

RUSAL's Digital Tools for the Proactive Control of Cells and Cell Lines

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Abstract

RUSAL Engineering & Technology Center has always paid attention to the development of digital control systems to enhance the performance and environmental indicators of cells and cell lines.

In 2022, the center introduced ELTM (Electrolysis Technology Monitoring System), an electrolysis technology monitoring system. The system, which continuously processes data from cells, precisely detects problems in cells and cell lines in real time and immediately warns personnel to urgently remedy a problem. The system has been successfully used by all potroom managers and process engineers.

Moreover, RUSAL continues to upgrade its existing high-amperage cell control systems. As an example, Virtual Cell, a digital twin, has been integrated in RUSAL's conventional SAAT process control system, which allows optimizing cell operation by means of virtual sensors and predictive analytics.

Plans are to supplement control systems with AI (Artificial Intelligence) algorithms in order to enhance control quality and prediction accuracy, and adapt them to different cell types. Pilot tests showcase improvements in operational efficiency and environmental indicators, and cost savings.

Keywords: Digital cell control systems, ELTM, Virtual cell, Digital twin, Artificial intelligence.

1. Introduction

Aluminum reduction cells and cell lines represent quite complex systems that are characterized by a multitude of stationary states and that are capable of operating in a wide range of parameters, i.e., in operating windows. Not all stationary states are energy – efficient or economically feasible. Now, it is the potline personnel who search for energy-efficient states or "select parameters"; they use their personal experience and various control tools, including digital ones: automated process control systems (APCS), MES (Manufacturing Execution System), video monitoring systems, etc. Such systems generate a huge amount of data that need to be used in cell control. Considering the growth of cell amperage, global deterioration in the quality of raw materials and the shortage of process personnel, the development of digital control systems has lately become a key element of the process of transforming the industry.

Since the mid-1990s, RUSAL's smelters have been replacing the outdated "Aluminium" process control system with the new generation "SAAT" systems, which are based on Siemens controllers and which are integrated with the upper-level *ELVIS* automated control systems. In the late 1990s, a proprietary Manufacturing Execution System (MES) – an automated workstation – was developed to collect and analyze process data, as well as the *Virtual Cell*, a dynamic model to solve analytical issues during aluminum production and train process engineers. These products have been continuously improved and enhanced since then.

In the meantime, RUSAL's facilities have additionally created a number of their own software (in various programming languages and with different interfaces) to address the growing need for software at all management and control levels. The problem is, such products are all different, and there are extremely weak connections, if any, between them. Therefore, it was a logical step for RUSAL, when developing digital control tools, to start combining all the software into ALECSYS, a uniform digital eco-system.

The purpose of this paper is to review the experience of deploying across RUSAL a uniform eco-system of digital tools to manage and control aluminum reduction technologies, as well as to present a strategy for its further enhancement and up-scaling (based on the two main components: ELVIS WEB and MES ELTM).

2. Development of RUSAL's Uniform Digital Eco-System

When developing the uniform digital eco-system, the objectives were as follows:

1. Integration of all the Web applications developed by RUSAL, so that there is a single access point, uniform services, and a single information space. Figure 1 shows a single point to access ALECSYS.
2. The eco-system development should involve up-to-date approaches to the designing and development of software.

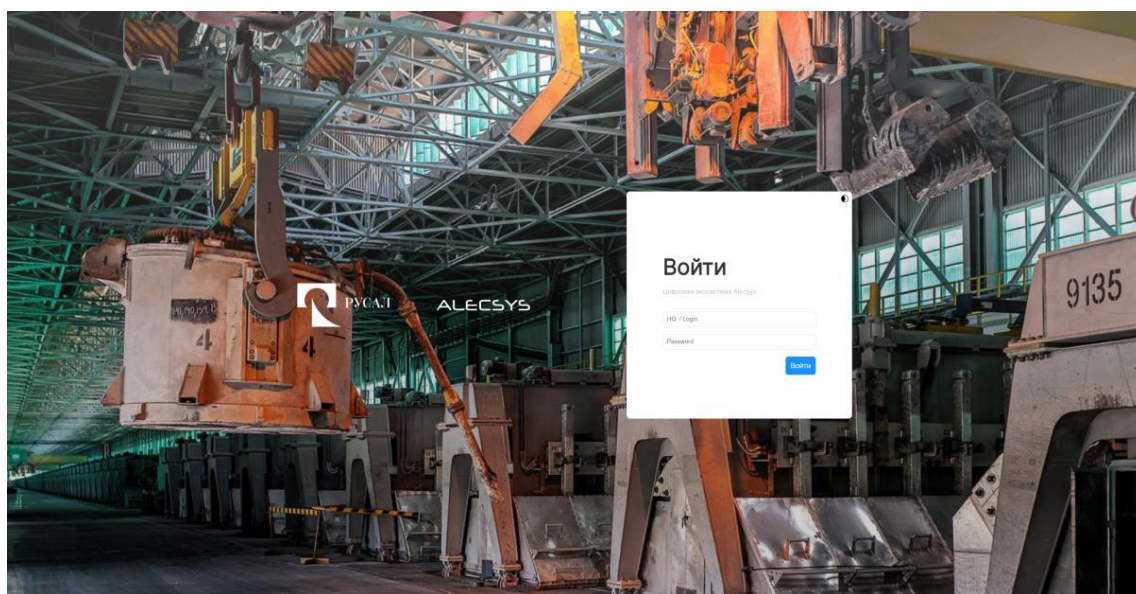


Figure 1. Single point of access to ALECSYS.

