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Simulation of Energy Consumption Processes at the Metallurgical Enterprises in the Energy-Saving Projects Implementation

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Abstract. The features of improving energy efficiency at a metallurgical enterprise based on portfolio management of energy-saving projects are considered. A simulation model of energy consumption at the metallurgical enterprise, which covers the entire metal products manufacture process, has been developed. The parameters, conduct, and visualization of simulation models of the main equipment such as an electric arc furnace and a ladle furnaces are described. With this software package's help, a comparison of the permissible values and the adjusting of the predicted consumption of active power by a metallurgical enterprise for each fixed point in time are carried out. The system calculates the operating mode regulation range of electric arc furnaces to ensure the continuity of steel casting during melting of a particular steel grade along the appropriate technological routes. The model likewise includes algorithms for transport equipment management that minimize disruptions in continuous casting machines' operation and simulate emergencies. The analysis of the results of energy consumption processes simulation at the metallurgical enterprise is carried out. As a result of modeling, it was possible to increase the productivity of a group of electric arc furnaces and ladle furnaces and reduce the maximum consumption of active power by the metallurgical enterprise. Experimental studies of energy consumption planning methods have been carried out based on real data on the metal products manufacture and electrical energy consumption by the production units of PJSC “Electrometallurgical plant “Dniprospeystal”. The use of the electrical energy consumption model allows in an integrated manner and responds to the dynamics of production processes to carry out further calculations of economic feasibility studies, analysis, and selection of options for the project's implementation of an energy-saving portfolio at the metallurgical enterprise.

Keywords: energy efficiency, energy-saving projects, metallurgical enterprise, energy consumption model, forecast, electric arc furnace.

1 Introduction

The task of energy-saving and efficient use of energy is one of the key issues for industrial enterprises within the Industrial 4.0 concept framework.

The common goal of improving energy efficiency at the metallurgical enterprise is implemented based on managing a portfolio of energy-saving projects, which are aimed at achieving the following objectives [1]: energy balance optimization; modernization of equipment and optimization of operating modes; minimization of natural gas consumption; optimization of energy efficiency, etc.

In concurrence with this, it should be noticed that today one of the main problems is the undeveloped mechanisms for using energy balances for planning and managing energy consumption at the enterprise level. To solve this problem, it is necessary to have a model for the dynamic assessment of the metallurgical enterprise's fuel and energy balance quality.

The presence of a holistic model of energy consumption will allow assessing the effectiveness of selected projects for the implementation of energy-saving measures, objectively assessing the share of each energy resource in the total flow, determining the energy intensity of a

specific product, workshop, and the entire enterprise, and adjusting the strategic direction in energy resource management.

The use of simulation modeling is most effective in the process of solving these problems. At the same time, the use of an agent-based approach to simulation modeling makes it possible to implement dynamic conduct, autonomy, and adaptation of model individual components, which provides mechanisms for flexible change and coordination of energy consumption parameters, based on the efficiency of energy use, management objectives, constraints and requirements, behavior strategies of individual departments, dynamics of the external and internal environment.

With the help of a simulation model, could be solve a number of tasks, including assessing the rationality and efficiency of the existing structure of energy consumption at the manufacture, forecasting the expected maturity of energy consumption when there is a situation of changing technology, assortment and quality of products, and comparing various technologies and equipment from a perspective of energy efficiency, optimal management of energy flows in response to changes in production conditions, etc.

2 Literature Review

Numerous researchers consider the principles and features of solving such problems as energy audit, energy monitoring and energy consumption planning at metallurgical enterprises.

One of the main approaches, which was used to calculate the required amount of electricity consumed by industrial equipment of metallurgical enterprises, is an approach based on the use of regression dependences of electricity consumption on significant factors of the production process [2]. The solution to the problem of electrical energy consumption forecast based on multivariate regression and correlation analyses is also carried out in the papers [3, 4].

In the paper [5] hybrid Petri nets are used for modeling and analysis of metallurgical processes. The dynamic flow of materials and real-time changes of each technological state in the metallurgical process is visually modeled.

In [6], it is proposed to use neural networks and deep learning, namely the extended short-term memory model (LSTM), to predict metallurgical manufacturing's energy consumption.

In [7], a method for electrical energy consumption forecasting at the metallurgical enterprise is proposed, considering such components as energy consumption, where the parts do not change during the entire expectation; consumption of energy where planned technological modernization; consumption of energy with new parts and technologies.

A significant proportion of research is devoted to predicting and optimizing the electrical modes of electric arc furnaces. An electric arc furnace's operation is accompanied by substantial fluctuations in the currents of

electric arcs, active and reactive electrical energy consumed from the net [8].

The papers [9, 10] deal with deep learning to predict electrical energy consumption for electric arc furnaces (EAF).

In [11] the principles of constructing a management system for the EAF electric mode are considered. The method for diagnosing the melting stage by the harmonic composition of the electric arc current signal is implemented.

In the paper [12], it is emphasized that the most energy-consuming process of steel production, associated with EAF, is a subject of automation limitation and decisions related to the volume of furnace charging, and operators usually make the timing of electrode input. This leads to suboptimal batching of the EAF due to complex conduct and relationships between variables, which are inevitably ignored during the decision-making process. The authors proposed a recommendation system based on a model of EAF functioning, which aims to support decision-making by the operator in real-time for an economically optimal technological process.

The paper [13] emphasizes that a significant share of energy losses in the metallurgical enterprise's technological processes falls on fuel gases, and they are the main source of energy losses in non-ferrous metal casting systems, heating of steel billets, and heat treatment. The authors consider various methods associated with the modernization of equipment and the improvement and optimization of the operating modes of the main equipment of steel production.

