

Method of electric mode control on metallurgical furnaces and system for automatic furnace control

Gocha Kurdadze

Doctor of Metallurgy

Director of Zestafoni Ferroalloys Plant JSC

Abstract

An automated control system for three-phase ore-thermal furnaces is presented, integrating a Siemens S7-1200 PLC, WinCC visualization, radar sensors, and energy meters for continuous monitoring and dynamic regulation of electrode positions, voltages, and currents. Electrode immersion and power are adjusted to minimize short-network asymmetry, stabilizing phase voltages and ensuring uniform thermal distribution. Implemented on rectangular (RPO-11,150) and circular (RKO-22,5) furnaces, the system increased furnace productivity by 5.3%, improved power factor (0.81 → 0.83), and reduced electricity consumption by 2.9%. This approach provides energy-efficient, stable, and high-performance operation of ferroalloy furnaces.

Keywords:

Ore-thermal furnace, Ferroalloy production, Automatic control system, Electrode position regulation, Short-network asymmetry, Energy efficiency, Power factor optimization, Three-phase electrical control.

Date of Submission: 20-03-2026

Date of acceptance: 03-04-2026

I. Introduction

Ferroalloy production is a high-energy, multi-phase metallurgical process characterized by significant electricity consumption and inherent process instability. Over the past century, accumulated experience in furnace operation has led to continuous technological improvements, with particular focus on automating the electrical control of ore-thermal (submerged arc) furnaces. The efficiency and productivity of these furnaces depend critically on the uniform distribution of power and thermal processes. Furnace performance is influenced by factors such as electrode immersion, short-network asymmetry, and the specific electrical resistance of the charge materials. Conventional control systems measure electrical parameters and adjust electrode positions but often fail to minimize energy consumption or optimize the power factor, resulting in reduced productivity and uneven thermal distribution. This work presents a method and system for automated electric mode control that addresses these limitations. By dynamically regulating electrode positions and power based on continuous voltage and current monitoring, the system minimizes short-network asymmetry, stabilizes phase voltages, and improves energy efficiency, resulting in increased furnace productivity and reduced specific electricity consumption.

Over the century-long history of ferroalloy production, the accumulated knowledge and experience have been continuously refined and are still being improved today. Against the backdrop of diverse technological reforms, special attention is paid to the automatic control systems of ore-thermal electric furnaces.

Ferroalloy production is characterized by high energy consumption and multi-phase process instability, which leads to losses and reduced productivity. It is known that as furnace power increases, specific heat losses and the amount of electricity required per ton of alloy decrease.

The optimal voltage also depends on the specific electrical resistance of the charge materials and the nature of the arc. Asymmetry in the short network causes the so-called "slow" and "wild" phase effects, which require intelligent regulation.

It is well known that ferroalloy production involves significant energy consumption. For example, if 1000 kWh of electricity is required to produce 1 ton of steel, approximately five times more electricity is needed to produce 1 ton of various ferroalloys (such as silicon, manganese, high-carbon ferromanganese, medium-carbon ferromanganese, ferrosilicon, etc.). A major share of the production cost of ferroalloys is attributed to electricity consumption, accounting for nearly half of the total costs.

It is also known that there exists a method and system for the automatic control of the electrical regime of a ferrothermal furnace.

This system involves measuring electrical parameters during the melting process from electrodes immersed in the charge, which are powered by a three-phase transformer via conductors. These parameters include phase active power, electrode active resistance, and voltage at the electrodes. The system also determines electrode positions, collects parameter values, and performs regulation when necessary. However, this method and system do not ensure a reduction in electricity consumption.

Moreover, the presence of an asymmetric network does not allow for an increase in the power factor, which is related to the uniform distribution of thermal processes. As a result, furnace productivity remains low, which in turn affects product quality.

The above-mentioned shortcomings are eliminated by a method for controlling the electrical regime of a ferrothermal furnace.