The single information space ensures the following advantages:

1. The ability to integrate data between different production facilities,
2. The increase in the period of storage of process data (for their further analysis); data can be stored for more than a year (instead of a current period of 1 month),

3. The ability to check and validate data from past periods (for example, when detecting data transmission errors), and
4. The adaptation of process applications and services to various types of devices (mobile devices, tablets, etc., i.e., not just PCs).

To create a single information space, it was necessary to implement the following four services:

- User authorization module;
- Report generation (PDF, Excel);
- Notification module (email, messenger); and
- Single knowledge base (Wiki).

Several micro-services and applications have been currently adapted to Web technologies, incl. their further integration into the ALECSYS eco-system:

- a. Elvis-Web – Visualization system of the APCS (Figure 2);
- b. Mobil – Crane operator’s workstation;
- c. SchlickPanel – Panel in the Anode Stud Cleaning Area;
- d. GOU map – System for the on-line monitoring of data from GTCs; and
- e. ELTM – System for the monitoring of reduction processes.

The interface of ALECSYS is shown in Figure 2.

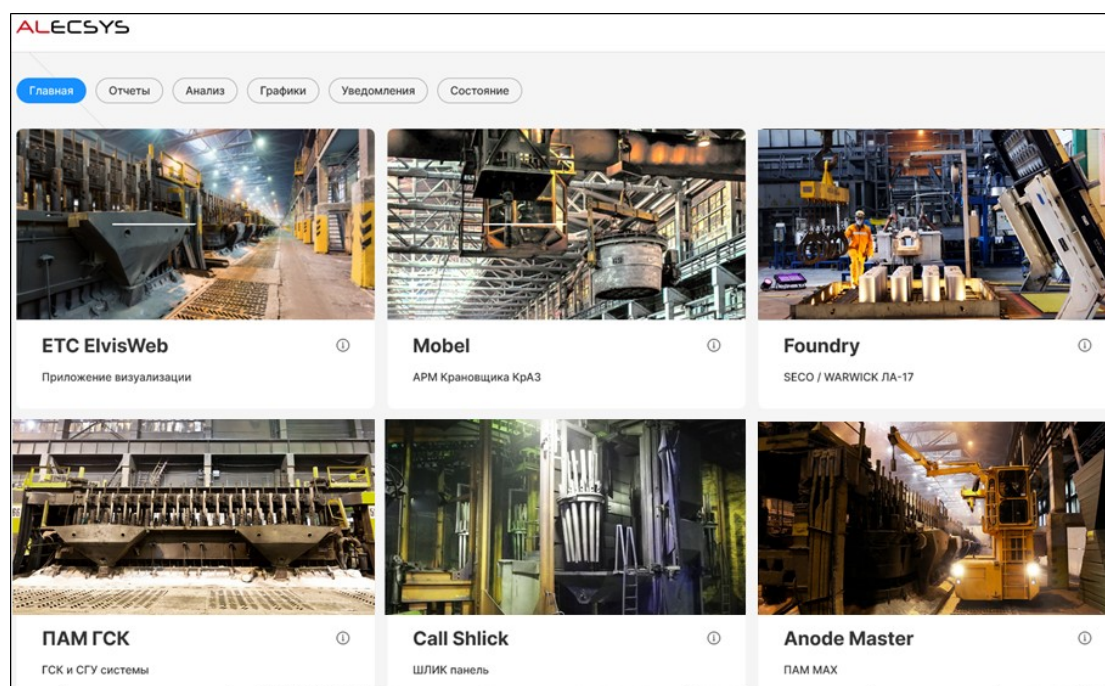


Figure 2. Interface of the single information space of the ALECSYS eco-system at AO RUSAL Krasnoyarsk.

Now, let us discuss the evolution of ALECSYS based on the two main tools of the eco-system.

2.1 Electrolysis Technology Monitoring System (ELTM)

The ELTM system has been developed to monitor the reduction process across large groups of cells (potrooms, potlines and smelters) [1]. The system’s key objective is to deliver automated control over process parameters to prevent and eliminate process disturbances/problems at early

stages. The monitoring system has been deployed across all of RUSAL's smelters. Now, the system is used by over 300 users, which are RUSAL's employees.

2.2 Purpose of ELTM System and Principle of Its Operation

The purpose of the ELTM system is to prevent process disturbances by continuously monitoring the process parameters of the reduction process (in automatic mode) and immediately notifying personnel.