Simultaneously, increasing the industrial production efficiency, mainly due to the introduction of resource and energy-saving technologies, equipment, and processes, makes it necessary to adjust the priority directions of energy-intensive industries development, including metallurgical enterprises [14, 15].

The analysis of existing studies has shown that forecasting and planning energy consumption in metallurgical enterprises is a multi-complex problem with probabilistic parameters and components, and the cause-and-effect relationship of energy consumption with each of these parameters is rather complicated and does not always have an unambiguous formal description. Thereby, modeling is considered the only way to reflect all elements of a metallurgical enterprise's production system in a virtual environment for carrying out numerous experiments aimed at holding predictive calculations, including energy efficiency parameters calculating while decision-making process of certain energy-saving projects and measures implementation.

In the paper [16], a predictive adaptation methodology is proposed to manage a portfolio of energy-saving projects at metallurgical enterprises based on interconnected systems of planning, monitoring and change management. It is based on a set of methods and models, including those, which are aimed at solving the problem of predicting energy consumption and assessing the quality of the energy and fuel balance in conditions of resources and risks.

3 Research Methodology

To fully consider all interdependencies, constraints, dynamics and uncertainties, it was decided to create a simulation model of energy consumption at the metallurgical enterprise. The agent model was created in the Anylogic modeling system and covered whole metal product manufacture processes.

The initial data in the construction of the model contained information on the movement of material flows and units of products in steel smelting workshops, preparation of steel ladles, secondary refining, and steel casting. Routes of melting through the units and processing times coincide with the actual production plan at the enterprise.

Each electric arc furnace (EAF) and every ladle furnace (LF) act as elements of the regulation model and objects.

The EAF process starts with the boot phase, during which raw materials are supplemented to the furnace. The melting phase begins when the electrodes are switched on and cut into the raw material. Another melting phase usually follows this. Further, the phase of bringing the steel to a given composition begins with the supplementation of additional materials to facilitate exothermic chemical reactions. Then, the steel is discharged into a ladle for further processing in the steel-making workshop. This is followed by an idle during which all necessary furnace preparations such as refractory stripping are performed before the next heating begins. Thereby, the following EAF conditions can be broadly identified: the beginning of the smelt period; end of the smelt period (beginning of the melting period); end of the finishing period (start of furnace idle). Electric arc heating of metal in steel-pouring ladles at the LF is carried out according to the same principle that is implemented in the EAF.

Metal blowdown with argon (nitrogen) at LF is carried out during the entire processing period. While the functioning of the LF, the following conditions can be distinguished: the beginning of the work period; end of the operation period (start of the aggregate idle).

One of the tasks of modeling energy consumption at the metallurgical enterprise is to increase the productivity of the EAF and the LF by eliminating their idle caused by the discontinuity of steel casting on continuous casting machines (CCM) as a result of emergencies and reducing the maximum consumption of active power by the metallurgical enterprise for a fixed time of day using the existing reserves for regulating of ladle furnace power.

Table 1 shows the sequence of actions while passing one of the routes by melting.

To build the model, information was used on the implemented technological routes for melting steel of a given assortment, for each of which the following are known: production units used in a certain sequence, time ranges for performing production operations at each

production unit, the amount of active electrical energy consumed by each unit, etc.

The implemented simulation algorithms make it possible to regulate the EAF and the LF's power based on the switching on of each of the electric furnaces in the group with a certain time lag. This lag does not exceed the duration of the EAF melt period preceding the launching. It does not go beyond the EAF control range that is permissible to ensure the continuity of steel pouring when melting a certain steel grade along the corresponding technological routes.

Table 1 – The sequence and duration of operations while passing the melting of one of the routes

Sequence of operation	Duration of operation
1) pouring steel from a ladle on a CCM	56 min
2) EAF idle	by simulating
3) performance of production operations on EAF	80 min
4) transportation of a ladle from EAF to argon purging system (APS)	1 min
5) performance of production operations at the APS	15 min
6) transportation of a ladle from APS to LF	1 min
7) LF idle	by simulating
8) performance of production operations in LF	40 min
9) transportation of the ladle from LF to CCM	2 min
10) time that normalizes the rhythm of the ladle on CCM before pouring	by simulating

Likewise, the model includes algorithms for managing transport equipment, which minimize disruptions in continuous casting machines' operation.

Thanks to multivariate calculations on the simulation model of transport services, the optimal routes of transport are selected depending on the formulations of energy consumption optimization and logistics management problems.

Table 2 demonstrates the sequence of actions in the operation of steel-making vehicles.

The automated electricity metering system transmits to the modeling system the value of the predicted active electrical energy consumption by the metallurgical enterprise for each fixed time of the day and the permissible active power value.

The consumption of active power by the metallurgical enterprise for each specific time of the day consists of the active electrical energy consumed by all enterprise units for the corresponding period.

