AL33 - AI-Based Autonomous Cell Control in RA-550 Cell Technology

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Abstract

In view of the rapid growth of computing capacities and the continuing development of digital equipment, it becomes quite important to use new tools to timely control the aluminum smelting process, predict operational perturbations, and autonomously make process control decisions to achieve optimal cell performance.

To control the RA-550 cell technology, a number of artificial intelligence (AI) tools have been developed and deployed, such as smart sensors, Big Data analysis systems, digital twins, and neural networks for machine learning. New sensors, both physical and smart, replaced some direct physical (manual) measurements and enabled real-time predictions of those data that had been previously inaccessible for direct physical measurement due to the lack of appropriate tools.

The Big Data analysis systems help reveal unique hidden patterns, predict process scenarios, including process abnormalities, and ensure an early detection of sick pots. The digital twins allow one to timely control the process, simulate potential long-term cell behavior under various conditions and have a better understanding on how to reach target cell performance.

Machine learning enables to understand an individual response of a cell (or a group of cells) to input changes. In addition, the digital twin allows teaching personnel different techniques related to optimal process control and AI system servicing.

In this paper, we would like to elaborate on some individual, shelf solutions we have obtained as a result of developing an AI system to control the RA-550 cell technology.

Keywords: Cell technology, Detection of process disruptions, Predictive models, Digital twin, RA-550 cell technology.

1. Introduction

Aluminum production is a complex process. It requires considerable human resources to continuously monitor and manage the process in order to ensure optimum productivity and avoid any possible process deviations. In view of the rapid growth of digital resources and artificial intelligence (AI) instruments, it now becomes possible to delegate some tasks, such as process control and problem/disturbance identification, to artificial intelligence (AI). By doing so, human resources become free to be used for solving rather complicated problems, or untypical problems. The use of smart sensors allows reducing the number of physical measurements. Moreover, AI-based process control allows establishing efficient process control algorithms and avoiding some deficient individual practices.

The most intensively developing RUSAL's cell technology, RA-550, incorporates AI tools providing for autonomous cell control. This paper describes some instruments and tools that are used by the RA-550 cell technology – such as virtual sensors, Big Data, digital twins and machine learning – for solving a number of particular tasks.

2. Main AI Tools Used by the RA-550 Cell Technology

2.1 Virtual Sensors

Virtual sensors are a tool capable to replace physical measurements. The sensors and data processing algorithms allow obtaining accurate and reliable values of various process parameters. They help optimize controls and reduce the human factor impact. In some cases, they help measure those parameters that are inaccessible for direct physical measurement and, thus, enhance management and control efficiency.

Software sensors supplement the capabilities of the virtual sensors and allow obtaining additional data and information regarding a system. The software sensors may be developed based on the algorithms and models that analyze input data and output particular data regarding processes and parameters. The virtual sensors are the key component of the RA-550 cell technology. Using AI, the sensors replace physical measurements and allow obtaining more accurate data regarding a large number of process parameters. As a result, it reduces both the need for direct operator interventions and the human factor impact, which helps increase productivity and decrease costs.

2.2 Big Data

The application of AI in the RA-550 cell technology allows analyzing more data. Quite a large amount of data obtained from all available sources is processed using AI algorithms that identify latent, or unobvious, relationships and correlations. AI interprets such data and generates a problem-solution map, which helps make more accurate and reasoned decisions.

2.3 Digital Twins

Digital twins are a virtual model of real systems and processes, which allows conducting a comprehensive analysis of how different external actions, or factors, may influence a process or affect a system. In the case of the RA-550 cell technology, the digital twin is used to predict parameters and their values. The digital twin allows simulating different multi-factor scenarios, conducting experiments without any risk for real, on-site processes and improving the efficiency and accuracy of process control.

An additional tool based on the digital twin is a training tool for personnel, for both novices and experienced persons. Simulation-based training is the most efficient way of staff training, which allows considerably improving the professional level of staff, so that they become enabled to solve more complicated process issues.

2.4 Machine Learning

The use of machine learning algorithms in the RA-550 cell technology allows conducting neural network analyses and identifying individual features of systems and processes, both in relation to one individual RA-550 cell and a group of RA-550 cells. The algorithms allow optimizing a system and reaching a rather high operational level. Machine learning is also one of the most important RA-550 elements.

The neural network analysis of individual features of a system allows optimizing cell operation and reaching maximum efficiency. The machine learning algorithms help analyze data, identify patterns and optimize processes.