The system performs the following functions:

1. Automatic collection and analysis of the data related to the operation of groups of cells (potroom/line/smelter);
2. Automatic notification of users regarding significant, incl. critical, changes in the process; and
3. Tools for the in-depth analysis of the process: parameters can be seen in real time and over a certain period, comparisons can be made between groups, and the root cause of problems can be determined.

The ELTM system provides for the possibility of adjusting and fine-tuning the criteria for identifying process disturbances. As a result, it is able to effectively identify process disturbances (or any risks of a disturbance) when:

- Process parameters are outside the range required,
- Statistical limits are reached, and
- Undesirable trends are detected.

The ELTM system allows adapting the monitoring parameters to specific requirements, using both standard statistical analysis rules [2] and the Cox-Stewart test [3] for identifying trends, as well as any combinations thereof. This ensures high accuracy and a timely response to potential problems in the process.

The ELTM system also ensures the possibility of conducting an in-depth analysis of the state of a process using various tools and methods, which allows identifying the root cause (s) of problems and developing effective solutions to eliminate such root causes.

The system allows obtaining data from any selected group (or sub-group) of cells, including their visualization in the form of charts and diagrams (Figure 3), identifying cell numbers and proceeding to analyze additional information by clicking the cell number (to be opened in ELVIS WEB for analysis).

Figure 3 shows one of the cases when the last temperature point on the graph (i.e. 952.2 °C) is below the statistical limit. The histogram on the right shows the number (QTY) of cells by temperature range, as well as the numbers of the cells being in a certain temperature range.

The ELTM system notifies personnel of any issues via e-mail (Figure 4). Also, it provides results of daily measurements of parameters (Figure 5).

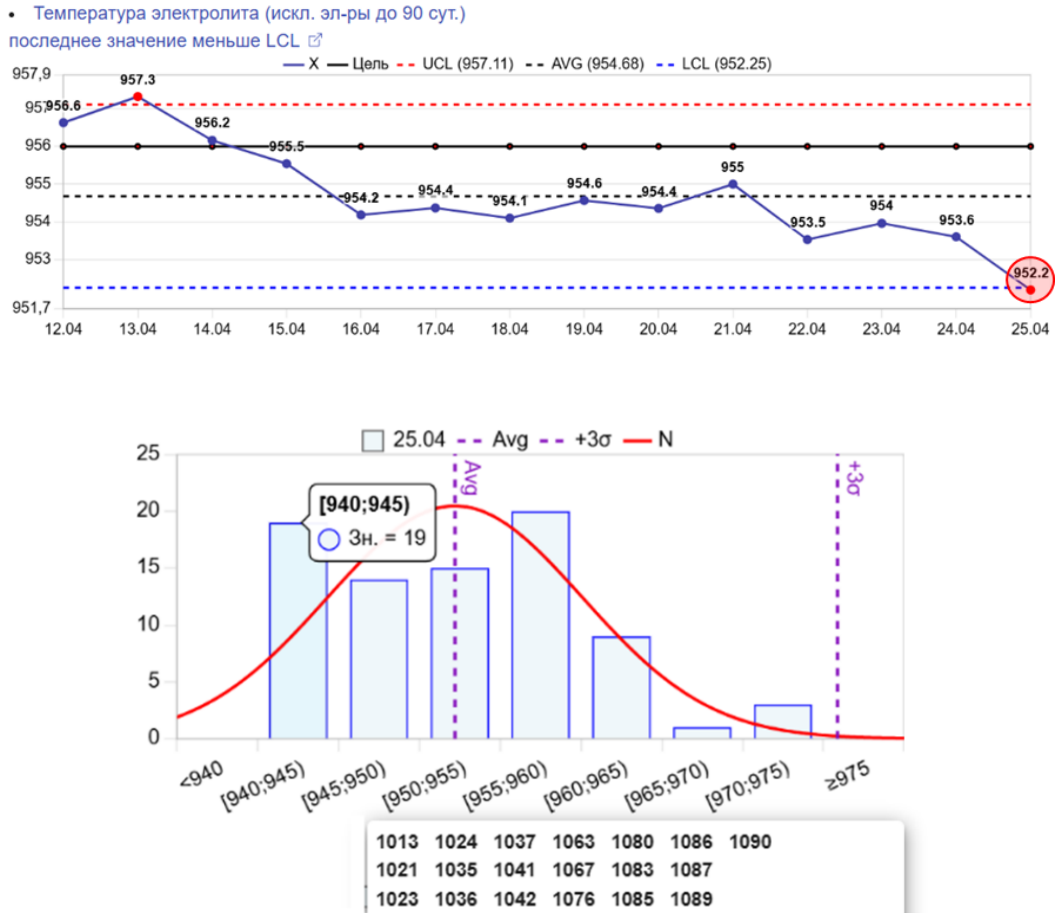


Figure 3. Bath temperature over a period of time, per potroom.

	downward trend
	upward trend
	above the upper border of tolerance
	below the lower control limit
	above the upper control limit

Group	Metal level	Bath level	Bath temp.	CR	Tapping	Amperage	V set.	V oper.	V goal	Noise	AE voltage max	AE voltage ave.	AEF	% high grade metal	Fe
BrAZ															
BrAZ potroom 1															
BrAZ potroom 2															
BrAZ potroom 3															
BrAZ potroom 4															

Figure 4. System notification regarding process disturbances.