Table 2 – The sequence of actions in the operation of vehicles of steelmaking

Vehicle name	Sequence of actions
Steel teeming ladle capsule of the steelmaking workshop	<ol style="list-style-type: none"> 1) start the work on the line (after the end of the steel drain from the furnace); 2) move under the crane; 3) stop under the crane; 4) wait for the ladle to be removed by crane; 5) return to the ladle; 6) finish the work
Steel teeming ladle capsule of the secondary refining section	<ol style="list-style-type: none"> 1) start the work on the line (with the start of the work of the steel teeming ladle capsule in the steelmaking workshop); 2) move to the pouring steel section; 3) wait for the removal of the ladle from the steel teeming ladle capsule; 4) return under the crane; 5) expect charging of steel ladle with melt; 6) move under the metal tweaking (evacuation); 7) wait for the end of processing at the evacuation installation; 8) move to the pouring steel section; 9) wait for the ladle to be removed by crane; 10) return to the secondary refining section; 11) finish the work
Crane of the secondary refining section	<ol style="list-style-type: none"> 1) start the work (with arrival of a steel teeming ladle capsule from a steel ladle); 2) move to the steel teeming ladle capsule, which came up; 3) lift the ladle with a crane; 4) move to the free aggregate of metal tweaking; 5) wait for the arrival of the steel teeming ladle capsule from the steel pouring section; 6) install a steel ladle with a crane on the steel teeming ladle capsule; 7) return to the place and finish the work
Crane of pouring steel section	<ol style="list-style-type: none"> 1) start the work (with arrival of a steel teeming ladle capsule in the pouring steel section from a steel ladle); 2) move to the steel teeming ladle capsule, which came up; 3) lift the ladle with a crane; 4) move to the required continuous casting machine; 5) move crane cart with melt; 6) put the steel ladle on the rotary stand of the continuous casting machine; 7) return to the place and finish the work

Data on the magnitude of the predicted consumption of active power of the metallurgical enterprise for each fixed time of day are entered into the system every day the next day ahead based on the forecast carried out by the chief power engineer. The declared value for the metallurgical enterprise acts as a permissible value of active power. Correction of a given technological route consists of changing the sequence of using production aggregates, the duration of production operations at production facilities, and adding or removing some production aggregates based on the results of the simulation model runs.

The automated control system for the technological process of steel-making receives signals from sensors and controllers and monitors the duration of technological operations at the production plants of each technological route and calculates the control ranges for EAF and LF that are permissible to ensure the continuity of steel casting during melting a certain steel grade according to the corresponding technological route.

With the help of a software package, it is possible to compare the permissible values and correct the predicted consumption of active power by the metallurgical enterprise for fixed time of day, depending on idle's

introduction before starting the EAF and/or the LF. Further, using an automated control system for EAF operation modes, signals are sent to a special agent-controller of the equipment to start each EAF ready for launching with a time lag that does not exceed the EAF melt duration period preceding the launch.

Suppose the magnitude of the predicted consumption of active power by the metallurgical enterprise for a specified fixed time of day exceeds the allowable value of active power. In that case, a signal is sent to the agent-controller of the equipment to start each ready-to-start LF with a possible shift of the electrical mode from the specified fixed time of day to the time following the specified, without disrupting the condition of the continuity of pouring steel while melting a certain steel grade in response to the introduction of idle before this start.

Figure 1 shows a simulation model of an electric arc furnace. Basic parameters: maximum power, maximum load, operating time in accordance with modes, etc. To accumulate statistics on energy consumption, a corresponding dataset and variables have been added.

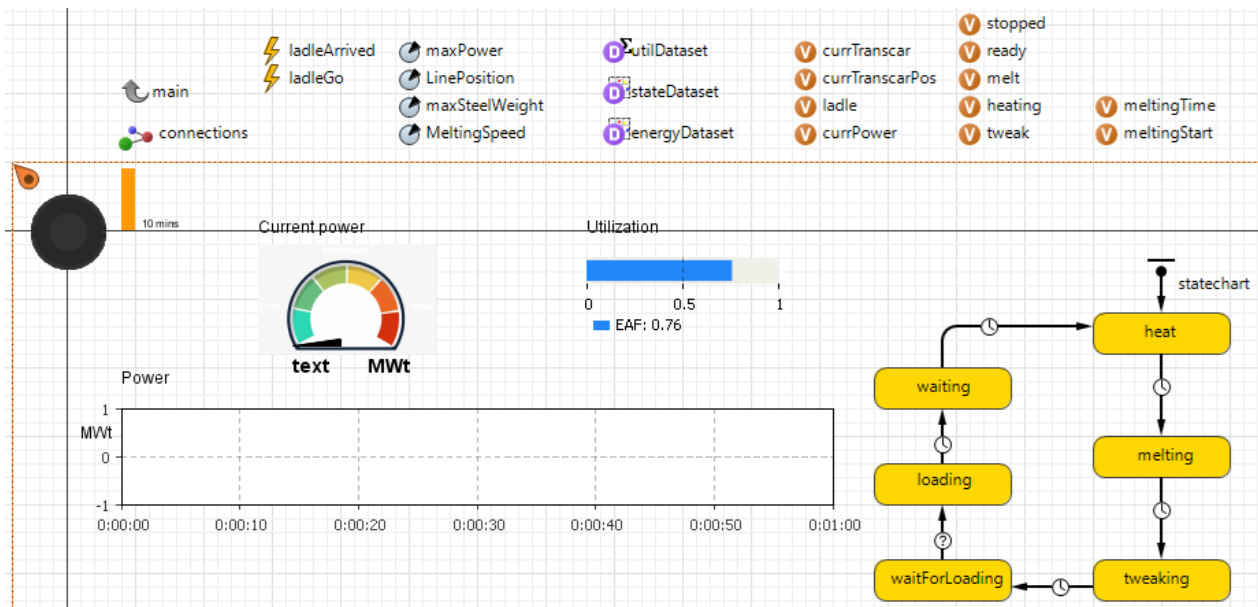


Figure 1 – Parameters, conduct, and visualization of a simulation model of an arc steel furnace

The conduct of the EAF agent is defined using a condition diagram, which considers such events as the beginning of the melt period; end of the smelt period (start of the melting period); end of the twerking period (start of furnace idle); waiting for the steel teeming ladle capsule; charging the steel teeming ladle capsule.