3. Virtual Cell as a Digital Counselor

The first digital counselor is a virtual cell that acts as a tool for real-time control over the RA-550 cell process.

Digital twins are an essential element of the virtual cell. They represent virtual models and simulations of a physical cell, which allow conducting a comprehensive analysis of how different external actions, or factors, influence the process and eventually provide for data-based process control. By processing data from physical and virtual sensors, a digital twin of the virtual cell allows – based on scientific and statistical correlations – calculating multiple process scenarios, as well as process parameters and values.

Virtual sensors are another key component of the virtual cell. They are a link between a physical cell and a virtual control system. The virtual sensors, like physical sensors, transmit data to the virtual environment for further analysis and processing. It allows having a rather clear picture of the real-time status of the cell.

The calculation of multiple process scenarios and further data refining by a machine learning AI system help the virtual cell optimize the process and select the best possible parameters. It analyzes the data obtained, looks for correlations between various factors and makes optimization efforts to achieve the best possible performance figures. As a result, the virtual cell generates recommendations and settings that are transmitted back to the physical cell for execution and implementation.

The advantages of the virtual cell are quite obvious. It enables rapid response to changes and deviations in the process, and making reasoned decisions and ensuring optimal cell performance.

The virtual cell always has room for further development and enhancement. Its capabilities expand with new and more accurate correlations obtained from Big Data processing and further refining by the machine learning AI system. A broader Big Data analysis allows increasing the number of data samples and making such samples more representative, and, thus, identifying more complex dependencies and patterns. Machine learning, in turn, will make it possible to create more accurate models and algorithms adapted to specific cell/cell group operation conditions.

Figure 1 demonstrates how the virtual cell interacts with the physical RA-550 cell. The figure shows data exchange between the physical and virtual systems, which allows for real-time cell control and optimization.

Figure 1. Interaction of the virtual cell with the physical RA-550 cell.

The left side of the Figure 1 shows a physical cell which is a tangible piece of equipment for the purpose of aluminum reduction. It is equipped with physical sensors collecting data regarding the status of the cell. Such data are transferred to the virtual cell for further analysis and processing.

The right side of the Figure 1 shows a virtual cell which is an intelligent, or smart, system for real-time control. The virtual cell receives data from the physical cell through virtual sensors. Using AI algorithms and methods, the virtual cell analyzes and processes such data for process optimization purposes and provides settings and recommendations to be transmitted back to the RA-550 cell for implementation and execution.

One of the advantages of the virtual cell is that it is capable of restoring both the heat and mass balances. It acts as a digital counselor. The virtual cell analyzes heat and mass balance data from the physical cell and provides optimization recommendations, which ensures efficient process operation.

Another advantage of the virtual cell is the ability of predicting cell operation under various conditions to be set by an operator. The use of a mathematical simulator and the Big Data analysis allow the virtual cell to predict cell operational parameters, which helps to make quick decisions and avoid possible problems and process deviations.

Thus, the virtual cell, which uses the mathematical simulator and acts as a digital counselor, is capable of many things, including accurate cell operation simulations, process optimizations and predictions. It does improve the efficiency and reliability of the aluminum reduction process.

4. Virtual Cell as a Training Tool

The virtual cell is not only an innovative tool to control and manage the process. It can also be used for training personnel; the virtual twin simulates different cell states, including process disturbances, which requires the person to take this or that decision under certain circumstances. The person gains experience and practical skills in how to respond to this or that situation that may occur in real life.

The process of training with the use of the virtual cell has a number of advantages. First, it helps reduce training expenses and reduce the risk of errors and emergency situations on a real production site. The personnel may gain experience and skills in the virtual environment without the need to approach a rather expensive piece of equipment.

Second, the virtual cell allows simulating different conditions and cell states that are difficult and/or dangerous for generation in a real cell. Process disturbances, emergency cases and abnormal operation can be simulated in the virtual environment, which allows the personnel to gain valuable experience in tackling such situations and be able to respond.

Third, the virtual cell allows the personnel to reach a higher level of knowledge and skills. It may be used for training persons new to the profession, so that they can get a better picture of cell operation and the processes ongoing. The virtual cell may also be used for training experienced persons helping them deepen their knowledge and develop new skills.