This method involves measuring electrical parameters during the melting process from three electrodes immersed in the charge, which are powered by a three-phase transformer via conductors. The parameters measured at each electrode, using transducers, include phase active power, electrode active resistance, and voltage at the electrodes. The method also includes determining electrode positions, collecting electrical parameter values, and performing regulation when necessary.

Prior to the start of the process, the furnace is equipped with radar-type sensors, a programmable logic controller (PLC), and an energy metering device.

Measurement of electrical parameters and electrode voltage is carried out based on the principle of continuous monitoring. In addition, dynamic automatic regulation of electrode positions is performed in such a way that the first electrode, located closest to the furnace tap hole, is the least immersed in the charge and is supplied with the highest power. The third electrode, located farthest away, is the most deeply immersed in the charge, while the middle (second) electrode is supplied with lower power compared to the first and third electrodes. This minimizes short-network asymmetry and ensures uniform distribution of power and thermal processes within the furnace.

Continuous monitoring of electrical parameters includes control of line and phase currents, voltages on the high- and low-voltage sides of the transformer, active, reactive, and apparent power, as well as the power factor.

Electrode positions are determined using radar-type sensors, and the data are transmitted to the programmable logic controller (PLC).

Collection of electrical parameters is carried out by an energy metering device using the Modbus RTU protocol, and the data are integrated into the PLC for further regulation.

Regulation of electrical modes is performed primarily based on electrode voltage values, and subsequently by power. When necessary and possible, transformer tap changing under load is applied.

For a rectangular open-type ferrothermal furnace, three self-baking electrodes with a diameter of 1000 mm and a five-stage transformer with a capacity of 11,150 kVA are used.

For a circular open-type ferrothermal furnace, three self-baking electrodes with a diameter of 1200 mm are used. These electrodes are arranged at the vertices of an equilateral triangle with a spacing diameter of approximately 3100 mm.

The method also involves preliminary uniform preparation of charge materials and determination of optimal electrical operating modes of the furnace in order to minimize specific energy consumption.

The system for automatic control of a ferrothermal furnace includes three electrodes immersed in the charge, connected via conductors to a three-phase transformer. Each electrode is equipped with transducers for measuring electrical parameters, specifically phase active power, electrode active resistance, and electrode voltage. The system also includes means for determining electrode position, collecting electrical parameter values, and performing regulation when necessary.

In addition, the furnace is equipped with radar-type sensors, a programmable logic controller (PLC), and an energy metering device for continuous monitoring of electrical parameters and electrode voltage. Furthermore, the furnace is equipped with dynamic electrode position control mechanisms arranged such that the first electrode (closest to the tap hole) is least immersed and supplied with the highest power, the third electrode (farthest) is most immersed, and the second electrode (in between) is supplied with lower power compared to the first and third electrodes. This minimizes short-network asymmetry and ensures uniform distribution of power and thermal processes within the furnace.

The system additionally includes a programmable logic controller (PLC) configured to execute a control algorithm based on electrode voltages, as well as a visualization interface (HMI/SCADA) for monitoring and controlling physical processes.

The programmable logic controller (PLC) is of the Siemens S7-1200 series, and visualization is performed in the WinCC environment.

The technical effect of the invention is to increase the efficiency of electricity use in ore-thermal electric furnaces, increase furnace productivity for the target product, simplify the technological process, and reduce specific electricity consumption. This is achieved using the method and system developed,

which provides optimal three-phase regulation based on the electrode voltages of ore-thermal furnaces, compensates for short-network asymmetry, and dynamically controls electrode positions.

The method includes dynamic automatic regulation of electrode positions such that the first electrode, closest to the furnace taphole, is the least immersed in the charge and supplied with the highest power, while the third electrode, farthest away, is the most deeply immersed, and the middle (second) electrode is supplied with lower power relative to the first and third electrodes. This minimizes short-

network asymmetry and ensures uniform distribution of power and thermal processes within the furnace.

This solution reduces specific electricity consumption, increases the power factor, and ensures uniform distribution of thermal processes, which increases furnace productivity.