Models of other elements were created in the same way – steel teeming ladle capsule of the steel-making workshop; steel teeming ladle capsule of the secondary refining section; LF; crane of the secondary refining section; crane of pouring steel section; CCM and rolling module.

So that, the main parameters of the EAF steel teeming ladle capsule are as follows: the own weight of the ladle of the steel teeming ladle capsule, the maximum weight of the metal to be charged and the actual weight of the metal that is charged from the EAF (it is needed to calculate the time for charging), the maximum speed. The conduct of the EAF steel teeming ladle capsule agent is specified using a conduction diagram, which considers such events as waiting for readiness from the EAF; charging of the steel teeming ladle capsule; moving to the casting crane; return to the steel-making workshop.

The crane management algorithm should minimize disruptions in the operation of continuous casting machines. Therefore, the developed simulation model makes it possible to evaluate two cranes operation algorithms: each crane serves the CCM aggregates strictly assigned to it; the crane serves the CCM aggregate depending on its current location and proximity to the aggregate that requires maintenance and the equipment

charge. During the process of developing algorithms for transport equipment management, a special agent CranesController was created, which is a task scheduler for workshop cranes.

The search for a crane to complete the task is carried out by checking the weight characteristics of the melt, the free zone, and excluding the situation of interlocking when the cranes are moving. The sequence of crane maintenance priorities is determined by the proximity to the current point and point of the base steel teeming ladle capsule.

Secondary refining is carried out on a two-position ladle furnace. The ladle with metal is installed by a casting crane on one of the two steel teeming ladle capsules of the ladle furnace, fed to the working position under cover of the installation for complex tweaking of metal. After reaching the predetermined temperature and chemical composition, the ladle with metal from the steel teeming ladle capsule ladle furnace is transferred by a casting crane for pouring to one of the continuous casting machines.

Vacuum treatment of steel is carried out in a ladle. During this process, metering batching counters for ferroalloys, the form for argon and argon-oxygen mixtures purging system, and a metal sampling system are laid down on the degassing hood.

Figure 2 shows a simulation model of the ladle furnace installation. The agent's conduct provides for the following events: overflow of metal into the ladle of the installation and its supply to the heating stand; metal heating, alloying additives; ladle transportation; evacuation; metal heating.

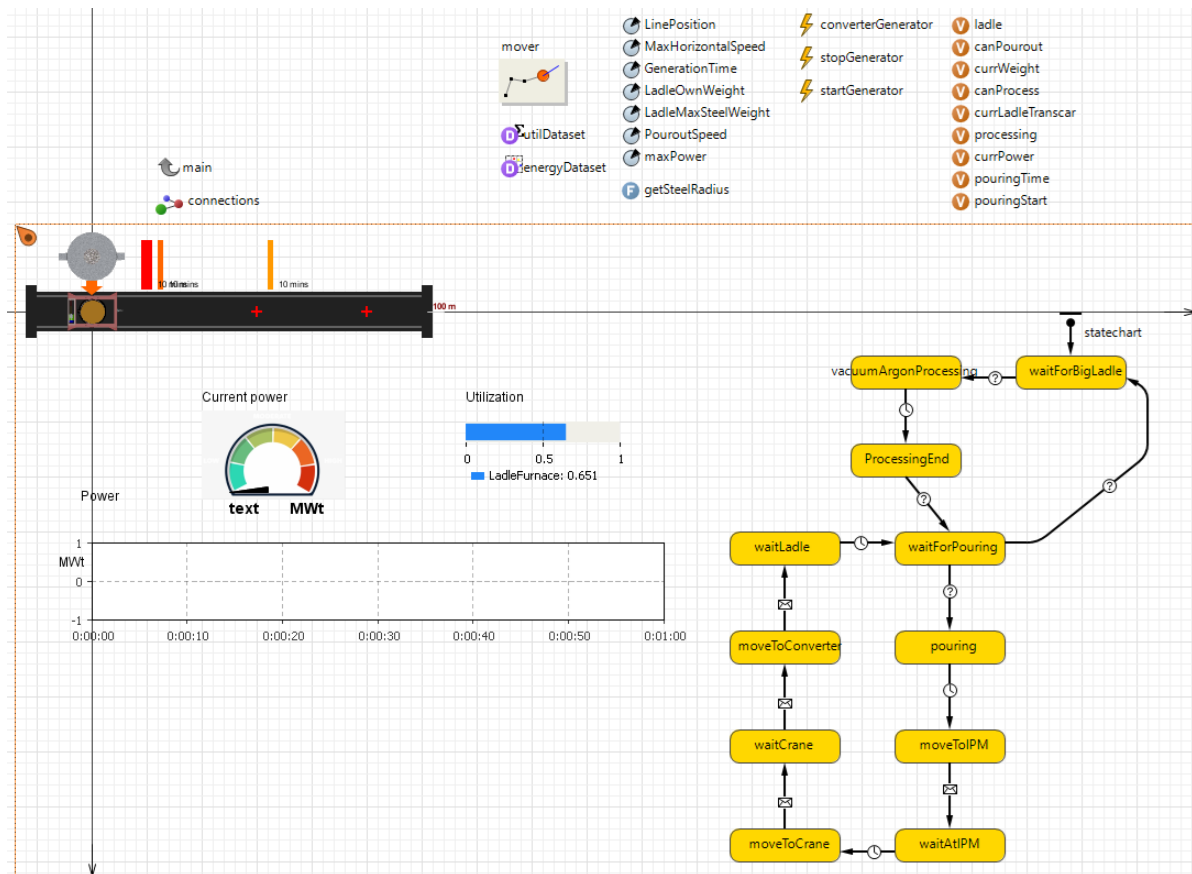


Figure 2 – Parameters, conduct, and visualization of the simulation model of the ladle furnace

Further, a ladle which is filled with metal supplied for pouring is installed by a casting crane on a liftable ladle turret. The ladle is covered with a hood, and after turning the turret, it is transferred to the working position. The intermediate ladle is also in a working position. The continuous pouring process begins.

