electric mode ARS with a neuron regulator was evaluated by comparing it with the performance of a serial arc power regulator AFAR–T-12 used in the EAF - 200 arc furnace. In order to do it, mathematical experiments were conducted on the created Simulink-models Fig.2. The models differed only either in existence or absence of the block which represented NARMA-L2 Controller neuro-controller model.

The created Simulink-model of the designed ARS EM with a neuro-controller Fig.2 consisted of the following functional blocks:

- Transfer Fcn 1 (LFF) block imitated inertia of the comparison block which formed the controlling signal (1);
- Dead Zone block constituted dead zone of the controller, which can be modified from 0 to 20%;
- Grain 1 and Gain 2 blocks served as signal amplifiers;
- TT-D block realized the model of the thyristor transformer – DC motor” system;
- Transfer Fcn 2 block realized spring oscillation which exist in the real ETM;
- Integrator (ETM) block served for transformation of the ETM motor angle speed into linear transitions of electrode and acted as an integral link;
- Backlash block represented backlash in the reducer of the ETM;
- Step 2 block set the arc power controller mode according to the arc’s current $I_{a.set}$;
- Step 1 (SDB) block served for initiating determined and occasional disturbances according to the arcs lengths;
- Gain 5,6(a, b) and Saturation 1,2 (NB1, NB2) blocks reproduced electric arc mode;
- Scope block served for construction of time dependencies of the arc’s current $I_a(t)$ and voltage $U_a(t)$.

Fig.3 shows the dependencies of change of an arc’s length, current and voltage, obtained on the Simulink-model while causing determined disturbances by AFAR-T-12 controller and Fig.4 shows time dependencies of the same coordinates of the burning mode but this time using the designed ARS arcs lengths with a neuro-controller.

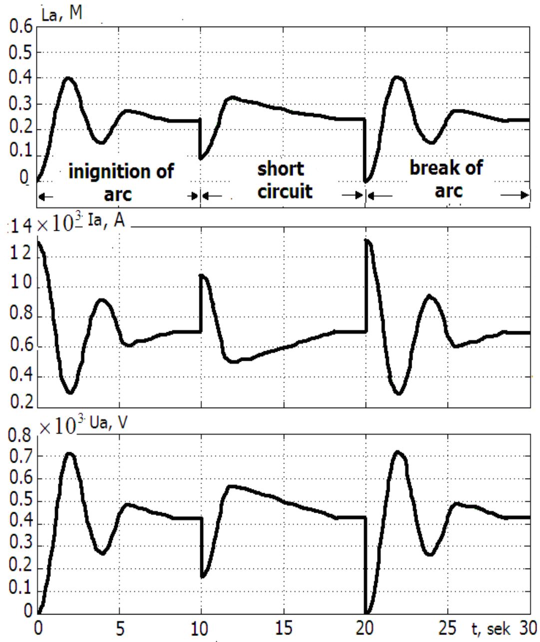

Fig.3. Time dependencies $l_a(t)$, $I_a(t)$ and $U_a(t)$ of ARS EM on the base of AFAR-T-12 controller

As follows from Fig.4 controlling burning mode with a system that used a neuro-controller allowed to implement aperiodic law of electrode movement according to which the arc current dispersion is minimized in the quasi-set models when causing occasional disturbances. Regulation time of separate disturbances was decreased by 30-40%.

Fig.5 shows obtained on the digital model time dependencies $l_{dis}(t)$, $l_a(t)$, $I_a(t)$ and $U_a(t)$ of ARS electric mode on the base of AFAR-T-12 controller under the influence of occasional disturbances, whereas Fig.6 shows processes of changes of the same coordinates of EM EAF-200 arc furnace but of the designed ARS arcs lengths with a neuron regulator.

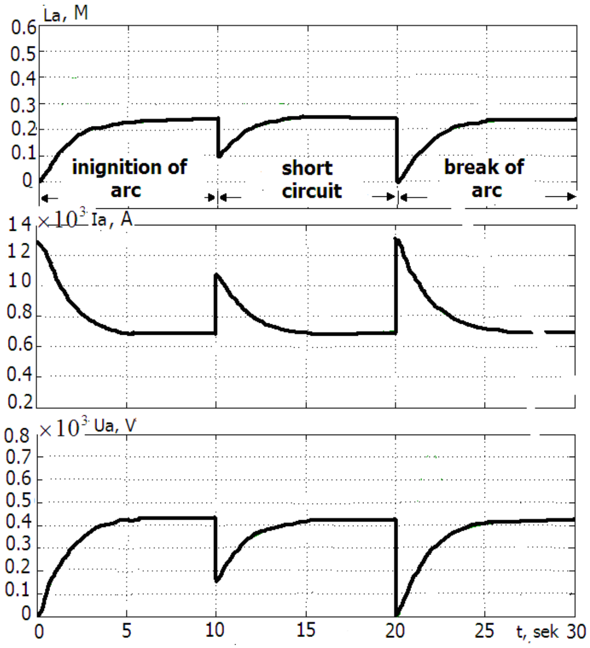

Fig.4. Time dependencies $l_a(t)$, $I_a(t)$ and $U_a(t)$ ARS EM with a neuro-controller

