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POWER DISTRIBUTION EFFICIENCY AND RELIABILITY RAISING BY USING THE VACUUM RECLOSERS

Abstract: *Topical matter of power supply for today is effective increase in the reliability of power supply in medium voltage overhead power systems by sectioning of lines with switching devices, such as disconnectors, controlled disconnectors or sectioning points. In such schemes, the manual approach to emergency management is used. This kind of schemes can be used where the overhead power lines are.*

Keywords: *efficiency, reliability, vacuum reclosers*

Remotely operated disconnectors or remote controlled sectioning points can also be installed instead of manual line disconnectors. This process of damage localization differs only in that all switching operations are performed remotely. Decision on switching is made by the dispatcher, constant communication with each controlled element of the network is necessary, otherwise it becomes virtually uncontrollable and the entire effect of remote control of disconnectors is eliminated.

Reclosers of E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute", electronically controlled, vacuum- interrupting distribution automation switch provides reliable, economical switching, sectionalizing, advanced metering, and automation systems for distribution circuits rated up to 38 kV. The Recloser switch combines solid cycloaliphatic-epoxy vacuum interrupters with a reliable, lightweight operating mechanism that utilizes a magnetic actuator to provide a lifetime of trouble – free operation. The solid polymer system does not rely on a gaseous, liquid, or foam dielectric. The ZX switch is highly resistant to ozone, oxygen, moisture, contamination, and ultraviolet light. Switch operations are programmed in an electronic control with accurate characteristics and a host of advanced features. When system requirements change, program settings are easily altered with no sacrifice of accuracy or consistency. Pomanique's reclosers meet all the requirements for outdoor use in accordance with the IEEE C37.60 and IEC 62271-111.

Reclosers of E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute" are self-contained small-sized complete switchgears with great functionality (Fig. 1).

The main idea of using reclosers is the following [1, 2]:

- One of the main problems of today's electric power industry is the frequent emergencies on medium voltage overhead lines. This is due to their considerable length and high wear and tear of the equipment of consumers connected to them. Therefore, power supply companies require the installation of sectioning devices on the overhead power lines of consumers, automatically separating this line from the general power grid in case of emergency situations on it. This kind of devices are the reclosers.

- In case of short circuits on the power line protected by the recloser, the fast-switching vacuum circuit breaker protects the fuse link of the tap-off fuse. And only on the 2nd or 3rd automatic reclosing cycle (depending on the setting of the microprocessor protection of the recloser), when it is already possible to talk about the stability of the circuit, the device allows this insert to burn out.
- In addition to the protective and sectioning functions, the reclosers of the E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute" can be used for remote monitoring and logging of the quality of supplied electricity, metering its consumption, including it being a part of automatic metering and telemechanics systems. It is possible to enter automatic transfer switches and backup power system with help of them.

Using of reclosers of E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute" significantly increases the reliability of the network, reduces the costs of its maintenance and losses from possible undersupply of electricity to the consumer, and allows keeping electricity metering at the border of consumers balance inventory. Currently, about 40% of overhead lines (OHL) have reach the end of its service life and more than 80% are in need of technical re-equipment.

FIGURE 1. *Installation example for reclosers, switching module and control unit*