The invention is illustrated in four figures:

Fig. 1 – shows the (RPO)-11,150 rectangular open-type ore-thermal furnace short-network schematic with the electrodes arranged in a straight line.

Fig. 2 – shows the (RKO)-22,5 circular open-type furnace short-network schematic with the electrodes arranged at the vertices of an equilateral triangle (spacing $D \approx 3100$ mm).

Fig. 3 – shows the first voltage distribution mode (example: 72–82–85 V).

Fig. 4 – shows the second voltage distribution mode after changes (example: 86–72–85 V).

To implement the method, research work and a series of measures were carried out, including uniform pre-treatment of charge materials and refinement of the furnace's optimal electrical operating modes.

The optimal electrical regime is defined as one that ensures minimal electricity consumption per ton of alloy while maximizing the transformer's rated capacity.

General principles used in the research:

As furnace power increases, specific thermal losses decrease, and consequently, electricity required per ton of alloy decreases.

Optimal voltage depends on the specific electrical resistance of the charge and the arc characteristics. Ore-thermal furnaces using carbon as the reducer operate with a charge-covered arc, with electrodes deeply immersed, ensuring arc stability at low voltages.

The lower the conductivity of the charge, the higher the voltage required.

Losses in the short network (between furnace and transformer) amount to 7–15% of the transmitted power.

In this regime, power, electrode voltages, and currents are regulated by raising/lowering electrodes and, if necessary, by switching transformer taps under load.

Modern automated furnace control systems allow better control not only of electrical regimes but also of temperature regimes and electrode wear processes.

Implementation for rectangular open-type ore-thermal furnaces (RPO)-11,150:

The invention was initially applied to three furnaces, each with a rectangular bath and three self-baking electrodes of 1000 mm diameter arranged in a straight line (Fig. 1). Each furnace is powered by a 11150 kVA, five-stage transformer of type EPTC-11150/10. Electrode immersion depth in the charge is 1200–1400 mm.

One implementation example corresponds to Fig. 1 (RPO)-11,150 furnace short-network schematic with straight-line electrode arrangement. The furnace is controlled using a Siemens S7-1200 PLC (not shown) and visualized in WinCC (not shown), displaying all electrical and temperature regimes.

Electrical parameters include current and voltage signals, such as line and phase currents, low-side short-network voltages, which are fed to a Lovato DMG800 energymeter (not shown). The data, processed via Modbus RTU protocol, are transmitted to the Siemens processor, including line and phase currents, high- and low-side transformer voltages, active, reactive, and total power, power factors, and network frequency. Electrode deposition information is also collected from radar-type sensors,

including taphole process data and electrode wear parameters (times since last wear, electrode length passed in previous and current shifts, whether the process is active, etc.).

Short-network asymmetry causes power redistribution among electrodes. Specifically, a phase leading its opposite-phase electrode becomes “wild,” while a lagging phase becomes “slow” (e.g., for forward direction, phase A leads phases B and C by 120° and 240° , respectively), causing 15–20% power transfer from the slow to the wild phase. Initially, several regulation options were tested: power control mode,

short-term current and resistance control modes, but later emphasis is shifted to electrode voltage control, prioritizing electrode voltage first, then power. During research, the voltage-based control concept led to the idea of adjusting electrodes and wears such that the “stable” phase (second electrode E2) operates close to slow-phase parameters, while the former slow phase E1 aligns with wild-phase parameters. Dynamic electrode deposition regulation was implemented so that the first electrode E1 (closest to top hole) is least immersed and supplied with the highest power, the third electrode E3 (farthest) is most immersed, and the middle electrode E2 receives lower power compared to the first and third electrodes. This minimizes short-network asymmetry and ensures uniform distribution of power and thermal processes within the furnace. Knowledge of which electrode affects others in terms of voltage distribution (in this case 3→2→1) allowed optimal electrode positioning to achieve the described regime. Observations are illustrated in Figs. 3 and 4 and the accompanying table.

