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# ENERGY CONSUMPTION PREDICTION SYSTEM USING AN ARTIFICIAL NEURAL NETWORK

The article considers the possibility of increasing the energy efficiency of a mining enterprise by correctly choosing the price category (PC) and the electricity. The effectiveness of a forecasting model for energy consumption by a rational choice of PC is shown, and a system for predicting energy consumption using an artificial neural network is developed. The prediction error is 0.908% using the architecture network of a multilayer perceptron (MLP 24-18-1).

***Keywords:*** energy management; artificial neural network; electricity tariff; price category; intelligent metering system; error prediction; architecture network; multilayer perceptron

The modern Russian electricity system is a set of interrelated consolidated electric power systems supplying electricity to the electrified part of the country and uniting generation and electric power transmission facilities. It should be noted that mineral resource sector enterprises are the most dynamically developing segment of the FPC (fuel-power complex) providing the required growth capacity for industrial production. On the one hand, being electricity market participants, they must comply with a number of requirements based on Russia’s legislative framework and regulated electricity market, on the other hand, seek to minimize the costs related to the purchase of electricity by correctly choosing the PC and electricity tariff.

The crucial task for mining industry enterprises is to reduce production costs while increasing volumes and profit. Electricity is one of the most significant monthly costs for the enterprises. The final electricity price for the enterprise is formed from five indices (Fig. 1).

The electricity tariffs for the population and their equivalent consumer categories are fixed throughout the year and have three components (peak zone, intermediate zone and the rest of the day). For legal entities the situation is more complicated – they have to choose the tariff from six PCs for the calculations. The question arises: "Is it possible to raise the mining enterprise’s energy efficiency by choosing the correct electricity tariff?" The decision is between: monetary economy of the long-term funds due to the rational choice of PC and the Automated Information and Measuring System of Commercial Energy Metering (AIMSCEM) or fixed costs when choosing the wrong tariff.

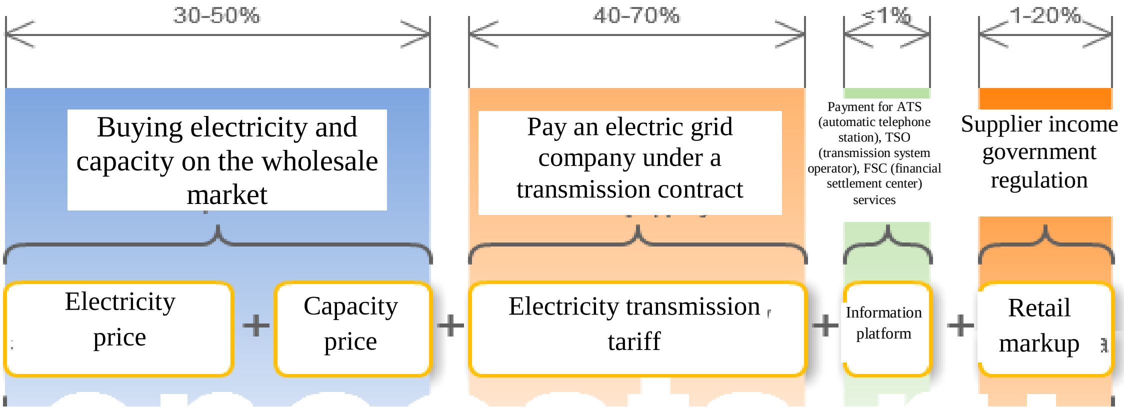


Fig. 1 Final electricity cost.

According to Russian legislation [1, 2], for legal entities, there are six free (non-regulated) prices PCs for electricity and capacity. For each PC, consumers are separated by the maximum capacity of power receivers, as well as the level of supply voltage.

The mining enterprise energy saving program is the result of an energy survey of production that makes it possible to develop a system of energy-saving measures and to assess commercial efficiency. Such a program includes low-cost, average cost, and high-cost measures. Energy saving requires the investment of certain financial assets and should be considered as one of the mining enterprise's investment activities.

The introduction of an AIMSCEM does not reduce the costs of energy resources. Experience shows that the installation of precision electronic electricity meters instead of induction ones may lead to an increase in electricity payments. However, a positive aspect of the AIMSCEM is the basis for the development and implementation of an energy saving measures system which can brings significant economic benefits.