Moreover, the virtual cell is a rather flexible and scalable tool. It can be adjusted to any needs and training requirements, which allows creating different scenarios and assignments for the personnel. Furthermore, training can be performed in real time, which ensures efficient knowledge assimilation.

Figure 2 demonstrates the interface of the virtual cell's training module that is used for testing and simulating different process conditions. The interface represents a graphic panel with different control and data representation elements.

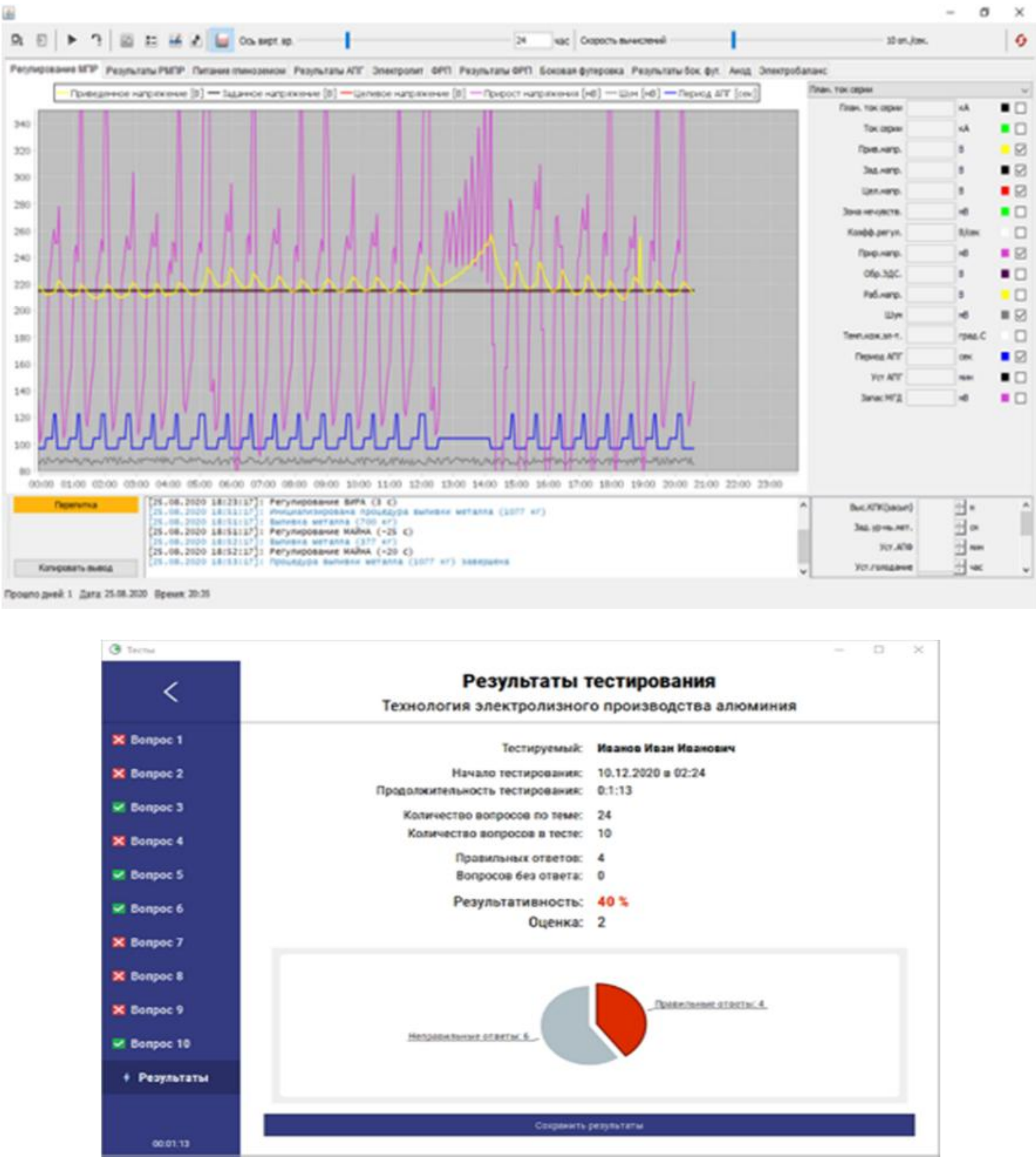

Figure 2. Interface of the virtual cell's training module.

The graphic panel shows graphs and diagrams representing dynamically changing, real-time parameters and their values during a simulation.