First case: electrode voltages averaged 72–82–85 V (Fig. 3).
 Second case (after changes): 86–72–85 V (Fig. 4).

With this voltage distribution, line currents (equivalent to electrode currents) decreased slightly, furnace power factor increased from 0.81 to 0.83, and power and thermal processes were distributed more evenly. This stabilized the furnace, reduced overloads, minimized electrode movement and immersion depth variations, thereby increasing productivity and reducing electricity consumption.

Implementation for circular open-type ore-thermal furnaces (RKO)-22,5:
 Three self-baking electrodes of 1200 mm diameter are arranged at the vertices of an equilateral triangle (spacing $D \approx 3100$ mm, Fig. 2) with immersion depth 2200–2400 mm. Each furnace is powered by three single-phase 7500 kVA, 17-stage transformers.

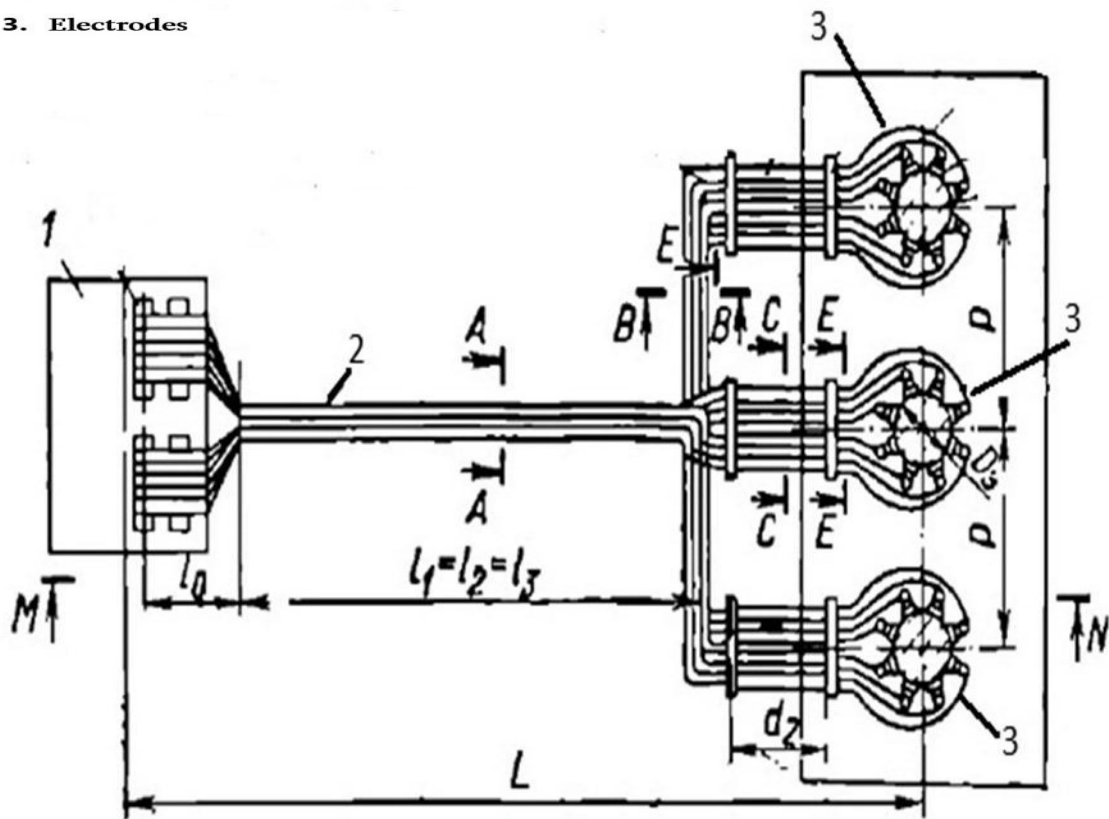
As with RPO-11,150 furnaces, 5% slow/wild phase effects occur because transformers are repositioned on one side of the furnace. Phase asymmetry is eliminated only if transformers are repositioned at 120° relative to the furnace. Optimal regulation uses voltage and power over wider limits, reducing frequent electrode movement. With properly selected charge material, the process remains stable, and automation maintains electrode voltage and power with minor corrections. Observations showed increased furnace productivity and reduced specific electricity consumption. For example, with the invention fully implemented in automatic mode, daily productivity increased by 3.58 tons (5.3%), and electricity consumption decreased by 150 kWh/t (2.9%). The invention is suitable for ferroalloy plants using rectangular (RPO-11,150) and circular (RKO-22,5) furnaces, as well as others similar three-phase ore-thermal furnaces requiring energy-efficient and stable electrical operation.