In this regard, the following issues are relevant: energy consumption management for the mining enterprise; development of an electric power accounting monitoring system; development of algorithms of energy consumption functioning; increased reliability and accuracy for planned calculations by using artificial neural networks.

The choice of a rational electricity tariff with the development of an artificial neural network model made it possible to predict the power load [3], choose the optimal tariff for electricity payment, adjust both the electricity and capacity consumption (based on the predicted monthly chart of the enterprise), reduce the error prediction and electricity payment costs [4, 5].

The aim of the work was to increase the mining enterprise's energy efficiency by correctly choosing the electricity tariff with the subsequent development of an intellectual energy consumption prediction system.

Research objectives:

1) Identify the main factors influencing the choice of PC for energy and key performance indicators of the AIMSCEM system calculation.
2) Make a comparative analysis of the calculation of one-part and two-part tariffs for electricity payment.
3) Perform economic evaluation of project efficiency under different PCs.
4) Develop an intellectual power consumption prediction system using an artificial neural network for a rational electricity tariff.
5) Make a prediction for the day ahead and a prediction for monthly energy consumption for a mining enterprise using back propagation of the error algorithm [6].

The calculations were performed based on the example of a mining enterprise belonging to the subgroup III of consumers for power distribution, with power above 670 kW. The voltage level should be considered high taking into account the balance participation limits (BPL) and a 110/10 kV subtransmission substation.

The primary analysis of load profiles allowed us to make an assumption about choosing the best tariff based on finding a form factor. The enterprise can enter into an agreement with a supplier that guarantees from 3rd to 6th PCs taking into account the consumer subgroup III. The correct choice of PC and AIMSCEM system is not enough, it is necessary to create an intellectual electric account monitoring system using artificial neural networks (the ability to predict energy consumption with high precision).

To solve the task, the following were used: mathematical modeling and time series prediction methods, statistical and regression analysis, artificial neural networks theory, mathematical package STATISTICA, Matlab, expert analysis methods.

The main factors influencing the choice of PC for electricity and the development of the AIMSCEM system for a mining enterprise are: determining the power consumer subgroup by capacity (III, capacity from 670 kW to 10 MW; exclusion of I and II PCs from consideration); analysis of daily, weekly load and planned monthly schedule (calculation of basic indicators for the analysis of electric load schedules); price calculation 1 MVt/h by PC (the account of PC features and components for electricity: purchase on the wholesale electric power and capacity market (WEPCM); transmission services tariff; the guaranteeing supplier's retail markup; payment for the services of infrastructure organizations), a comparative analysis of the electricity cost different categories; comparison of one- (III and V PC) and two-part (IV and VI PC) tariffs.

The Key Performance Indicators of the AIMSCEM system calculation system are: energy savings from implementation for a year, capital investments, implementation period, operating costs, project performance indicators (for 5 years): net discounted net income ($NPV$); profitability index ($PI$); discounted payback period ($DPB$). The choice of PC and AIMSCEM system selection includes consideration of organizational, technological (system of transition to a different voltage, reserve reduction) and research (intellectual energy consumption prediction system based on neural networks, identification of risks for the AIMSCEM system) aspects of the issue.

Energy consumption prediction for a mining enterprise using artificial neural networks is shown in Fig. 2.

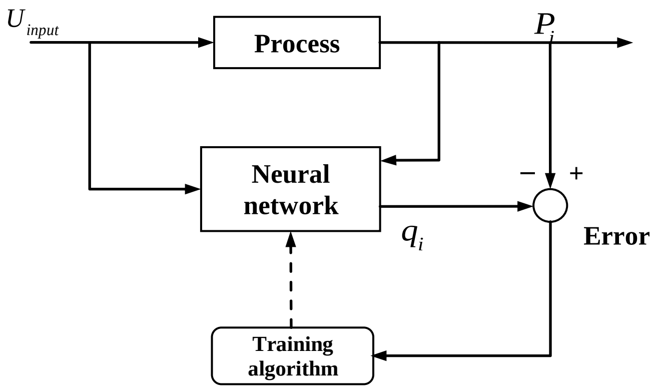


Fig. 2 Energy consumption prediction using ANN for a mining enterprise.