The bottom part of the interface accommodates tool panels for control and data analysis. One can select and adjust different process disturbances, such as voltage change/drop, and other parameters in order to see how they influence cell operation.

The module's interface allows testing and analyzing different scenarios, including simulating process disturbances. It helps analyze and optimize cell operation, avoid potential problems and develop particular control strategies.

Training with the use of the virtual cell has been carried out at a number of facilities and for persons having different levels of knowledge and skills. There have been facilities with the personnel having a rather high level of knowledge and skills and lots of experience. In addition, there have been facilities where the personnel required more intensive and comprehensive training.

Different scenarios and situations have been used in the training process to cover a wide range of possible disturbances and problems that may occur in real life, e.g., change in cell parameters, control system malfunctions, abnormal operation due to external factors, etc.

The use of the virtual cell for training purposes has proved to be positive in terms of knowledge assimilation and skill gain. The personnel are now able to use such knowledge and skills in real-life situations, and they are now more confident and competent when dealing with a physical cell.

The virtual cell is a step ahead in the field of personnel training, which makes the personnel more professional. The company is able to provide training of a high quality, standardize processes and optimize cell operation at all levels.

5. Elvis Web 2.0 Digital Sensors – Environmental Improvement

The main strategy of improvement is to control each alumina feed point through an automated alumina feed system, where each feed area is viewed as an individual cell. This means that each feed point has its own unique features and requires an individual approach in terms of management and control. The "each feed point is an individual cell" approach ensures more accurate and efficient cell control; it also allows identifying and solving alumina feed problems in each individual alumina feed point (area).

The above approach is the key to flexible cell operation and problem prevention. Each point is independent from other points in terms of control, which provides for a higher level of control and process efficiency.

Intelligent, or smart, technical means, such as the unique Elvis Web 2.0 digital sensors, play an important role in tackling process-related environmental issues. They help minimize perfluorocarbon (PFC) emissions and control low-voltage emissions, as well as to prevent anode effects (AEs). Such innovative solutions considerably contribute to environmental sustainability and process efficiency.

Figures 3 to 5 demonstrate the Elvis Web 2.0 interface at the moment of identifying various deviations leading to a low-voltage AE.