Tables and indicators

Parameters:	Periods	Electrode-1	Electrode-2	Electrode-3
Voltage, V	Old	72	82	85
	New	86	72	85
Line current, A	Old	571	614	602
	New	483	603	552
Cosine-(cos φ)	Old	0.81	0.83	0.79
	New	0.86	0.87	0.75
Electrical power- MW	Old	2,2	2,9	2,7
	New	2,8	2,0	2,7

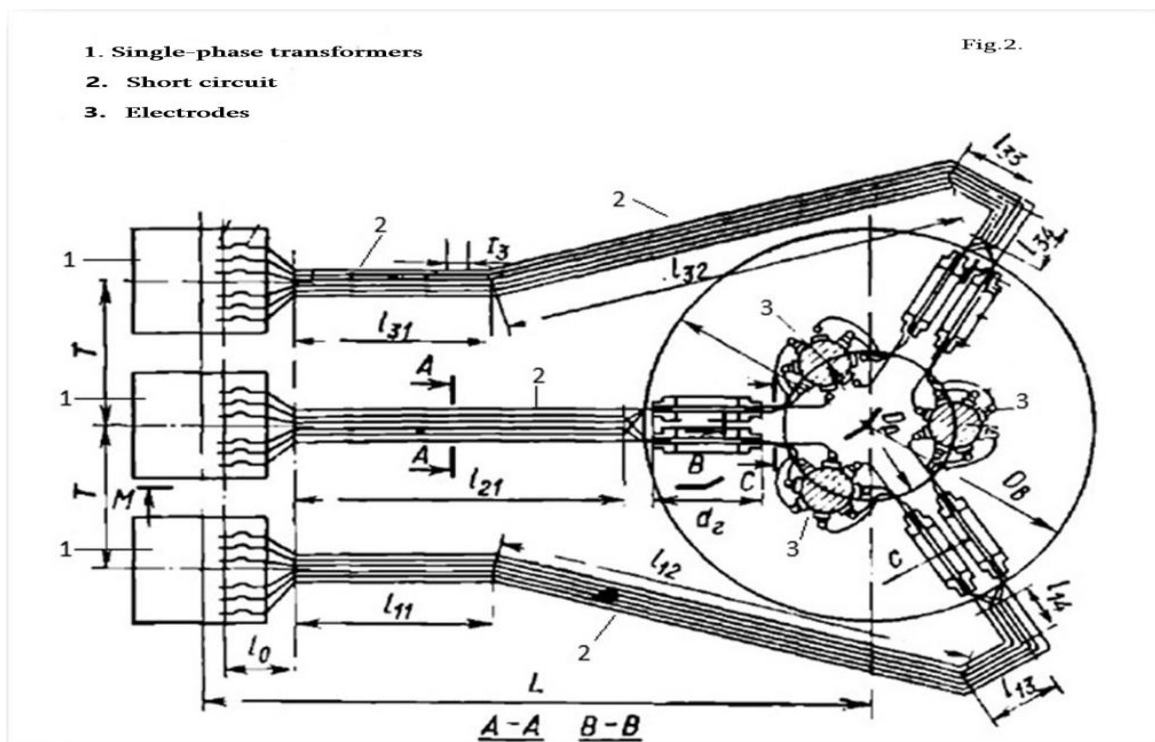
1. Three-phase transformer
2. Short circuit
3. Electrodes

Fig.1.