The task of energy consumption prediction can be regarded as constructing the function $P$ depending on actual data on load, energy consumption history, temperature, lighting, humidity, precipitation, wind speed and direction:

$$P = F\big(t, \Delta t, n, k, P(t-\Delta t), \ldots, \\ \ldots, P(t), P(t-n\Delta t), \ldots, \\ \ldots, X_i(t), X_i(t-n\Delta t)\big). \qquad (1)$$

The prediction $P$ value should be in a $\delta$ given prediction confidential interval with a given probability belief $p$. The value $k$ specifies the prediction type – short-term, etc. Where $t$ is the current time, $\Delta t$ is the time interval between the measurements; $n$ is the number of intervals in the past, $k$ is the number of intervals in the future, $m$ is the number of the measured characteristics; $X_i$ at $i = 1, \ldots, m$ is the measured characteristics included in the list of historical influencing factors (except for the consumed power itself these are the temperature $T$ and humidity $w$, the length of the day, etc.). The depth in the past $n$ and the list of independent variables or influencing factors $X_i$ should also be determined.

The function depends on the independent variables taken as factors that influence the value of energy consumption for which we have reliable evidence: daily schedules of meteorological parameters, temperature, lighting, humidity, precipitation, wind speed and direction.

Based on the function (1), an energy consumption prediction algorithm was drawn up based on the operation of the multi-layer perceptron shown in [7], the use of artificial neural networks in the tasks of energy consumption prediction, as well as modeling and prediction in works [8, 9]; the study of short-term prediction of electrical load using the artificial neural networks [10–12].

Fig. 3 shows an algorithm for constructing a neural network for diurnal prediction. This algorithm is applicable for both weekly and monthly prediction.

As part of the research, back propagation of the error algorithm was used to predict the energy consumption of a mining enterprise; factors that influence power consumption were taken into account.

In blocks *1–3* the initial conditions for the neural network were started and installed (weighting values, number of training samples $NP$, $ANN$ parameters, the given small value $e$ which determines the prediction accuracy), the values of the electrical load $P_1, \ldots, P_{24}$ were read, and then the conversion process was performed in the relative values $Y_i$ that are within the range $0 \le Y_i \le 1$ where $1 \le i \le 24$).

In block 4, the calculation of the values of the signals on the inputs and outputs of the hidden layer $j$ and output layer neurons $k$ was made using the following formulas:

– $j$ layer neurons inputs

$$net_j = \sum_{i=1}^{24} w_{ji} Y_i, \quad j = 1, 2 \ldots, 5; \tag{2}$$

– $j$ layer neurons inputs

$$Y_j = 1/\left(1 + e^{-\left(net_j + \Theta_j\right)}\right); \tag{3}$$

– $k$ layer neurons inputs

$$net_j = \sum_{i=1}^{5} w_{kj} Y_j \;, k = 1; \tag{4}$$

– $k$ layer neurons inputs

$$\left(P_{prog}\right) Y_k = 1/\left(1 + e^{-\left(net_k + \Theta_k\right)}\right). \tag{5}$$

Here $w_{ji}$ and $w_{kj}$ are the weight coefficients respectively between the neurons of $j$-rd and $i$-th layers and $k$-th and $j$-th layers; $\Theta$ – bias. To limit the search space during training, the objective error function found by the least square method [6] is minimized:

$$E_p = \frac{1}{2} \sum_{k=1}^{KN} \left(d_k - Y_k\right)^2, \tag{6}$$

where $d_k$ is the desired value of the load at the output, $Y_k$ is a calculated value, $KN$ is the number of neurons in the output layer.

Then the gradient descents in the scales space are calculated $w_{ji}$ and $w_{kj}$, and scales adjustment is made.

The following characteristics were obtained on the basis of gradient descents calculations: $h$ – training speed ratio; $a$ – moment determining the training acceleration. In this algorithm $h = 0.3$; $a = 0.61$; $e = 10^{-6}$ (chosen according to the prediction error of minimization criterion).

Block *6* determines whether all samples were used. If all, then the total error for all samples in block *7* is calculated, and the condition in block *8* is checked. If the condition is fulfilled, the training process ends, otherwise the process repeats.

To solve the energy consumption prediction task, the back propagation of error algorithm was used to minimize the root-mean-square deviation of the current output of multilayer perceptron and the desired output.