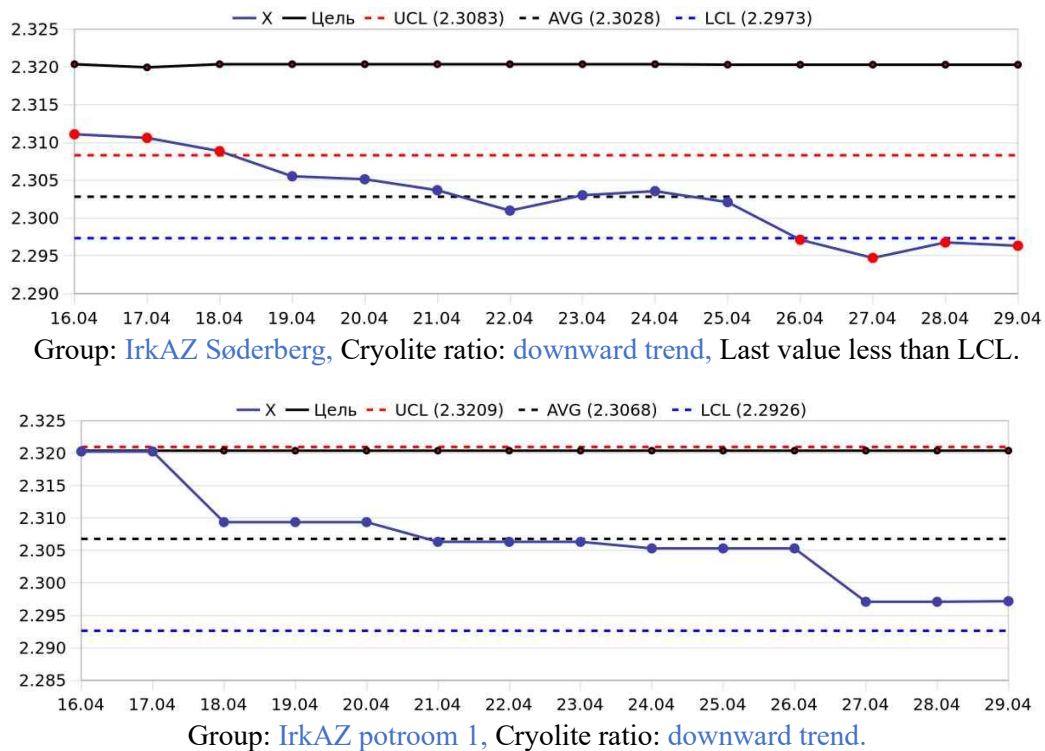


Figure 5. Notification regarding the parameters measured on a daily basis, this notification is sent to the system users on a daily basis.

To improve efficiency and facilitate access to data from mobile devices, some basic information about the state of a cell can be obtained through a social network using a special bot (Figure 6).

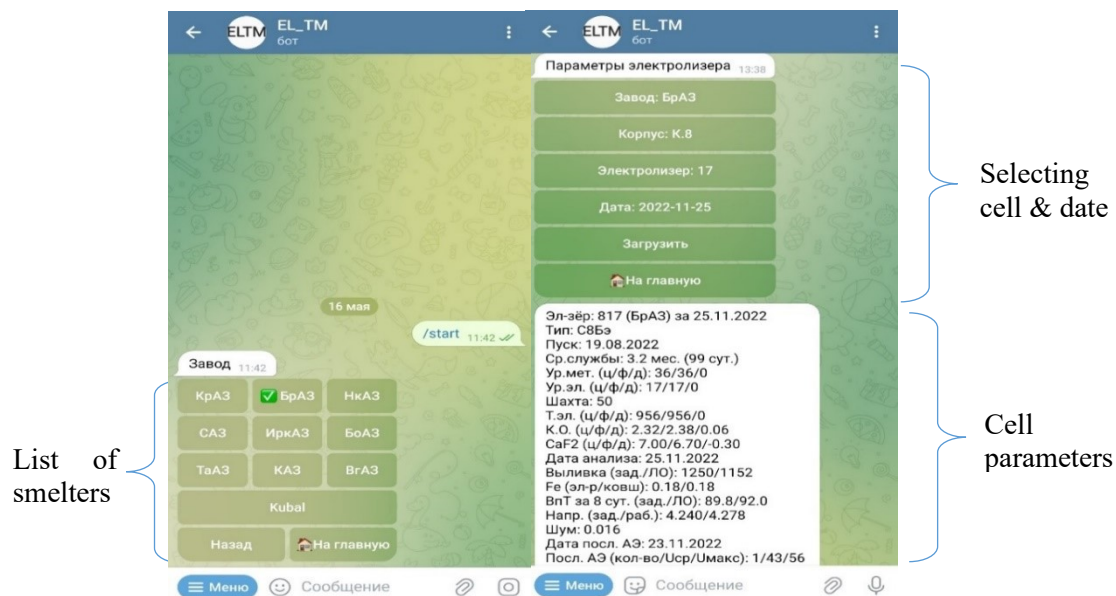


Figure 6. Real-time cell information.