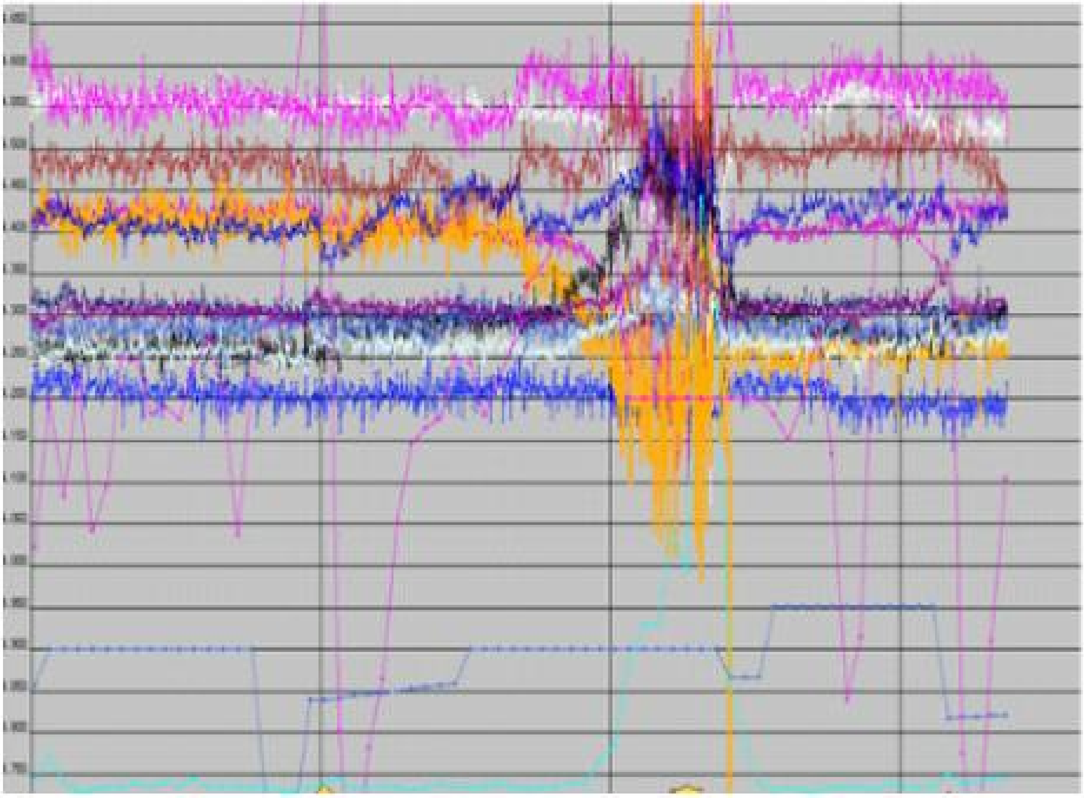

Figure 3. Elvis Web 2.0 interface: current of individual anodes.

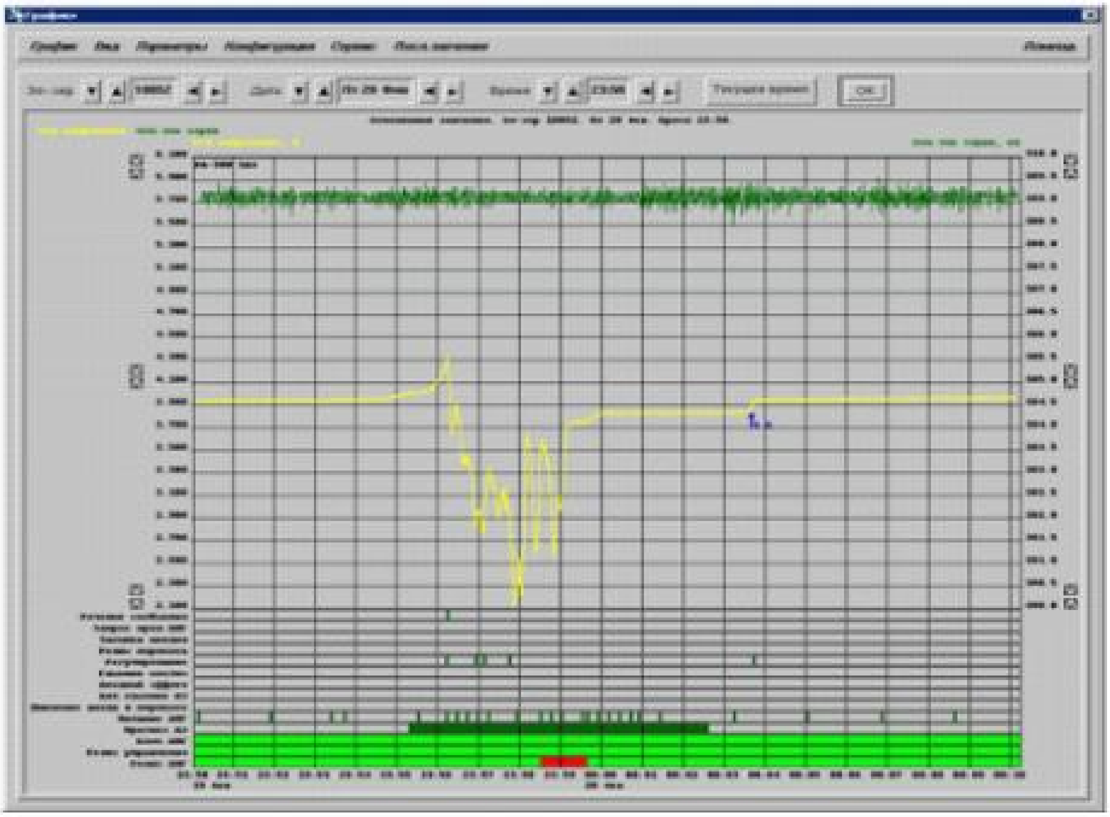

Figure 4. Elvis Web 2.0 interface: cell voltage.