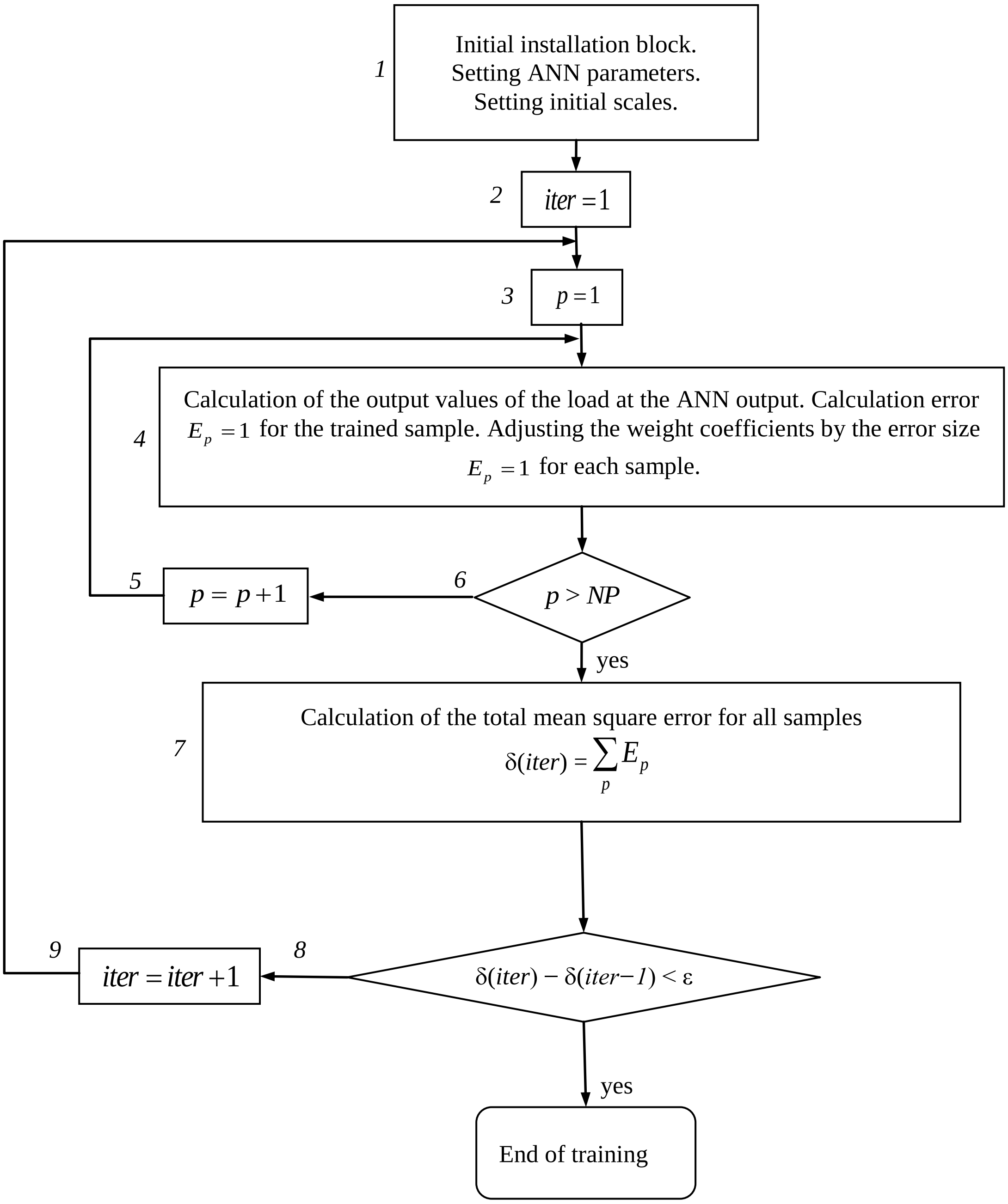


Fig. 3 Back propagation of error algorithm.

Prediction at the system output is compared with the actual load value, and, when the error exceeds a predetermined allowable level (for example, over 2 %), the system re-retrains using the new data.

Table 1 shows the main characteristics of the obtained predictive neural network for the prediction of energy consumption.

*Training performance/Control performance/Test performance*: network performance on the selections used for training. The value of the network performance depends on the type of output variable network.