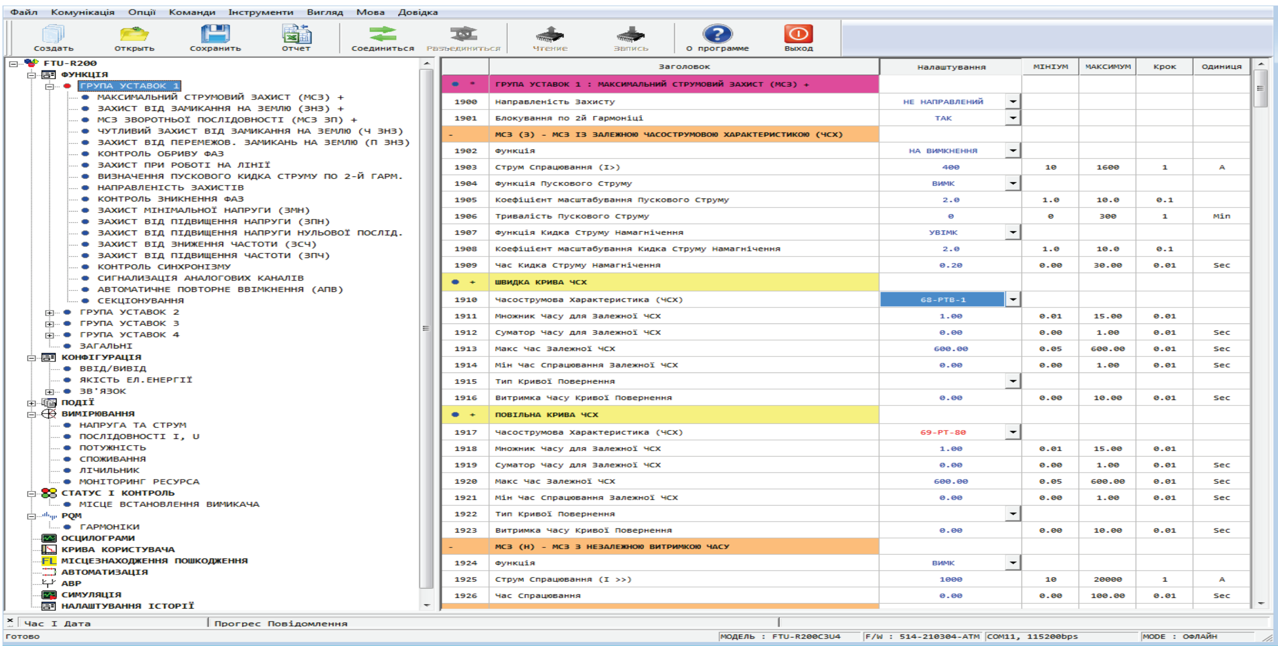

FIGURE 2. *Mnemonic frame from SCADA system*

The weakest link in the power supply system is 6 (10) kV overhead distribution networks. However, this requires large costs during the construction phase, and sometimes is not feasible due to the complexity of the placement [2, 3]. Also, in order to increase the safety of power supply to consumers, it is possible to repeatedly reserve and section the lines with manually operated disconnectors. But this method also has disadvantages. Therefore, the reliability of power supply of such power lines is increased by sectioning it into several relatively short sections with the installation of intermediate automatic protective switching devices-reclosers. Reclosers of E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute" are small circuit breakers located at the top of distribution poles and are usually used on very long distribution feeders.