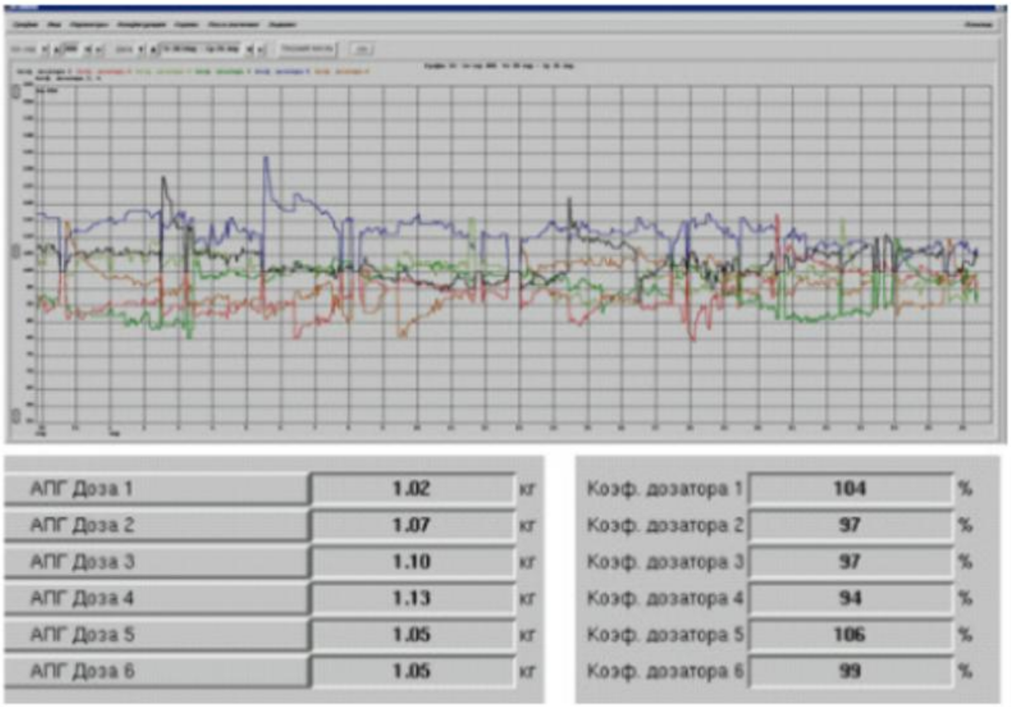

Figure 5. Elvis Web 2.0 interface: cell process parameters.

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Anodic passivation evaluation in a feed point area is of great importance for ensuring efficient alumina feed during aluminum reduction. It allows identifying problematic feed areas in the vicinity of each individual feed point and detecting and solving alumina feed problems.

To prevent AEs, which negatively affect the process, automated AE elimination is used prior to their occurrence. It becomes possible because of the individual settings of each feeder, which depend on the anodic current around the feed point. As was mentioned above, each point has unique features and requires an individual approach. The automated feed system continuously monitors and analyzes the anodic current and dynamically adapts the settings to prevent AEs.

The above approach allows not only preventing AEs but also ensuring a stable and efficient alumina feed in each feed point (area). Stable alumina feeding is essential for higher productivity and process quality, and the means of automated disturbance elimination and dynamic setting adaption help ensure the above.

Another achievement is the possibility to predict AEs (AEs 15 minutes in advance and low-voltage AEs 23 minutes in advance), so that operator can promptly respond to problems and take measures to prevent emergencies. As a result, the system operates in a safe and stable fashion.

6. Automated Evaluation of Actual Productivity

A wireless online tool for monitoring the actual productivity of the RA-550 cell is based on the analysis of anode movement (or the movement of anodes), which represents a cutting-edge technology for a precise and reliable assessment of cell productivity. The tool automatically and quite precisely assesses productivity, including a highly precise prediction of current efficiency (CE) (+/-0.5 %).

One of the key advantages is the possibility to precisely assess the level of the metal pad in relation to the anode bottom, which allows obtaining data regarding process status and efficiency. Analyzing the movement of the anodes allows identifying potential problems, such as heterogeneous current distribution or the nonconformity of actual productivity with target productivity.

The wireless online monitoring tool in Figure 6 provides a continuous real-time picture of the reduction process (tapping shown in Figure 7). The fact that the tool is quite precise and reliable is of great advantage: the personnel can efficiently control and manage the process, prevent possible disturbances and productivity losses, and, ultimately, increase efficiency and cost effectiveness.

As a result, the wireless online tool for monitoring actual productivity, which is based on the analysis of anode movement, is an innovative solution ensuring accuracy, reliability and promptness, increases process efficiency and decreases operational risks.

Figure 6. Wireless online monitoring tool.