*Training error/Control error/Test error:* network error on the selections used for training. This is a number that is actually optimized by the training algorithm. It is a root-mean-square value of errors under certain observations where the individual errors are calculated by the network error function which is a function of the observed and expected levels of the output neuron activation. The error in the test selection is interpreted as a model error prediction accuracy measure.

*Training.* This field contains a brief description of the training algorithms used for network optimization. It stores several codes, followed by the number of epochs performed by the algorithm, and an optional stop code which shows how the final network was selected. OR91b code shows that the backpropagation method was used, that the best found network was chosen (by the "best” that is the "minimum test error"), and that this network was found at the 91st epoch.

Prediction research of the best prediction models for an artificial neural network with activation function obtained, the hyperbolic tangent, MLP 24-18-1 architecture, the prediction error was 0.906 % without taking the factors into account.

In addition, the economic evaluation of the project effectiveness for various PCs taking into account the main factors of the final cost of electricity was determined: price (range of transformation voltage, power distribution categories, pricing zone, maximum capacity); schematics of the enterprise power supply from which the voltage level is dependent; the BPL affecting the formation of the weighted average price of the electricity; AIMSCEM system installation with the calculation of project payback cost.

The schedule of the enterprise site load for a typical day is shown in Fig. 4.

Comparative analysis of one-part and two-part tariffs under the per-unit system for a mining enterprise by price categories is shown in Figure 5. As a base price, the cost of 1 MWh for the third PC was taken.

Comparative analysis showed that the cost of 1 MWh is higher for the two-part tariffs (IV and VI PC) than for the one-part tariffs (III and V PC). Fig. 5 shows that for the one-part tariff for the 3rd PC, the payment cost for 1 MWh is minimal. Nevertheless, will such a tariff be optimal throughout the year subject to changes in energy consumption for this enterprise? Depending on the payment for the electricity chosen by the PC consumer, the consumption pattern and the ability to plan the final cost of energy consumed per month can vary by 50%. Consideration should be given to the specifics of the price categories:

– the third PC provides for the payment for transmission services under the one-part tariff; it does not require hourly planning of electricity consumption;

– the fourth PC provides for the payment for transmission services under the two-part tariff; it does not require hourly planning of electricity consumption;

– the fifth PC provides for the payment for transmission services under the one-part tariff (like the third one); it requires hourly planning of electricity consumption;

– the sixth PC provides for the payment for transmission services under the two-part tariff (like the fourth one); it requires hourly planning of electricity consumption;

Therefore, to choose the best PC, two questions must be answered: What type of boiler transmission tariff is more beneficial? Can a mining enterprise carry out detailed planning of hourly consumption?

Table 1

NN model result

| Architecture | Training performance | Control performance | Test performance | Training error | Control error | Test error | Training/ Elements |
|---|---|---|---|---|---|---|---|
| MLP 24-18-1 | 0.169209 | 0.182035 | 0.141871 | 0.00906 | 0.0520651 | 0.0524561 | OP91b |

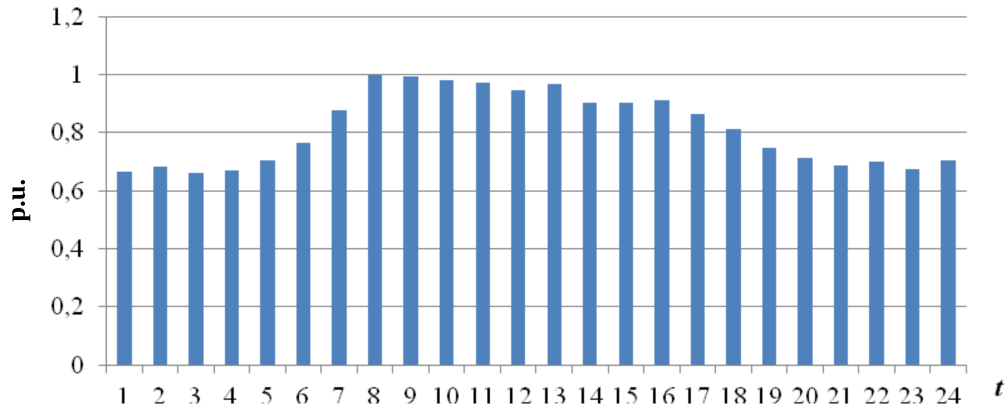


Fig. 4. Schedule of the mining enterprise site load on a typical day.