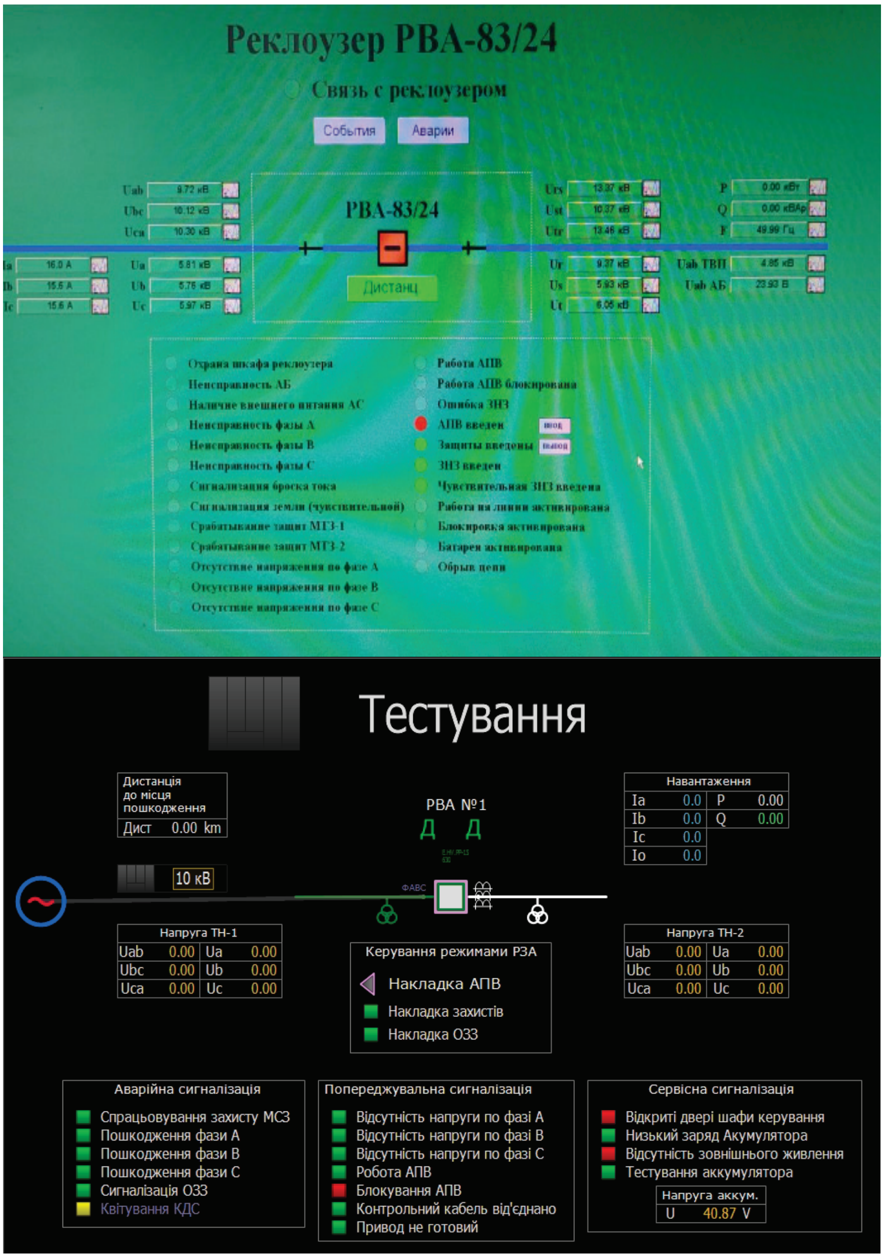

FIGURE 3. *Mnemonic frame from SCADA system*

Their function is to isolate the feeder section in the event of a malfunction or overload and thus minimize the number of unattended customers. Because they act like small circuit breakers, they have the ability to automatically restore power in situations of temporary failure, hence the name "recloser". This device is remotely controlled and allows the electrical network manager to detect a fault on the overhead line directly at the time of the fault, make decisions quickly and send the emergency repair team to the right area.

Recloser of E.NEXT-Ukraine Company and "Igor Sikorsky Kyiv Politechnic Institute" includes:

- vacuum (SF6) switching device;
- system of primary current and voltage converters;
- autonomous operational power supply system;
- microprocessor relay protection and automation system with the ability to connect telemechanics systems;
- a system of ports for connecting telemetry devices;
- software complex.

The advantages of the developed recloser [3, 4]

Installation of poles. Reclosers have external (external) pole installation, and due to this:

- Increased level of insulation – the insulation of the poles of the switching module is made of epoxy resin, which has high insulating properties, resistance to ultraviolet radiation, and the ability to self-cleaning from precipitation and pollution.
- No risk of internal short circuit – in the event of an internal fault or lightning strike in the switching module, a short circuit will not occur, since the poles are insulated with solid insulation without the risk of explosion. On the other hand, reclosers with indoor poles have a high risk of explosion.
- Maintainability – in the event of a malfunction of one of the poles, it is possible to quickly replace the recloser pole, which is cheaper and more practical with a long service life, in comparison with the internal version, where this is not possible, in case of a malfunction, the entire switching module is replaced.

Drive mechanism. In the proposed reclosers, a spring drive mechanism is installed, which makes it possible to manually turn on and off the recloser in the presence of voltage on the line, while it does not need the presence of an auxiliary power supply, which cannot be done with a magnetic drive mechanism. Also, the latter requires frequent checking of the capacitor, which may lose capacity, which is likely under unfavorable climatic conditions (high temperature). The spring-loaded mechanism of the drive provides a higher mechanical pressure on the power contacts, which minimizes the risks of contact welding, and also withstands a higher short-circuit current compared to a magnetic drive. The spring-loaded drive mechanism is used at high-voltage switchgear/substations, which confirms the reliability and durability of this drive mechanism.

Current measurement. Reclosers use built-in current transformers (CTs) to measure current, which provide a whiter class of accuracy than Rogowski coils. The error in measuring the phase currents for CT and Rogowski coil is 0.1% and 1%, respectively, when measuring a single-phase earth fault, the error for CT and Rogowsky coil is 0.01% and 0.2%, respectively, which is a very important factor in networks with an isolated neutral LEP 6-35 kV, where earth fault currents are small compared to phase-to-phase short-circuits.

Body material. The recloser body is made of expensive 304 stainless steel, 4 mm thick, powder coated, this will ensure a long service life even in the most aggressive environments, compared to the low grade stainless steel body.

Auxiliary transformer (TSN). Complete with reclosers, single-phase TSNs with built-in fuses are used, with the ability to mount on the recloser body, which minimizes the time and material costs for installing the recloser on the power transmission line support.

Reclosers are the workhorses of distribution automation. Reclosers reduce outage duration and frequency, lower operating costs, and improve customer service and overall system reliability. The E.NEXT Molded Vacuum Recloser (MVR) raises the standard of recloser performance by incorporating state-of-the-art vacuum-interrupter technology with the field-proven E.NEXT-Ukraine solid-dielectric insultation system and long-life operating mechanism and magnetic actuator system. The E.NEXT MVR reclosers are compatible with the industry standard Laboratories Controls.