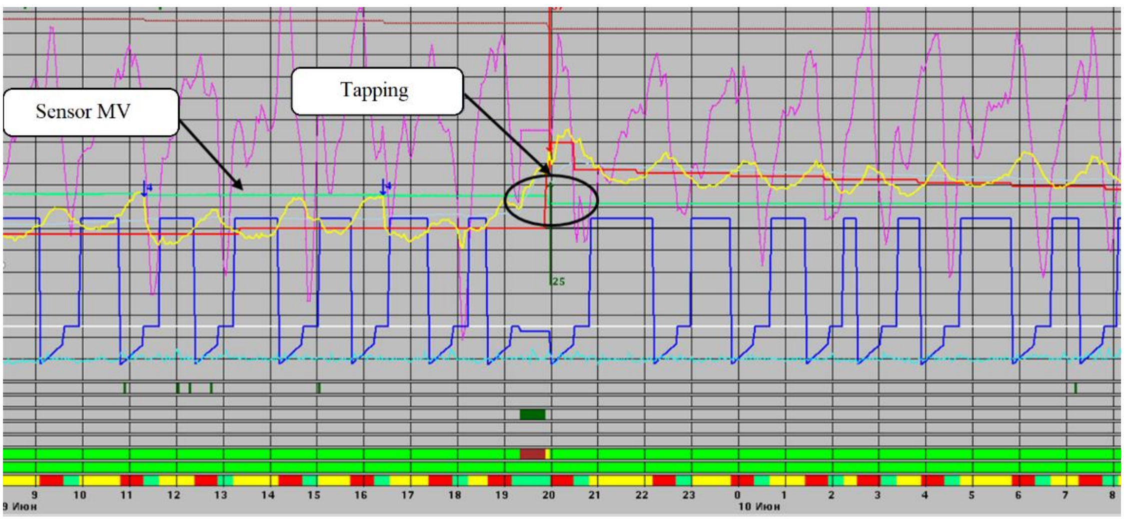

Figure 7. Elvis Web 2.0 interface: data regarding the amount of metal produced by the cell.

An obvious advantage of the tool is that it replaces physical measurements of the metal pad, so that it becomes considerably easier and faster to control the process. An automatically forming tapping order helps automate and optimize the process and exclude the human factor, so that the operation can be performed the way it should. The production process eventually becomes more efficient, expenses for manual labor decrease, and the productivity becomes higher.

7. A Wireless Online Tool for Monitoring the Cathode

An innovative mobile tool was developed to monitor the state of the cathode. The tool detects deviations in the cathode and helps prevent negative consequences.

It has been proved that the tool is able to operate under various industrial conditions. It can be integrated in many processes and used at various metallurgical facilities, which confirms its efficiency and reliability.

One of the key features of the tool is an algorithm for predicting cathode block/collector bar problems/damages, which is able to analyze data and predict such damages/problems. The tool provides recommendations and solutions that get integrated into the ELVIS software, the use of which allows promptly and efficiently taking measures to prevent said problems and maintain productivity.

The innovative tool (Figure 8) and the related software have a great potential for improving and enhancing processes and increasing efficiency in the metallurgical industry. They help promptly respond to potential problems, minimize damage risks and reduce expenses for the repair and replacement of equipment. Moreover, they help optimize production processes and improve the reliability of a system.