Continuously cast blank, obtained on CCM, enters the relaying conveyor roll of the rolling mill. The pouring operations' duration includes cutting continuously cast blanks to the specified length and transferring the blanks to the rolling.

Figure 3 shows the initial screen for installing the model. Here it is possible to set the initial parameters. The model is scalable: it can work with any number of steel-making equipment, cranes, etc., and any parameters of distance, technological routes of melting, time characteristics of the operations performed, and parameters of energy consumption.

Figure 4 demonstrates the bench-testing rig during the process of simulation.

Observing the modeling process, the following can be admitted:

- current and total electrical energy consumption;
- volume of steel production;
- total load-graph of the metallurgical enterprise;
- Gant diagram (with an indication of forwarding and late indicators of starting-up and closing dates of technological operations, as well as idle and simulation of emergencies);

- diagrams and corresponding values of the load factors of the main equipment and vehicles.

The model is fully animated in both 2D and 3D.

Figure 5 represents a visualization for an EAF, which displays the current value of power consumption, a block diagram of the remaining time for the current operation, a graph of electrical energy consumption, a condition diagram showing the current condition in which the EAF is located.

During production operations, that may arise unforeseen circumstances that lead to idle or emergencies.

For example, for EAF, idle can be caused by the following events:

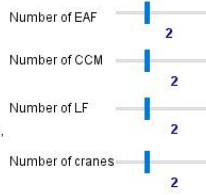
- interchange (extension) of electrodes;
- additional charge, squaring-up, rammer of furnace burden;
- sampling of chemical analysis;
- measurement of temperature;
- slugging practice;
- addition of ferroalloys;
- oxygen lancing;
- lack of additional charge;
- isolation fault;
- error of accumulator station;
- nitrogen in the hydraulic system;
- fault of mechanical aid of furnace (injection lance, crown, baffle, angular inclination), etc.

Model of energy consumption at the metallurgical enterprise

The model of energy consumption at the metallurgical enterprise reflects the entire production process from filling ladles with molten metal in steel mills to the operation of continuous casting machines of billets. With the help of the software complex the comparison of admissible values and adjustment of the value of the forecasted consumption of active power by the metallurgical enterprise for each fixed moment of time is carried out. Also in the model are algorithms for controlling transport equipment that minimize interruptions in the operation of continuous casting machines

The model is scalable: it can work with any number of electric arc furnace (EAF), continuous casting machines (CCM), argon purging system (APS), ladle furnace (LF), cranes, etc. and any distance, timing and capacity parameters.

Experiment settings



Run



Operations

Pouring steel from a ladle on a CCM: 56
 Duration of production operations on EAF: 80
 Duration of production operations at the APS: 15
 Duration of production operations in LF: 40
 Time that normalizes the rhythm of the ladle on CCM before pouring: 5

Transport

Transcar section length: 40
 Crane section length: 40
 Time of transportation of a ladle from EAF to APS: 1
 Time of transportation of a ladle from APS to LF: 1
 Time of transporting the ladle from LF to CCM: 2