2.3 Prospects of Further Improvement and Enhancement

Further improvement and enhancement of the ELTM system will be aimed at the following: increasing accuracy and flexibility, and providing for integration with up-to-date technologies. The main areas of improvement include:

- **Implementation of artificial intelligence (AI) tools** for predicting abnormalities and automating corrective actions, which will reduce the time of response to disturbances and reduce the risks of process destabilization [4],
- **Extension of the system functionalities**, in particular, the implementation of a module for analyzing the electrical balance of cells and the potroom index. This will help to optimize control and reduce energy losses, and
- **Extension of integration with all the related products of the ALECSYS eco-system**, such as Virtual Cell, ELVIS ACS, which will help to improve process control.

In the long run, the system will become an assistant to the production manager and allow the Company to achieve its key goals and objectives to increase its competitiveness.

2.4 Development of ELVIS WEB

The *ELVIS-WEB* module (ELVIS stands for Electrolysis Visualization) has been developed based on up-to-date web technologies for the real-time control of cells. With *ELVIS-WEB*, process engineers can remotely monitor the operation of cells from anywhere in the world (via the Internet and a browser).

In recent years, ELVIS has been actively developing in two areas.

2.5 Application of the Virtual Cell

Virtual Cell is a digital model adapted to calculate complex variables considering some specific aspects of Søderberg and pre-baked cell technologies; it has been created to optimize cell operation. Fundamental physical and chemical laws of the aluminium reduction process were integrated into its core; an optimization module and an interface for automatic control of the heat balance have also been developed. The Virtual Cell was integrated into the existing automated process control system (APCS) for data exchange with a real control object. The objective was to create an algorithm that would help maintain the bath temperature and cryolite (bath) ratio within certain limits. However, math optimization can provide many solutions that are optimal from a theoretical point of view but impractical from a process point of view. Therefore, the followings improvements have been made [5]:

- The interface of the Virtual Cell program has been improved: new windows and a menu of the optimization module.
- Mathematical models in the calculation core of the Virtual Cell program have been improved, so that the following can be reflected more accurately: the heat transfer through structural elements of various types of cell, the cell behavior during muck (undissolved alumina) formation, and the operation at low superheat temperatures.
- A comprehensive and optimal algorithm has been developed to control the heat balance through optimization of the cell voltage and Bath Ratio (BR).

To optimize cell control, it has been proposed to divide the so-called space of states into 5 areas (Figure 7) and define a control strategy for each of them:

- **Area I:** (close to target BR and temperature values): no calculation to be made, the interval between AlF_3 feeds to be calculated based on the basic consumption, no voltage change (a minor correction is possible to save energy).

- **Area II:** (high temperature, high BR): a comprehensive optimization based on the sum of squared deviations, including a decrease in voltage to save electricity and AlF₃.
- **Area III:** (high temperature, low BR): a bigger interval between AlF₃ feeds or AlF₃ feed termination, and a limited decrease in voltage to avoid a dramatic drop in BR.
- **Area IV:** (low temperature, low BR): heating only, AlF₃ additions as minimum as possible.
- **Area V:** (high BR, low temperature): it is not recommended that any optimization starts due to inconsistency in this area.

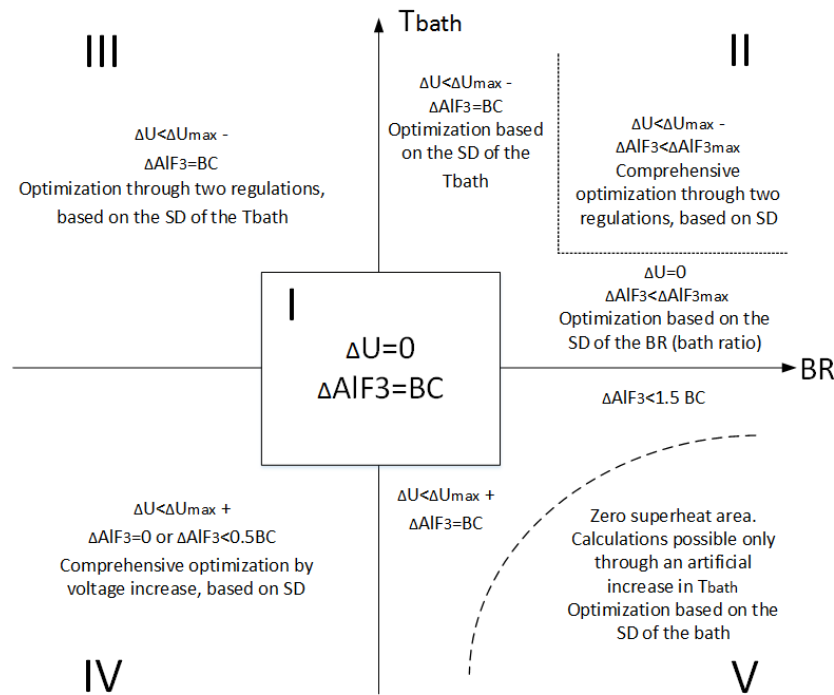


Figure 7. Space of states (Areas of Bath Temperature T_{bath} and Bath Ratio BR).