1. Single-phase transformers
2. Short circuit
3. Electrodes

Fig.2.



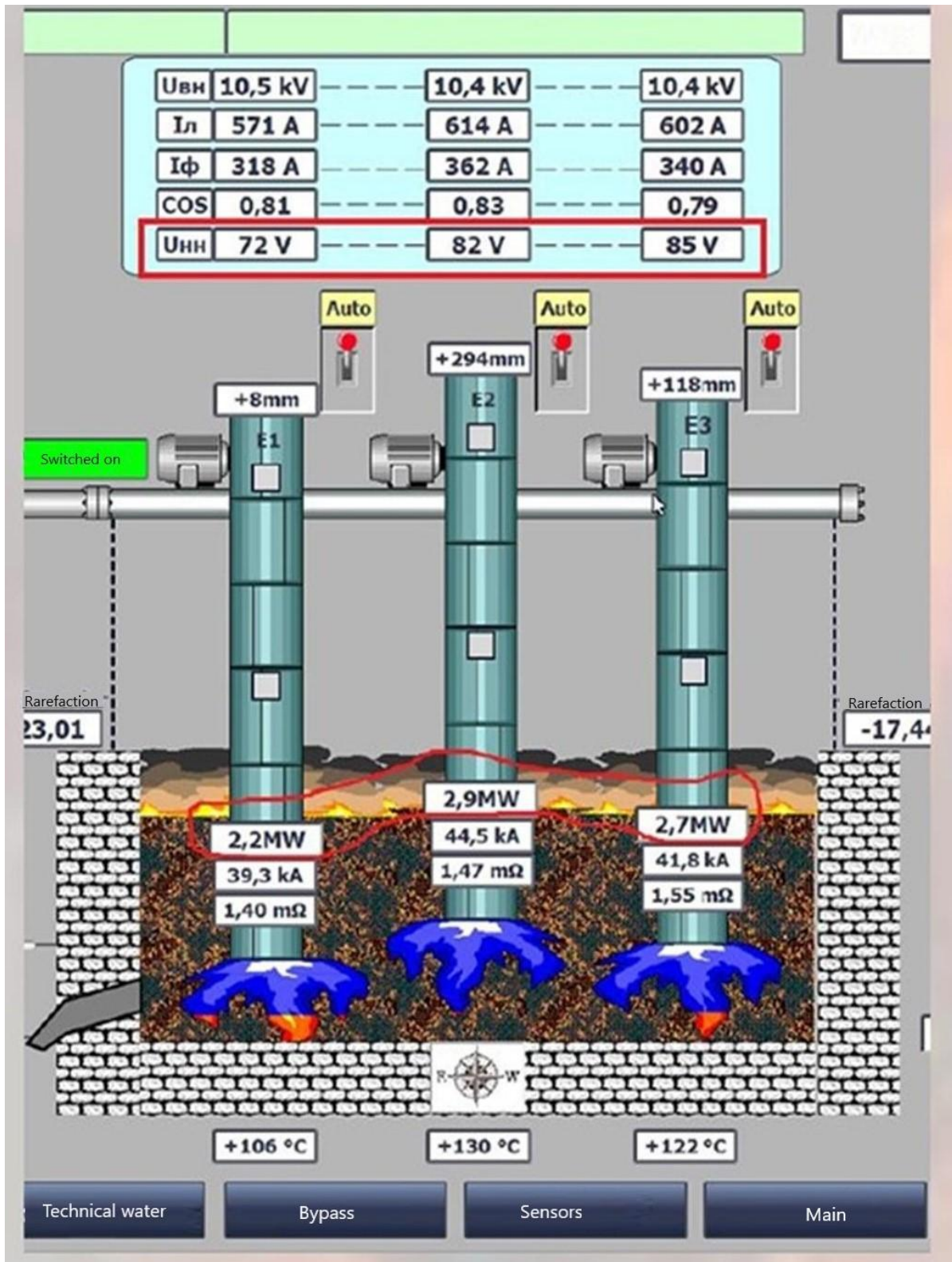


Fig.3.