Figure 3 – Setting model parameters

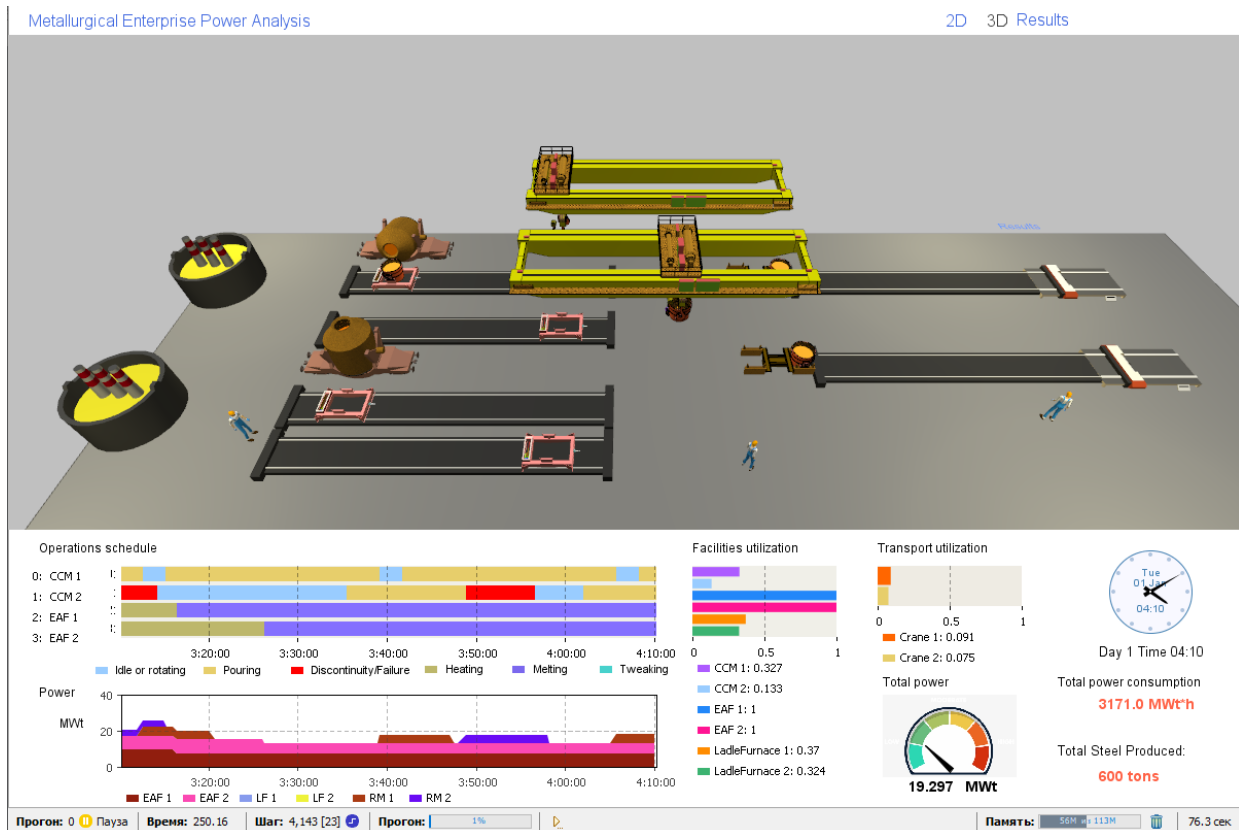


Figure 4 – Bench-testing rig for predictive modeling of electrical energy consumption at the metallurgical enterprise

The model provides for the simulation of equipment failures (aggregates and transport modules), which was carried out by specifying the probability law of the intensity and recovery time distribution.

The imitation was carried out by blocking the operation of the equipment.

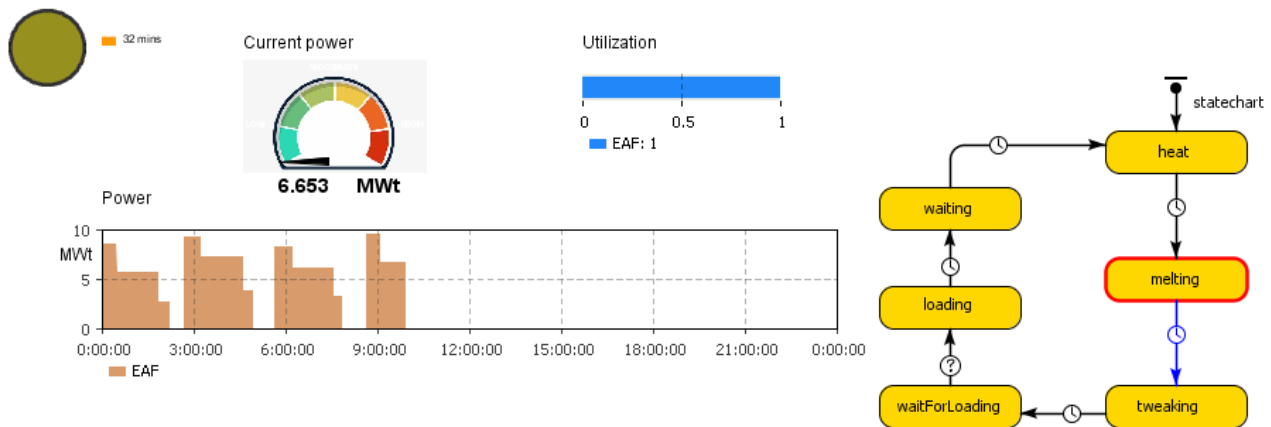


Figure 5 – Results of modeling electrical energy consumption for EAF

4 Results

Experimental studies were carried out with a model of energy consumption based on real data of metal products manufacture and electrical energy consumption by the production units of PJSC “Electrometallurgical plant “Dniprospetsstal”.

An example of a graph reflecting the dynamics of calculated and actual values of daily electrical energy consumption by workshops and divisions of PJSC “Electrometallurgical plant “Dniprospetsstal” is shown in Figure 6.

The presented graph shows that the model's calculations not only reproduce the actual indicators with sufficient accuracy but also well track sharp fluctuations in electrical energy consumption.

Table 3 and Figure 7 represent electrical energy consumption data for January 2020, indicating the results of the implemented hourly electrical energy consumption planning methodology.

Rate areas are the following:

- 0:00-7:00 – night;
- 7:00-9:00 – half-peak;
- 9:00-11:00 – peak;
- 11:00-19:00 – half-peak;
- 19:00-23:00 – peak;
- 23:00-0:00 – half-peak.

Savings in January 2020 amounted to 93 752, 09 UAH.

5 Discussion

As a result of modeling, it was possible to increase the EAF and the LF's productivity to reduce the maximum consumption of active power by the metallurgical enterprise for a fixed time of day. Experimental studies of the planning method have shown that using the developed algorithms leads to a decrease in the overall error in predicting power consumption. The experimental studies of the energy planning methodology showed that the increase in forecast accuracy for hourly planning at the level of individual departments for 2019 was approximately 8 %.