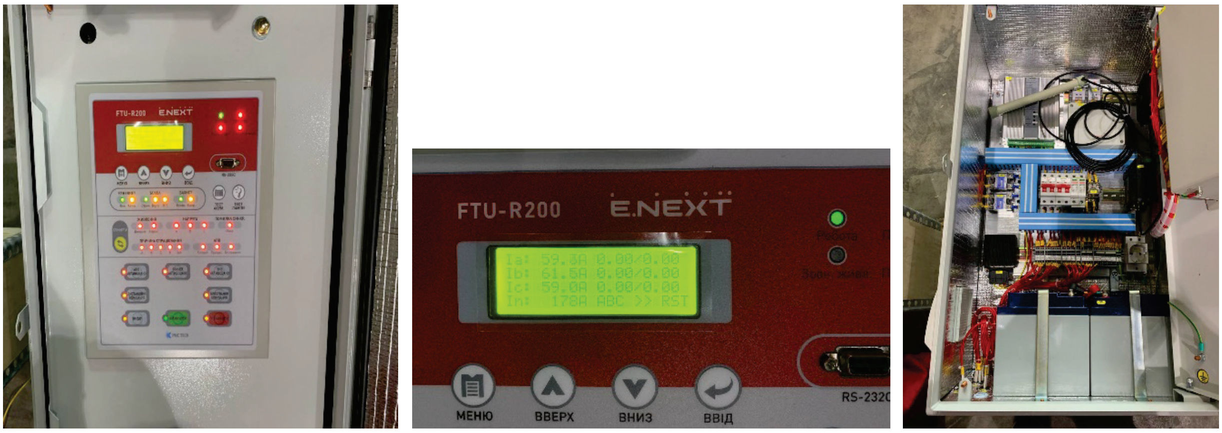

FIGURE 4. *The control unit of the E.NEXT Molded Vacuum Recloser*

Sensitive earth fault protection in reclosers E.NEXT is typically set to immediate lockout. This detection of small leakage currents (less than 1 ampere) on a medium voltage line can indicate insulator failure, broken cables or lines coming into contact with trees. There is no merit in applying reclosing to this scenario, and the industry best practice is not to reclose on sensitive earth fault. Reclosers with sensitive earth fault protection capable of detecting 500 mA and below are used as a fire mitigation technique, as they provide an 80% risk reduction in fire starts [4], however they are never to be used as reclosers in this application, only as single shot distributed circuit breakers which allow for sensitivity to verify the existence of these faults.

E.NEXT reclosers have over 5 years of proven field performance incorporating innovative technology and unique E.NEXT expertise, including embedded sensors with the highest accuracy and least environmental sensitivity in the market. And with multiple controller options, E.NEXT reclosers are designed to continually meet and exceed the growing demands of power distribution.

Why E.NEXT?

Increased reliability – the highest creep distance among the recloser poles on the market ensures long-term performance in any environment.

Unparalleled performance – the HCEP (Hydrophobic Cycloaliphatic Epoxy) material of the poles provides the best insulation for outdoor use, shedding water and debris, thus reducing the probability of flashovers even in heavily polluted areas.

Simple, fast and safe maintenance as all the electronics are in the low voltage unit, eliminating the need for a bucket truck to isolate potentials to service electronics

Key benefits of E.NEXT reclosers:

Easy integration with multiple controller options.

Long life and low maintenance

- Magnetic actuators and superior design allow pomanique's reclosers to operate for a rated 10,000 full load operations.
- Less moving parts = less maintenance for 25 years.

High reliability

- Pomanique designed a simple, magnetically actuated operating mechanism that could dependably operate with only one moving part.
- Vacuum interrupter technology make recloser with maximum reliability and minimal maintenance.
- Environmentally friendly.

Optimized Measurement

- Reclosers are equipped with current transformer and voltage sensors in each bushings to measure current and voltage.

Microprocessor based controller

- Controller provides more enhanced functions in protection, monitoring, metering, communication and recorder, and can also support your power distribution system to be more reliable.
- Simple integration into Ethernet or serial-based communication networks.

Conflicts of Interest: The author declares no conflict of interest.

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INFLUENCE OF CHANGING CLIMATIC CONDITIONS ON HEAT PUMP EFFICIENCY

Abstract: *The analysis of energetic and economic efficiency of application of heat supply systems on the basis of brine heat pumps of different types for a covering of heating loading is carried out. The influence of bivalent temperature on the power choice of the heat pump system is shown.*

Keywords: *heat pump, bivalent temperature, heat load, additional source.*

Introduction

Reserves of traditional hydrocarbons such as gas, oil, coal are declining every year. And their use is associated with a negative impact on the environment.

Today, there is a need to move to greater use of renewable energy sources, which are inexhaustible and can guarantee energy and environmental security.