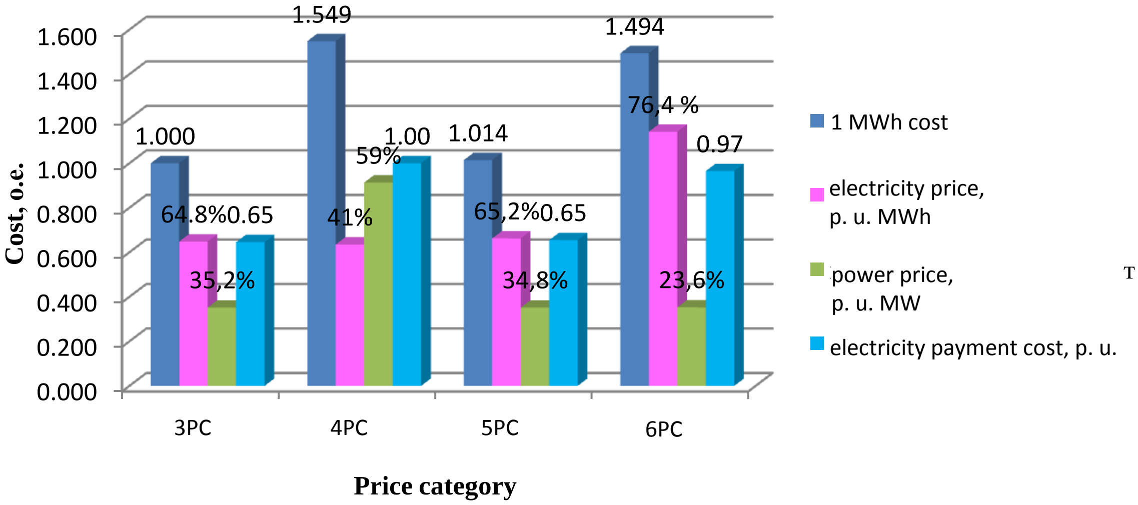


Fig. 5 Comparative analysis of the electricity cost in various price categories

The PC choice economic efficiency estimation taking into account the costs of AIMSCEM system is shown in Fig. 6.

The graph shows that the choice of prospective price category is effective for the enterprise for the 5th and 6th PCs, taking into account the calculation of the economic indicators of the project. Negative values $NPV$, $P_i$ will make it possible to judge the ineffectiveness of the PC choice, the deviation of the 4th PC choice because the $DPB = n = 5$, project will not yield either profit or loss, therefore the project should be rejected. For the 6th PC the profitability index $P_i$ and net present value ($NPV$) is higher than for the 4th and 5th PCs.

The development of an energy consumption prediction system using an artificial neural network was carried out according to the algorithm described above. The graphs shown in Fig. 7 were obtained.

The input variables to create the neural network were the hourly load values $P_i$ ($i = 1,...,24$) for the day preceding the predicted one (24 values) and for the day a week ago (24 values). In the input layer they get rated, that is, converted to the relative values. In the output, 24 values of the predicted value (a day ahead) are obtained. Results for diurnal prediction: the error of the best neural network was 0.908 %, multilayer perceptron type, MLP 24-18-1 architecture, hyperbolic tangent activation function.

The prediction error can be reduced by setting additional parameters on the network input: day status (weekday, weekend), average temperature value [13]. When taking into account these parameters, the relative error of the neural network was reduced to 0.799 %.