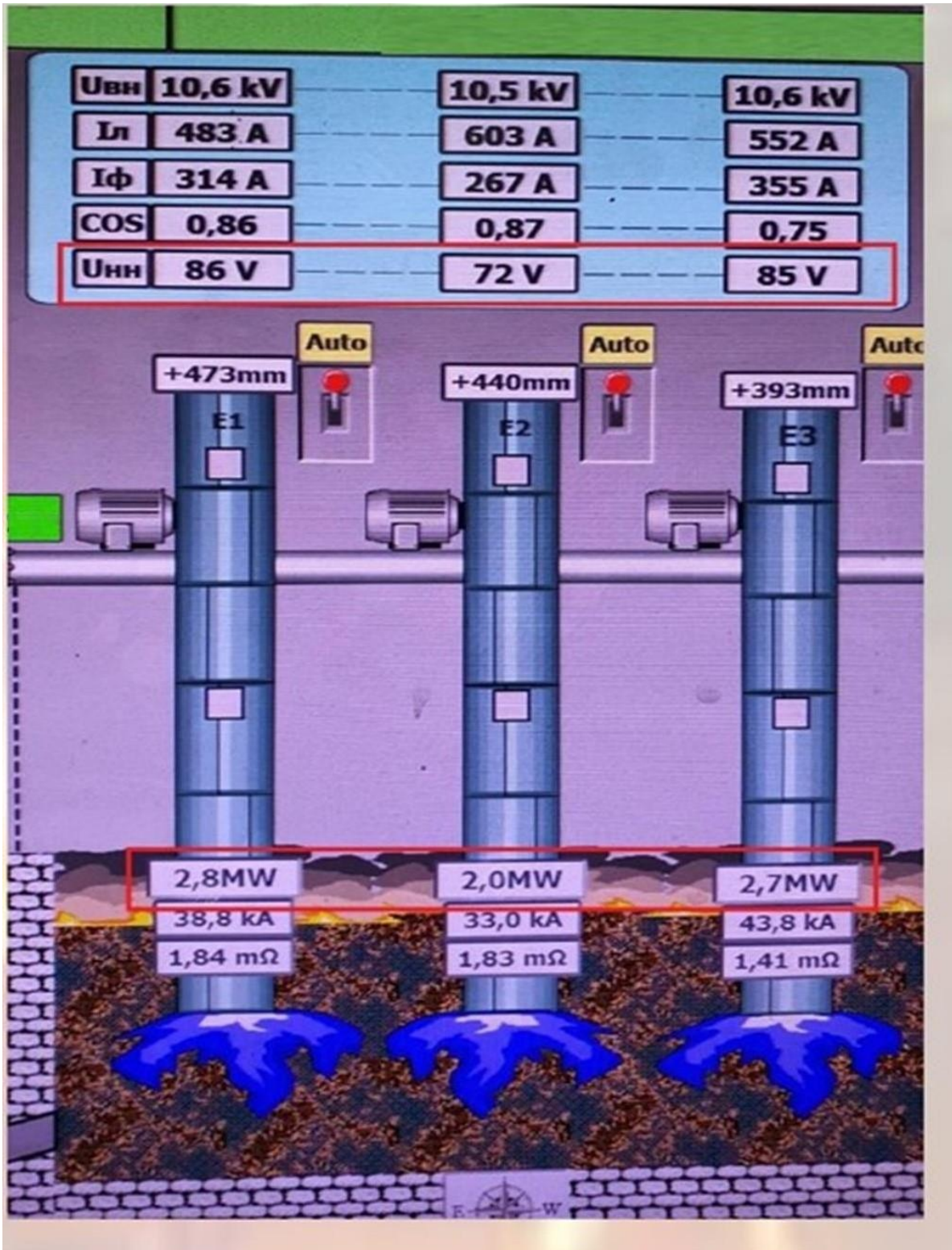


Fig.4.

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