Among renewable energy sources, the use of low-potential environmental energy, converted to high-potential using heat pumps (HP), is promising.

Experience shows that HP is one of the promising types of equipment for creating heat and cold supply systems.

Currently, in some countries, the level of development of this method of heat supply is such that HPs are intensively displacing traditional methods based on the direct combustion of fossil fuels.

The source of heat for the heat pump used in the heat supply system can be water, soil and air, wastewater, ventilation air, and other heat carriers, the temperature of which is 4-12°C.

In the case of widespread implementation of heat pumps, emissions of CO_2 and carcinogenic compounds formed during the combustion of minerals are also significantly reduced.

According to [1] HPs are used for buildings of energy efficiency of class C and above. When using HP in the heating system, the most common is the bivalent scheme, when HP provides most of the heat load for heating the building, and the rest is covered by an additional source: electric, gas, or solid fuel boiler. To determine the power of the HP it is necessary to know the bivalent temperature at which the additional source is connected. The bivalent temperature is influenced by many factors: the type of HP, weather conditions (ambient air temperature and duration of their standing).

The value of the bivalent temperature affects the share of heat load that covers the HP, so studies aimed at determining the bivalent temperature depending on the ambient temperature are relevant.

The goal of this paper is to analyze the influence of ambient air temperature on the temperature of bivalent HP in the heating system and determine the proportion of coverage of the heat load by the heat pump.

The object of the study was an individual residential building with a heating area of 1500 m^2 with a thermal load on the heating system of 100 kW, which is located in Kyiv.

Presentation of the main research material

Climatic conditions of Kyiv are characterized by a short time of low ambient temperatures during the heating period. This is the reason when choosing a heat pump not to choose it at maximum power.

The paper considers a bivalent scheme of heat supply of the house when the heat load is distributed between the heat pump and an additional peak electric heater, which is connected only when the outside air temperature is below the bivalent.

The heating system has a battery tank with a built-in electric heater.

To determine the influence of ambient temperature on the value of bivalence temperature and HP power, statistical data on the duration of the standing ambient temperatures in the heating seasons during the 2015-2020 years for the city of Kyiv (Table 1) was collected.

TABLE 1. *The number of hours of ambient temperatures in different heating seasons*

Ambient temperature, °C	Heating power, kW	A number of hours of standing temperatures, h					
		St. year	15-16	16-17	17-18	18-19	19-20
8	29	654	864	732	531	645	831
5	36	1480	1797	1590	1632	1323	1824
0	48	1225	711	1206	1188	1245	738
-5	60	627	105	201	171	324	48
-7	64	336	189	261	243	231	48
-10	71	130	129	159	201	81	0
-15	83	31	63	54	12	0	0
-20	95	5	0	0	0	0	0
-22	100	0	0	0	0	0	0
Average temperature heating season, °C		0.77	3.78	2.16	2.63	2.93	5.43
Number of heating hours, h		4488	3858	4203	3978	3849	3489
Heating load, MWh		230.6	175.4	201.6	176.3	169.5	145.1

Based on the obtained data, an integrated graph of the dependence of the coverage of the heated load on the capacity of the heating system for the specified period was constructed (Fig. 1).

Figure 2 shows the effect of outdoor air temperature during the heating period on the power of the heat pump.

The graph (Fig. 2) shows that the increase in outdoor temperature during the heating period shifts the bivalence point towards higher temperatures (decreases the power of the HP and increases the load factor).

For a given building, it is proposed to use HP with a capacity of 60 kW to 70 kW, which will depend on the type of HP and the manufacturer. The bivalent temperature will vary from minus 5°C to minus 9.4°C with coverage of 97-99% of the heat load.