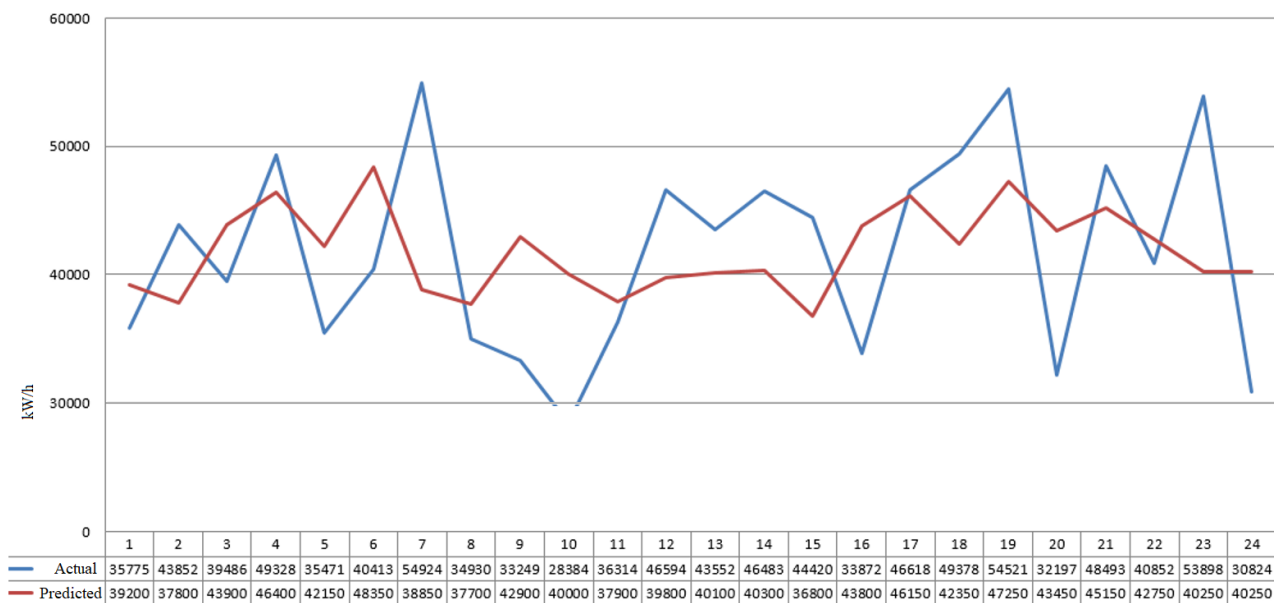


Figure 6 – Daily forecast based on simulation results and actual electrical energy consumption at PJSC “Electrometallurgical plant “Dniprospeksstal”

Table 3 – Electrical energy consumption data at the PJSC “Electrometallurgical plant “Dniprospeksstal” per month (January 2020)

Date	Peak	Half-peak	Night	Total	Value , UAH	(-) economy, (+) overexpenditure, UAH
1	175 695	290 172	186 495	652 362	1 366 280,88	13 048,56
2	191 974	334 179	203 090	729 243	1 527 297,37	15 978,20
3	253 033	436 783	241 853	931 669	1 951 250,29	59 860,88
4	248 730	426 878	274 632	950 240	1 990 144,65	3 117,75
5	205 054	354 242	269 959	829 255	1 736 758,50	-63 003,00
6	248 854	471 515	222 966	943 335	1 975 683,09	83 013,59
7	213 073	432 592	263 097	908 762	1 903 274,78	-36 609,37
8	228 182	405 443	203 488	837 113	1 753 215,98	76 478,40
9	184 980	351 215	223 656	759 851	1 591 401,54	-25 595,24
10	210 729	378 059	203 130	791 918	1 658 561,38	47 846,65
11	190 895	328 902	225 139	744 936	1 560 164,16	-19 214,84
12	177 863	317 738	252 792	748 393	1 567 404,36	-82 318,98
13	194 019	341 821	195 559	731 399	1 531 812,81	30 929,74
14	168 850	276 062	181 445	626 357	1 311 817,05	9 086,51
15	172 303	324 414	211 770	708 487	1 483 826,83	-29 140,11
16	193 735	355 909	235 231	784 875	1 643 810,81	-28 778,14
17	199 446	314 617	227 337	741 400	1 552 758,50	-9 350,16
18	234 450	424 270	226 566	885 286	1 854 107,59	52 519,44
19	244 186	448 000	279 843	972 029	2 035 778,66	-11 198,68
20	219 189	366 951	265 957	852 097	1 784 597,87	-33 723,71
21	228 787	413 983	246 267	889 037	1 861 963,53	13 292,59
22	236 107	484 613	269 486	990 206	2 073 847,84	-7 104,49
23	300 318	465 766	296 408	1 062 492	2 225 240,75	54 819,27
24	275 928	487 008	316 751	1 079 687	2 261 253,27	-14 227,88
25	241 459	448 563	289 063	979 085	2 050 556,46	-29 463,96
26	249 736	492 291	300 716	1 042 743	2 183 879,23	-31 964,09
27	271 999	456 771	318 009	1 046 779	2 192 332,07	-23 659,46
28	280 074	521 433	331 764	1 133 271	2 373 477,45	-28 812,33
29	300 227	522 442	333 717	1 156 386	2 421 888,58	696,77
30	263 480	525 525	359 280	1 148 285	2 404 922,17	-96 825,59
31	260 011	508 577	279 936	1 048 524	2 195 986,72	16 548,59
Total:						-93 753,09