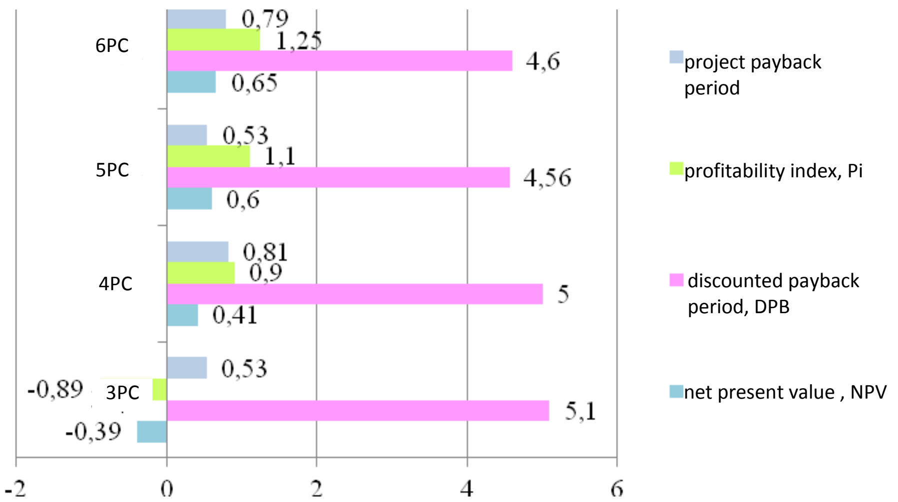


Fig. 6. Calculation of the project economic efficiency.

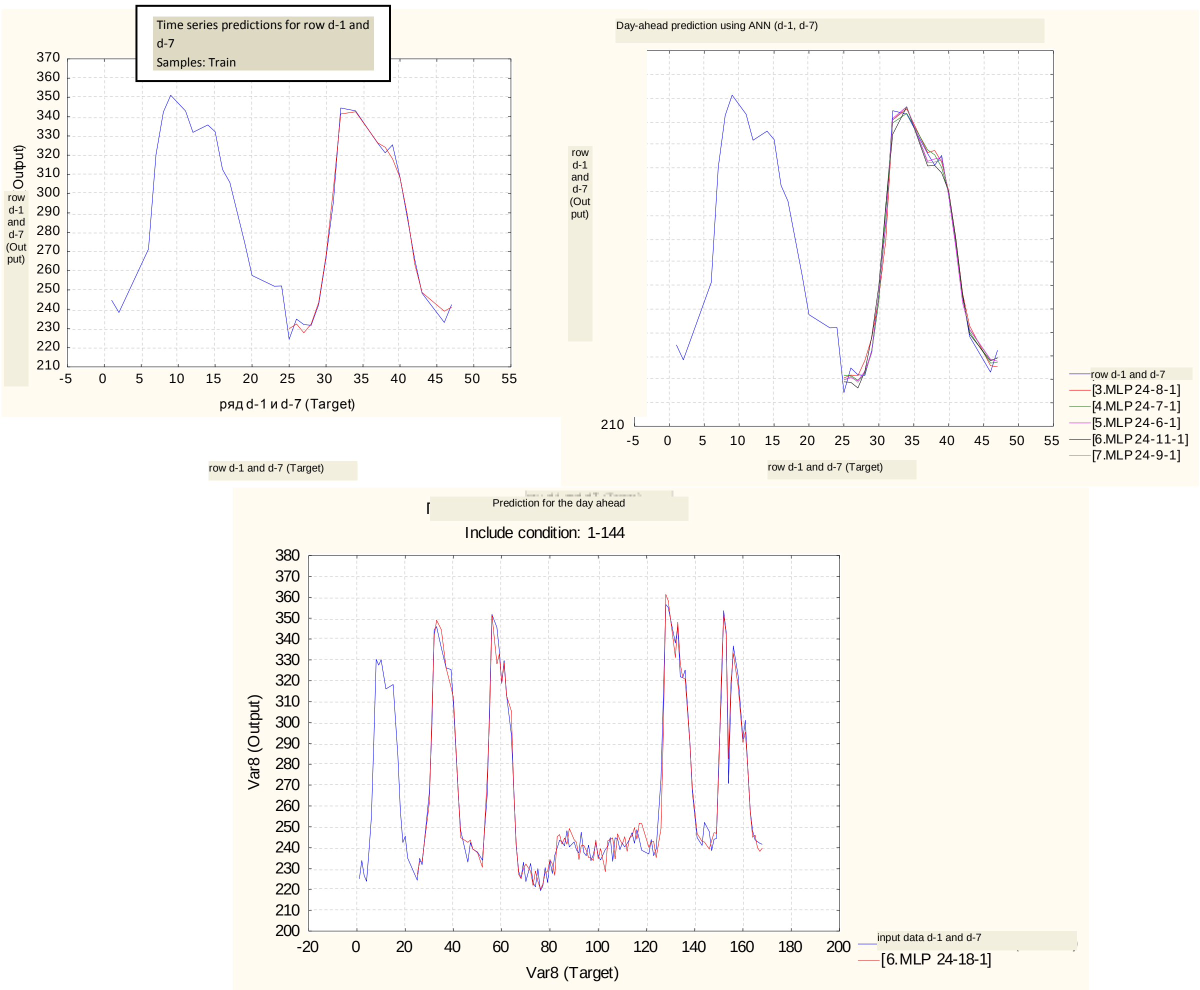


Fig. 7. Day-ahead prediction graphs using MLP 24-18-1 for mining enterprise.