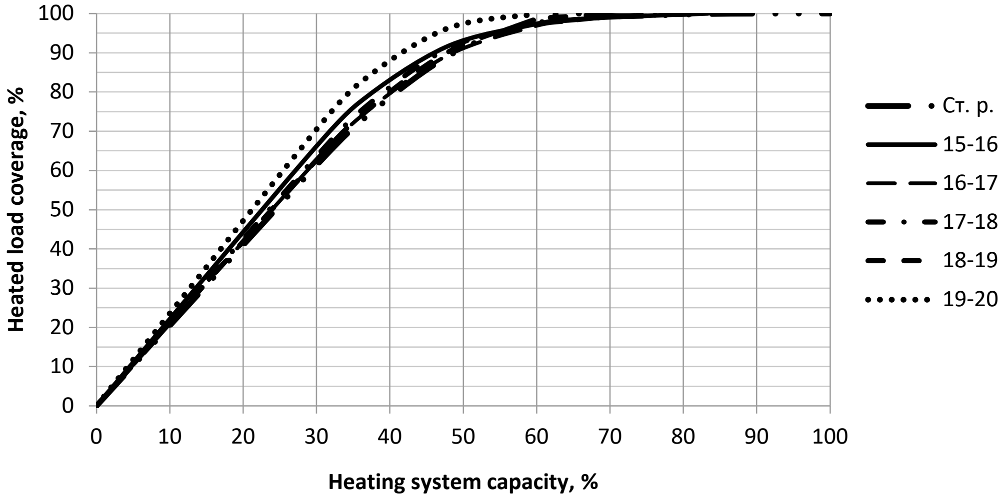

FIGURE 1. *Dependence of the heat load coverage factor on the capacity of the heating system in the heating seasons during 2015-2020 for the city of Kyiv*

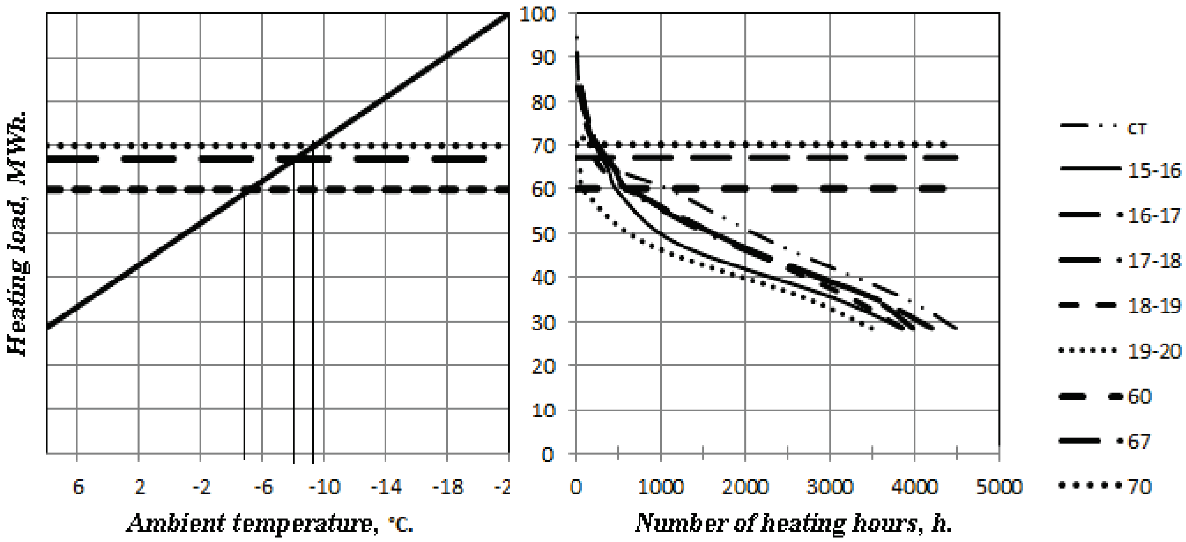

FIGURE 2. *Determination of the bivalence point*

During the day, the outside air temperature may drop below minus 8°C, but the use of the accumulator tank (AT) in the heating system, external insulation of the building walls (a brick wall cools 6 times slower [1]), and allowance of reduction the heating temperature at night by 3°C [2] reduces energy consumption by an additional heat source, and HP will work with less load.

To analyze the energy consumption of an additional heat source, statistical information about the average daily temperatures below minus 8°C for a certain period was analyzed.

The value of the average daily temperatures below minus 8°C is shown in Table 2.

Table 3 shows the values of the amount of heat from an additional source with and without AT. Using a battery tank saves 13-58% of heat from an additional source.

TABLE 2. The value of average daily temperatures below minus 8 ℃

Heating seasons	December		January		February	
	days months	variations t_3, °C	days months	variation t_3, °C	days months	variation t_3, °C
15-16	30-31	-8.2…-9.2	1-6; 18-25	-8.2…-16.5 -8.2…-9	–	
16-17	7	-8	6-9; 26; 30-31	(-9.1)-(-16.5); -9.7; -8.2…-12.4	1; 7-10	-9.1; -9.3…-17.2
17-18	–		14-16; 23-26	-8.2…-10; -8.6…-9.3	24-28	-8.4…-13
18-19	–		8-11 25	-8.1…-11; -10.7	–	
19-20	–		–	–	–	

TABLE 3. The amount of heat from the additional source

Month	Heating seasons				
	15-16	16-17	17-18	18-19	19-20
The heat from an additional source of AT, kWh	2584	2600	1351	545	–
The heat from an additional source without AT, kWh	2985	3235	2695	1298	79

Tables 1-3 show that the coldest heating season is 2016-2017, and the warmest is 2019-2020.