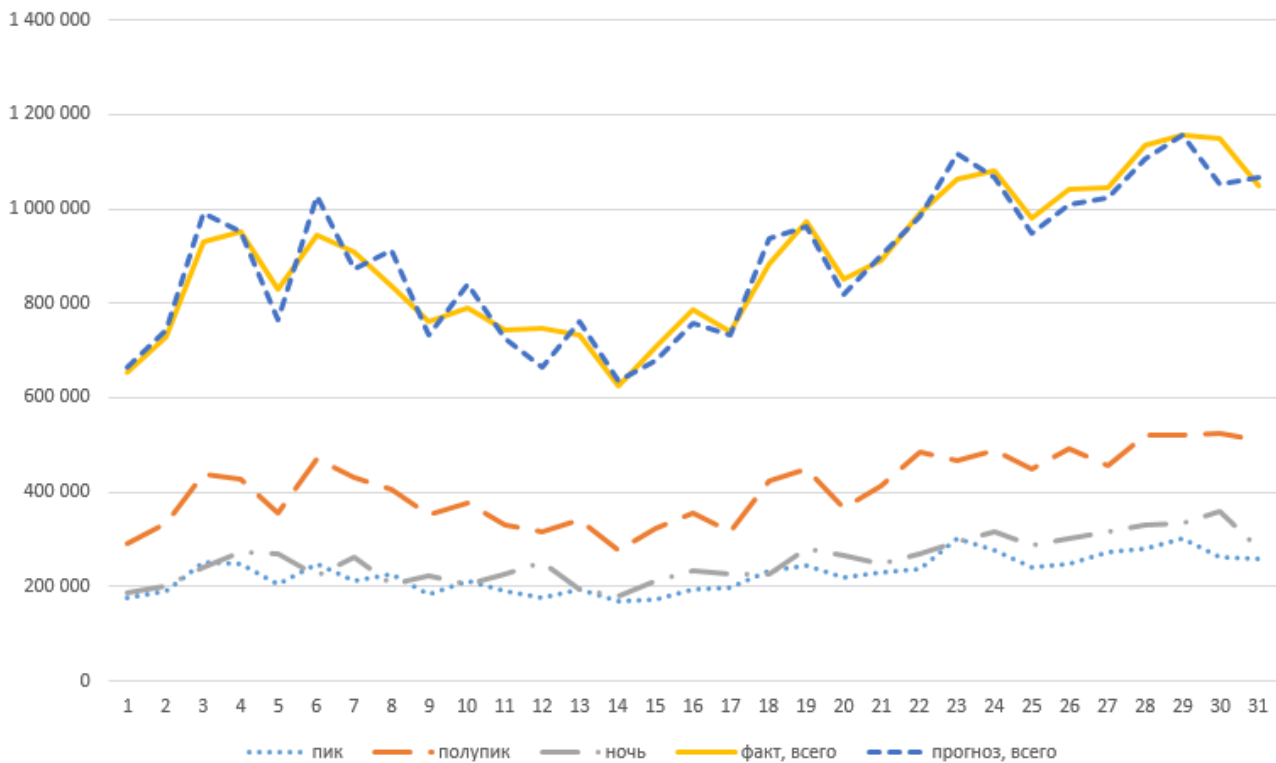


Figure 7 – Results of modeling and actual power consumption of PJSC “Electrometallurgical plant “Dniprospeystal” for January 2020

6 Conclusions

The paper analyzed the existing research in the field of electrical energy consumption analysis and energy efficiency management of metallurgical enterprises. At the same time, improving electrical energy efficiency at the metallurgical enterprise is possible based on managing a portfolio of energy-saving projects. Nevertheless, to analyze the feasibility of projects, considering the complex dynamics of production processes, it is necessary to model and assess the quality of the fuel and energy balance of the metallurgical enterprise. The problem of forecasting and planning electrical energy consumption in metallurgical production is a complex multi-parameter problem, has a probabilistic component, and the cause-and-effect relationship of electrical energy consumption with each of these parameters rather complicated and does not always have an unambiguous formal description.

In the paper, a simulation model of electrical energy consumption at the metallurgical enterprise, which covers the entire process of producing metal products, was developed. The parameters, conduct, and visualization of the main equipment's simulation models were described: an arc steel furnace and a ladle furnace.

With the help of the developed software package, the permissible values are compared and the values of the predicted active power consumption by the metallurgical enterprise are corrected for each fixed time of the day. The system calculates the control ranges for the operating modes of arc steel furnaces allowed to ensure the

continuity of steel casting during melting of a certain steel grade along the appropriate technological routes.

The model also includes algorithms for managing transport equipment that minimizes disruptions in continuous casting machines' operation and simulate emergencies. The analysis of the simulation results of electrical energy consumption processes at the metallurgical enterprise is carried out. As a result of modeling, it was possible to increase the productivity of a group of arc steel furnaces and ladle furnaces and reduce the maximum consumption of active power by the metallurgical enterprise.

Experimental studies of electrical energy consumption planning methods were carried out based on real data on the production of metal products and electricity consumption by production units of the PJSC “Electrometallurgical plant “Dniprospeystal”.

The use of the electrical energy consumption model allows in an integrated manner and in response to the dynamics of production processes to carry out further calculations of economic feasibility studies, analysis, and selection of options for the project's implementation of an energy-saving portfolio at the metallurgical enterprise. With the help of the model, it is possible to solve a number of tasks, including the assessment of the rationality and efficiency of the existing structure of electrical energy consumption at the enterprise, forecasting the expected levels of electrical energy consumption during changing technology, verities and quality of production, and comparing various technologies and products based on the energy efficiency, successful management of energy flows in response to the changes in production conditions, etc.

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