Tests in pilot cells have shown that the Virtual Cell is able to accurately calculate the voltage and AlF₃ feeding interval to achieve the target bath temperature and cryolite ratio. This has been confirmed by comparing calculated data versus actual values. Figure 8 shows the optimization program interface.

Testing of the optimization module: To check the efficiency of the cell control algorithm developed, test calculations were made in various state areas. As an example, let us consider the first quadrant (high temperature, high BR, moderate superheat). Figure 9 demonstrates a simultaneous optimization of the bath temperature and cryolite ratio (CR) based on the sum of squared deviations. Initial conditions: temperature = 975 °C, BR = 2.45. The results demonstrate that a simultaneous achievement of the target values for both parameters is possible only by expanding the permissible range of values [6].

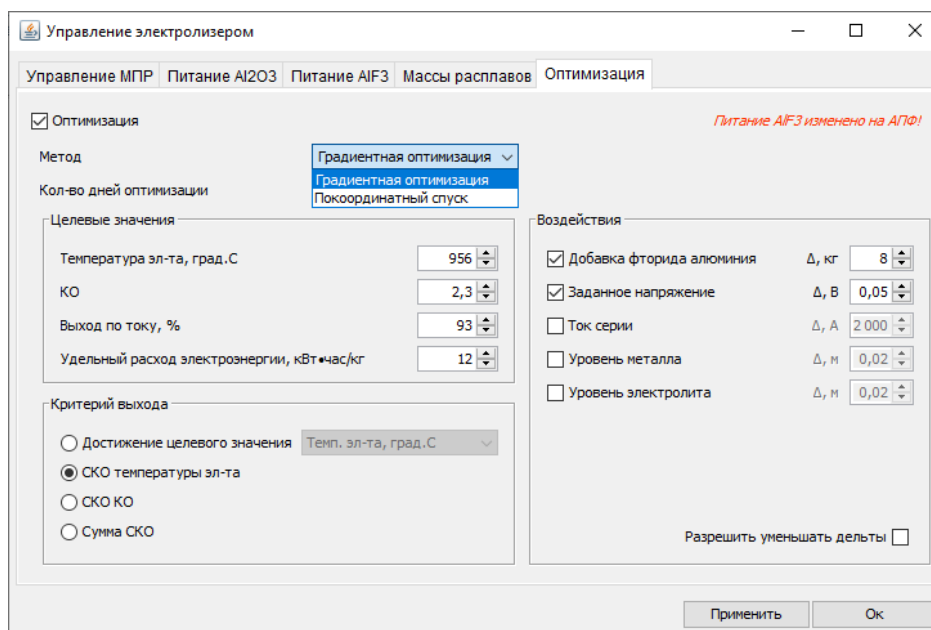


Figure 8. Setting optimization parameters.

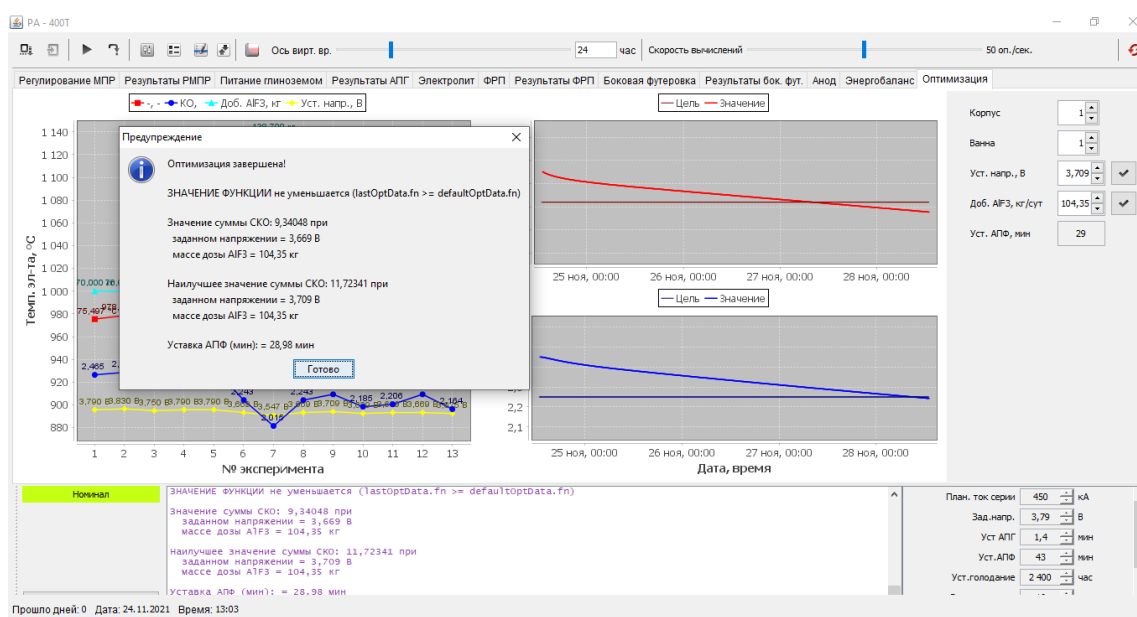


Figure 9. Comprehensive optimization of a cell from the 1st quadrant.