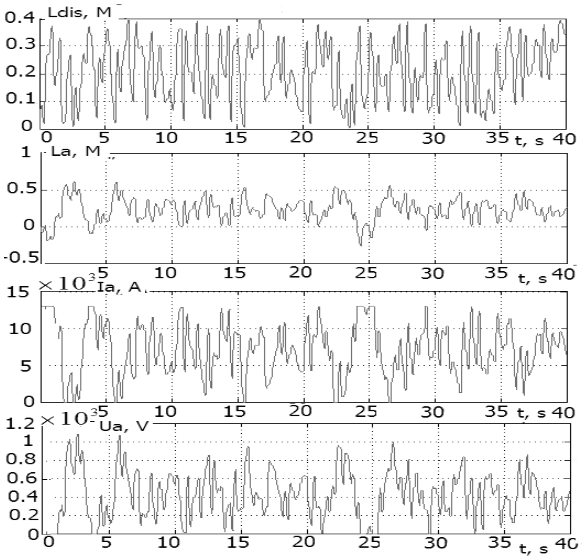

Fig. 5. Time dependencies $l_{dis}(t)$, $l_a(t)$, $I_a(t)$ and $U_a(t)$ of ARS EM on the base of AFAR-T-12 controller under the influences of occasional disturbances

The analysis of $I_a(t)$ and $U_a(t)$ dependencies showed the decrease of the arcs current and voltage dispersion of ARS with a neuro-controller in 1.4-1.6 times

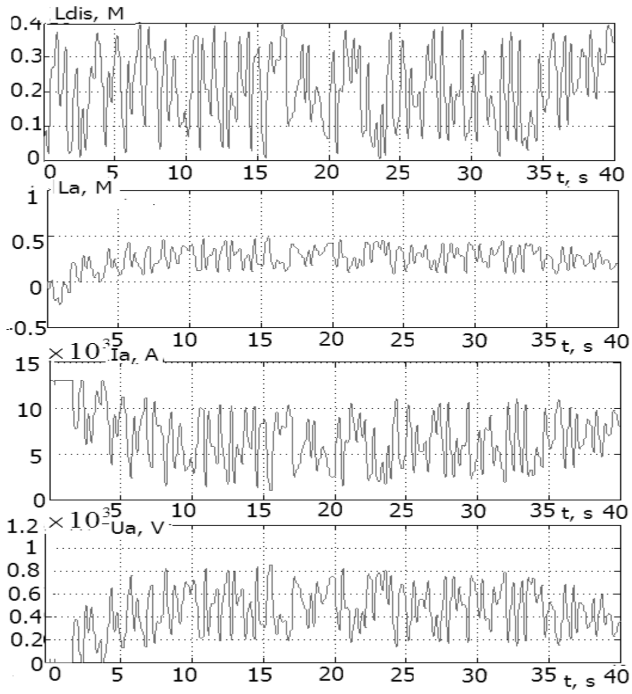

Figure 6 – Time dependencies $l_{dis}(t)$, $l_a(t)$, $I_a(t)$ and $U_a(t)$ of the designed ARS EM with a neuro-controller under the influence of occasional disturbances

Conclusions

The use of the designed structure of ARS electric mode EAF with NARMA-12 Controller makes it possible to improve dynamic precision of the EM coordinates at the set levels. Regulation time of the determined disturbances is decreased by 30-40% whereas dispersion EM coordinates in quasi-set modes of the process of electric steelmaking is decreased in 1.4-1.6 times.

REFERENCES

[1] Rubtsov V. P., Yelizarov K. A., Yelizarov V. A., The study of electro-mechanic arc furnace power controller with an AC motor,, Vestnik MEI. - №5, 2010.pp. 54 – 60.
[2] Medvedev V.S.., Potyomkin V. G., MATLAB 6 neuro-networks, M.: DIALOG – MIPHI, 2002, pp. 217 – 221.
[3] Kuznetsov B. I., Vasilets T.E., Varfolomeev A. A., NARMA – L2 controller synthesis for a guidance and stabilization system, ISSN 2074 – 272X. Electrical and Electrician 2011 № 4, pp. 41 – 46.
[4] Mineev A.R., Korobov A.I., Pogrebisskiy M.Y., Modelling of electro-technological processes and equipment, Sputnik, Moscow 2004.

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