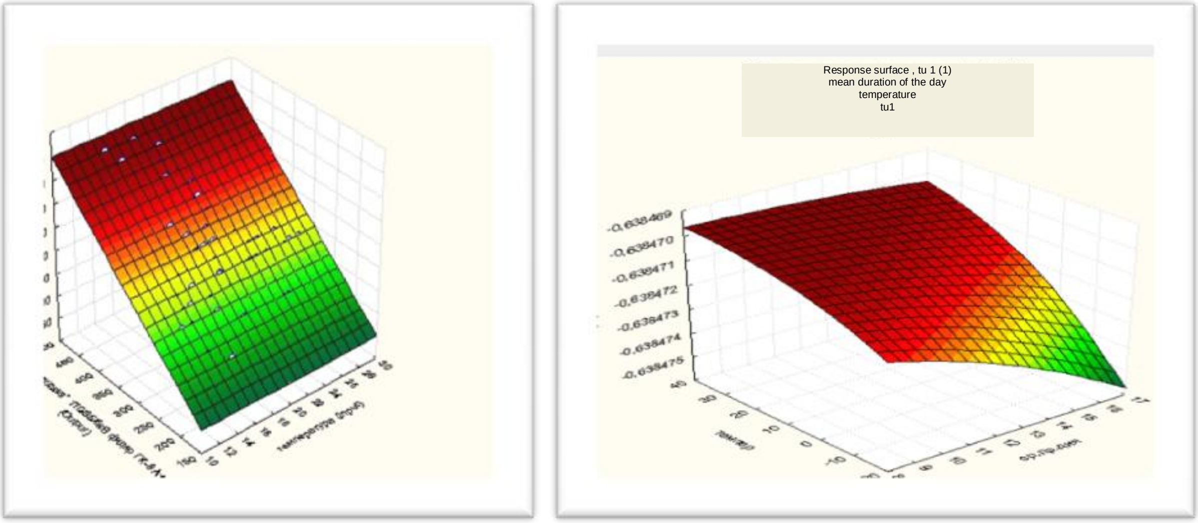


Fig. 8. Level of element activation for day status (weekday, weekend) and temperature.

The response surfaces of the dependent variables for energy consumption prediction were obtained. The element activation level is the weighted sum of its inputs with the addition of thresholds. Therefore, the activation level for the neural network is a simple linear function of inputs. Further, this activation is transformed by a sigmoid (*S*-shaped) curve.

## CONCLUSION

It is possible to improve energy efficiency for a mining enterprise through the rational choice of PC and tariff for electricity costs with the creation of an intellectual electricity accounting monitoring system through the introduction of prediction functions based on the work of artificial neural networks. The cost of 1 MWh for two-part tariffs (fourth and sixth PCs) is higher than for one-part tariffs (third and fifth PCs). However, the greatest reduction in payment for electricity is observed in the application of tariffs (fifth and sixth PCs) where it is possible to predict the schedules of electrical load, thereby reducing the maximum power at peak hours (reduced power payment component).

The use of artificial neural networks makes it possible to predict the energy consumption of mining enterprises on the basis of the data for a weekly load, the data on energy consumption in the last month, air temperature, day status (weekday, public holiday, pre-holiday day). The development of the intellectual energy consumption system for a mining enterprise makes it possible to choose a rational PC, thereby reducing electricity costs.

Introducing such a system will allow to optimally plan and monitor the fulfillment of the enterprise load schedule; predict the production cycles and peak energy consumption values; the possibilities of redistribution of load and analyze the possibility of changes in the enterprise's operating schedule.

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| **Keywords:** | energy management; artificial neural network; electricity tariff; price category; intelligent metering system; error prediction; architecture network; multilayer perceptron |
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