To improve the stability of cell operation, the Virtual Cell’s program also has a noise control algorithm. This algorithm – which can be adapted to different types of cells – provides for a temporary increase in the set voltage when noise appears (such noise can also be assessed as the “MHD instability”). In one of the cells (Figure 10), the decrease in voltage resulted in noise (since the stability threshold had been exceeded). After the noise control algorithm had been allowed to be used, the virtual APCS made a “volt addition” and changed the target voltage. The noise decreased because of this “volt addition” but soon started to grow again. The second “volt addition” resulted in the complete disappearance of noise, this is due to the decrease in the bath ratio (BR) because of the addition of AIF₃.

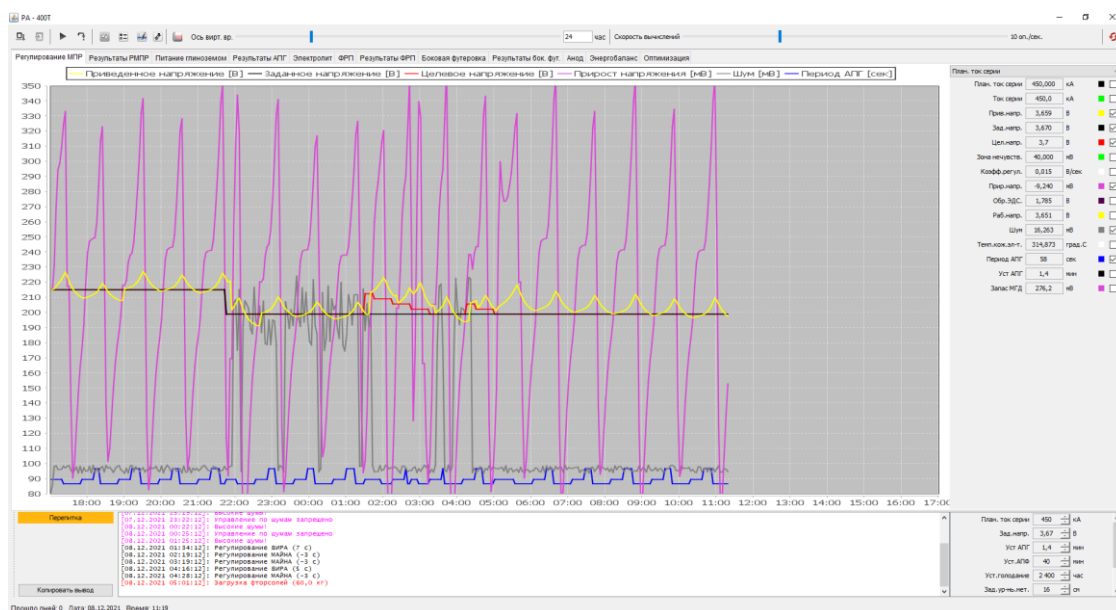


Figure 10. Noise control algorithm.

The work described above allowed refining the mathematical simulator (which is part of the digital twin), improving the optimization module and procedures, and preparing the Virtual Cell for application as part of the APCS. The developed algorithm for controlling the set voltage and BR was tested in pilot cell areas. During said work, test programs were also refined, training exercises were created, and the interface of the Virtual Cell’s program was improved.

2.6 Information and Analytical System

When developing the RA-550 cell technology, we were able to integrate AI tools in cell control [7]; our approach was to use the knowledge and skills of process engineers, which they have acquired over years of work. We have converted their experience into digital models, twins and sensors. The use of virtual sensors allows prediction in real time those data that cannot be measured physically. This replaces manual measurements and provides more detailed information about the process.

With the help of Big Data, we have learned to:

- Determine unique patterns in data;
- Predict different process situations; and
- Detect deviations in cell operation at early stages.

Digital twins allow:

- Controlling the process in real time;
- Simulating the behavior of cells in certain conditions;
- Providing recommendations to achieve target process indicators (TPI).

In addition, digital twins are an excellent tool for training personnel.

The main digital model is a digital twin – a virtual cell – which is configured to simulate the operation of a real cell and provide for its intelligent control (Figure 11). The main objectives of such a digital twin are as follows: it allows simulating the operation of a cell, predicting its behavior and controlling the process in real time. The operation of the digital twin is based on four types of data:

- Uncontrolled input data: parameters that cannot be changed, such as external conditions or initial process parameters;
- Controlled input data: parameters that can be adjusted, such as temperature, pressure or flow rate;
- Uncontrolled output data: the result of cell operation that depends on the input data and cannot be changed directly, such as: output quality, product QTY, etc.; and
- Controlled output data: parameters that can be adjusted to achieve the desired result.