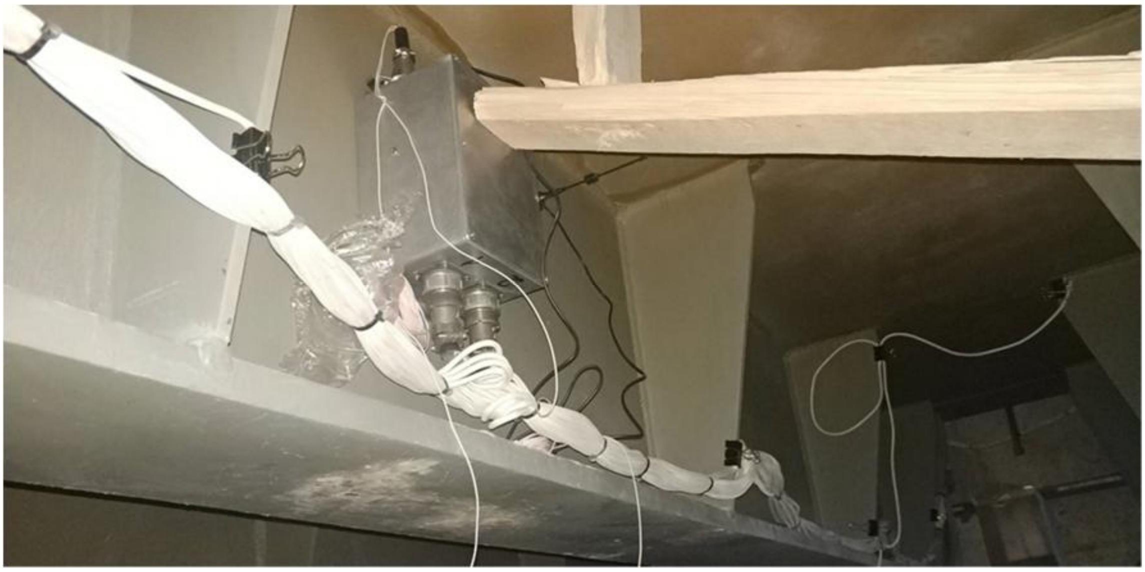

Figure 8. Innovative tool for minimizing cathode damage risks.

One of the main advantages of the mobile tool is that it is wireless, i.e., it requires no physical connection (wire) to collect and analyze data regarding the cathode. Therefore, it is flexible and easy in installation and use. In addition, it eliminates the need to take physical measurements in hard-to-reach spots. Because of this tool, it become possible to obtain accurate data regarding the cathode without any interventions into the cell, which makes things easier and saves both time and resources.

Another advantage is the possibility to power the tool from the cell itself. Thus, the tool functions independently of its voltage, which may vary from 3.5 to 100 V. It helps ensure stable operation and minimize the dependence on external power sources.

The tool also automatically monitors cells in risk groups and identifies potential problems and deviations, which helps take prompt measures to prevent such problems. It increases the reliability and safety of the system and reduces the risk of emergencies.

All of the above benefits ensure an efficient and reliable monitoring of the cathode and its state, reduce the need for manual measurements in hard-to-reach spots and help promptly respond to any possible issues.

8. Conclusions

The paper has discussed the results of developing several algorithmic and software means to detect problems and predict values of the parameters controlled (based on using a combination of methods of mathematical statistics, intellectual data analysis and machine learning.) ‘Voting’ and ‘meta-classification’ prediction models have been developed based on applying ensemble algorithms to the daily average data monitored. Such models (being able to establish patterns and trends) can identify the occurrence of a process perturbation/problem.

Using the technology of associated rules, it has become possible to develop a model that, by analyzing incidents and identifying cause-and-effect relationships, forms rules determining both the status of a process and the probability of a process disturbance. To detect process deviations (based on instant monitoring techniques), there are algorithms identifying changes to time series of the parameters controlled and looking for “problem” anodes.

Various models and algorithms have been implemented as software. A prototype of an information and analytical system of prompt control over the aluminum smelting process has been developed.

Plans are to further enhance the models by improving their prediction accuracy, further develop and enhance algorithms helping to analyze parameters (and how they influence each other) and expand the base of types of process disturbances.

It should be noted that statistical research has allowed not only developing models of virtual sensors for the bath ratio and temperature – which (the sensors) ensure good prediction results – but also developing corresponding software for their application.

The Virtual Cell program uses a brand-new module with a quite informative interface: a module to optimize controls. The module uses two optimization algorithms and several types of objective functions. The ultimate goal of this module is to apply the optimal controls calculated to the automatic control of real cells. However, for the use of this module in such automatic control, it is still required to work on options/conditions of exiting the optimization procedure. Nevertheless, the informative interface/visualization will definitely help process engineers to better grasp some of the already implemented control algorithms, such as bath chemistry stabilization.

Another important and quite considerable result is the development of a training module to train the personnel, which comprises three elements: Virtual cell, which is the main training tool containing a number of interactive examples; a learning package containing theoretical information regarding the reduction process, as well as the methods of performing laboratory assignments, incl. examples of such assignments; and software to test the knowledge and skills of the personnel, incl. a base of tests. The further improvement of the training module will include both the interface and the contents: new tests teaching to identify different situations, theoretical materials regarding more complex control algorithms, etc. Here, the most important thing is its application and testing on the personnel.

It is also important to continuously verify both real and virtual algorithms (to see if they match), to supplement magnetic field libraries, to enhance the communication between the virtual cell and the ELVIS software, etc., and such work is continuously done.

Also, software documentation (User guides for different software) has been developed. It will help in the operation of the software.

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