The use of underfloor heating with a coolant temperature of 35°C increases SCOP and reduces electricity consumption by up to 19%.

The bivalent temperature depends on the power of the HP and does not always correspond to its optimal value.

To determine the efficiency of different types of HP, several variants with a capacity of 60-70 kW were selected to cover the heat load (heating) of different manufacturers. Depending on the type and amount of HP [3, 4], the power of the main source of the heating system and, accordingly, the bivalence point and the amount of heat from the additional source change (Table 4).

TABLE 4. Characteristics of HP

Brand	Power, kW	COP	Number, pcs.	General power, kW	Point bivalence	Price, $
HeatHouse-Geo18	17.2	4.59	4	68.8	-8.9	25628
AIK MINI PRO20	20	4.22	3	60.0	-5.2	19572
Vaillant flexoTHERM exclusive VWF 197	19.7	4.7	3	59.1	-4.8	31587
HP20S25W-M-BC	20.1	4.9	3	60.3	-5.3	38700
IDM SW 17 COMPLETE	17.18	4.71	4	68.7	-8.86	51208
DeWix DW20000	21.11	4.31	3	63.3	-6.6	21000
NIBE F1345	67	3.8	1	67	-8.14	24400

The results of calculations of the influence of the bivalent point on heat production by different energy sources (external environment – Q_{EE}, compressor – Q_C, additional source – Q_{AC}) in the coldest heating season (2016-2017) and the warmest (2019-2020) shown in Figure 3.

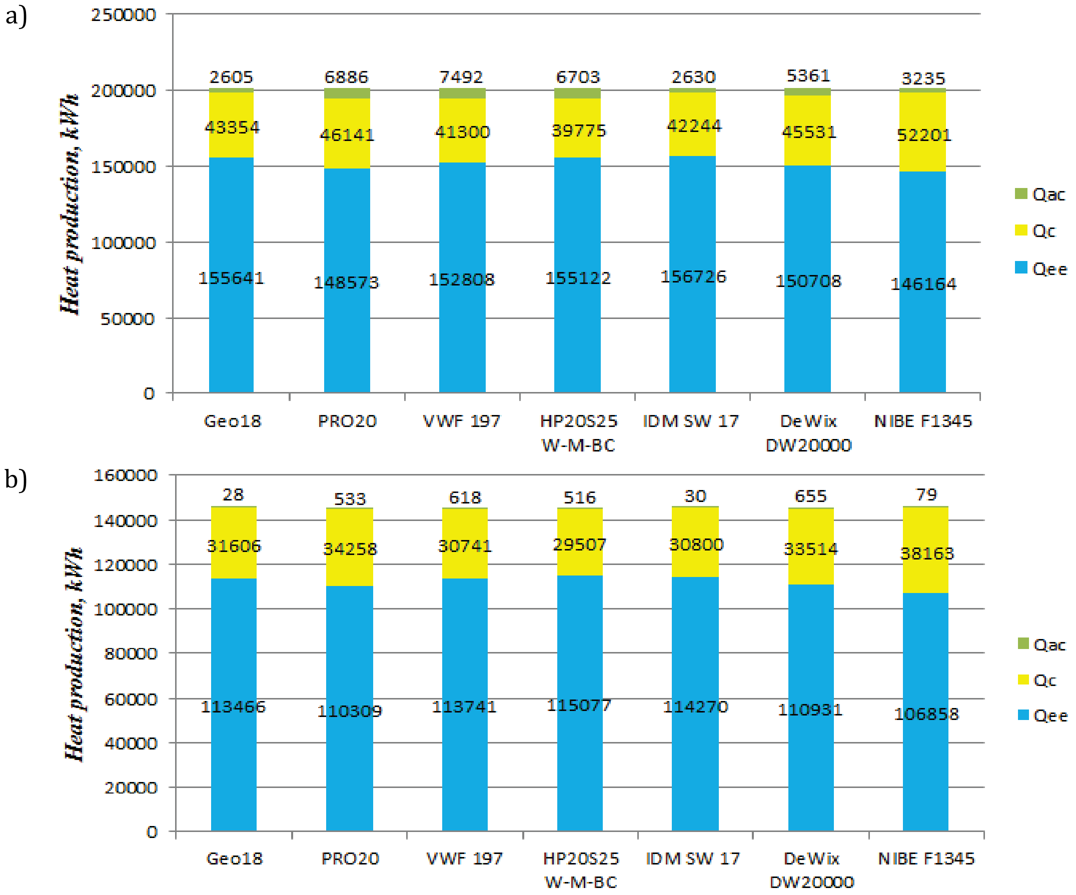

FIGURE 3. *The amount of heat received from different energy sources in the heating system in the heating seasons: a) 2016-2017; b) 2019-2020*

Depending on the amount of heat spent on heating, the payback period of the HP system will change (Table 5). To determine the annual savings from the installation of HP it was compared with a gas boiler (boiler efficiency 95%) to determine the cost of fuel used [5].