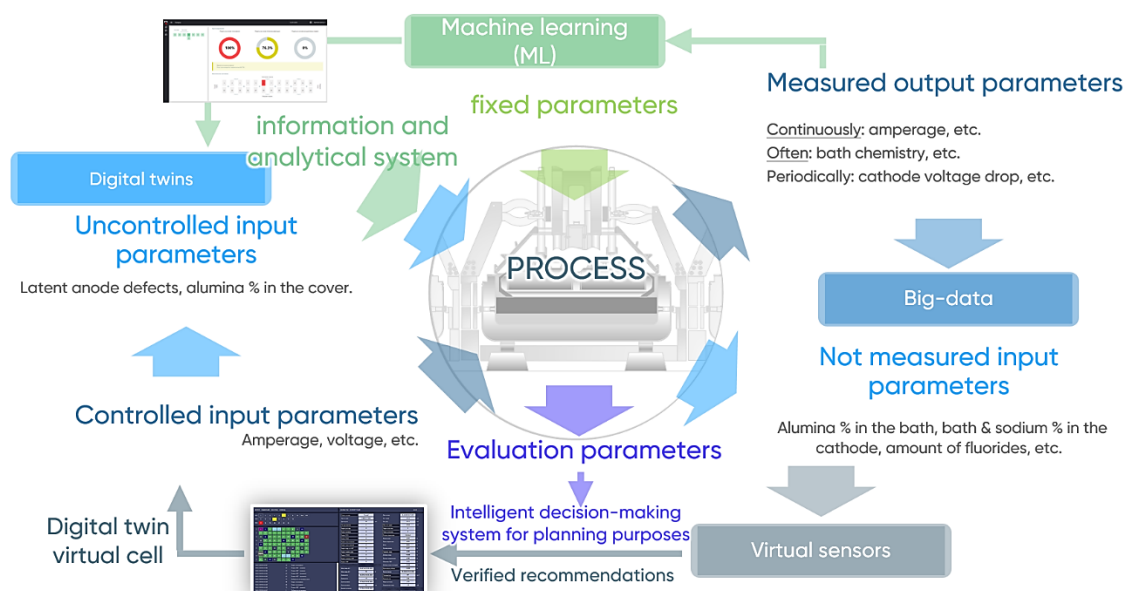


Figure 11. Reduction process control chart, including digital tools.

The main objective of the digital twin is to predict the behavior of a cell based on such data and optimize its operation. In particular, using uncontrolled parameters, we create mathematical models (digital twins) that reflect real processes. Based on all these data, prediction and real-time control are performed, incl. maintaining the thermal balance. The main advantages of the virtual cell are as follows:

- Mathematical modeling: a digital twin is an exact copy of a real cell, which displays all the processes ongoing in real cell;
- Digital advisor: it helps to restore the thermal and mass balance, and optimize the system's operation; and
- Application of physical and chemical laws: the laws of thermodynamics and process kinetics are part of the structure of the digital twin.

This digital twin is currently integrated into the ALECSYS eco-system, which allows combining simulation and control into one platform. This ensures a higher prediction accuracy and higher cell operation efficiency.

Additionally, the Virtual Cell is equipped with training modules that train personnel and test their theoretical knowledge. Employees can study the behavior of the cell being in various states, simulate changes to process parameters and predict its response to control.

In addition to the Virtual Cell, an information & analytical system (IAS) is used. It is based on AI. It provides real-time intelligent control of processes; it controls their state, monitors and predicts the key process indicators. The system predicts all the probable states of the cell and promptly notifies of possible disturbances or deviations. This system has helped us achieve the following:

- Predict disturbances with an accuracy of 90 %, and higher. This allows us to be aware of possible problems in advance, which reduces the risk of equipment downtime;
- Detection of hidden disturbances. In the past, it took 5–14 days to detect a problem before it appeared, and now it takes only 3–9 days, i.e., twice as fast;
- Identification of problems with automated control systems (ACS); and
- Prediction of anode effects (AEs) before they occur.

The information & analytical system (IAS) is also currently integrated into the ALECSYS eco-system, which improves performance indicators.

3. Conclusions

The deployment of ALECSYS, a uniform digital eco-system, allowed RUSAL to increase the stability and efficiency of cell operation control. Automated monitoring and AI tools open up new prospects for reducing the time of response to abnormalities and increase process transparency.

Prospects for improvement and enhancement are associated with a deeper implementation of AI algorithms (based on Big Data analysis) into cell control, the use of digital sensors and the expansion of functionality.

RUSAL's experience confirms that digitalization is an integral element of competitiveness in the context of the global transition to a low-carbon economy. Further enhancement of ALECSYS will allow the Company to reduce its carbon footprint, reduce emissions and provide for fully autonomous production lines in the future.

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