TABLE 5. *Payback period of the heating system with different HP*

Brand	Heating season					
	16-17			19-20		
	Electricity costs, UAH	Savings, UAH	Payback term, year	Electricity costs, UAH	Savings, UAH	Payback term, year
Geo18	77211	96208	7.3	53145	71672	9.8
AIK MINI PRO20	89085	84334	6.4	58448	66369	8.1
VWF 197	81970	91450	9.5	52683	72134	12.0
HP20S25 W-M-BC	78083	95336	11.2	50439	74379	14.3
IDM SW 17	75389	98031	14.4	51795	73022	19.3
DeWix DW20000	85499	87921	6.6	57404	67413	8.6
NIBE F1345	93133	80286	8.4	64247	60570	11.1

From Table 5 it follows that the shortest payback period of 8.1 years has a HP of AIK MINI PRO20 company with a total capacity of 60 kW and a bivalent point of -5.2°C. Although, the cost of electricity (compressor drive and water heating in the additional source) is higher compared to other HP due to the lower SCOP.

An increase in the bivalent temperature leads to an increase in the payback period of the heating system with a heat pump. This is due to the fact that the most significant factor in the calculation is energy consumption, which affects the profitability of the heating system, and the price of HP.

When determining the optimal heating system, it is necessary to take into account the point of bivalence and the payback period of HP.

Conclusions

The analysis was performed of statistical data on changes in outdoor air temperature during the heating season for the period 2015-2020 for the city of Kyiv. The coldest heating season is 2016-2017, and the warmest is 2019-2020. The heat load of the building heating system varies from 145.1 MWh to 201.6 MWh depending on the season.

When the bivalence temperature changes from minus 4.8°C to minus 8.9°C, the power of the HP changes from 59.1 kW to 68.8 kW. Accordingly, the amount of heat from the main source changes 194-199 MWh in the coldest heating season and 144-145 MWh in the warmest. The heat from the additional source is 2605 – 7492 kWh, 28 – 655 kWh respectively.

The payback period ranges from 6.4 years to 19.3 years, depending on the heat consumed during the heating season and the type of HP.

Comparison of heat supply systems with different HP allowed to choose the most optimal option to cover the heating load of a given building – HP AIK MINI PRO20.

Conflicts of Interest: The author declares no conflict of interest.

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NEURAL NETWORK MODEL FOR ENTERPRISE ENERGY CONSUMPTION FORECASTING

Abstract: *This research paper investigates the application of neural network models for forecasting in energy. The results of forecasting the weekly energy consumption of the enterprise according to the model of a multilayer perceptron at different values of neurons and training algorithms are given. The estimation and comparative analysis of models depending on model parameters is made.*

Keywords: *electrical loads, daily schedule, modelling, neural network, multilayer perceptron, MLP.*

Introduction

In the presence of the electricity market, the need to obtain forecast values of energy consumption is due to economic and technological reasons. Improving the accuracy of the forecast of electric loads allows to avoid overloading of generating capacities, to improve the quality of electricity, and to minimize its losses. Moreover, the projected loads significantly affect the market value of electricity, which is important both at the level of the individual industrial consumer planning its application for electricity, and at the level of the entire power system. High-level accuracy of power system planning allows to optimize the use of energy, distribute electrical loads between network facilities and meet the requirements for reliability and quality of electricity supply. This points to a great relevance and importance of the tasks related to modelling and forecasting of electrical loads for planning the optimal modes of operation of electricity consumers and power supply systems.

Analysis of recent research and publications

The quality and accuracy of the forecast depends on the chosen mathematical model. There are a large number of models and methods for loads prediction, which are usually based on the retrospective dynamics of power consumption and the factors that affect it, to identify a statistical relationship between model parameters and process characteristics. Ukrainian and foreign scientists, including V. Vynoslavsky, A. Prakhovnyk, V. Rozen, A. Voloshko, P. Chernenko, worked on the development of mathematical modelling and forecasting of electric loads [1-5].

In recent decades, the mathematical apparatus of artificial neural networks (ANN) has been successfully used for prediction, models based on which can establish a relationship between the output characteristics of the system and input factors using the learning procedure. The use of artificial neural networks allows to achieve forecast accuracy up to 96-97%, which will have a significant impact on the management of electrical loads. The choice of network type and its configuration depends on the specific task, available data and their volume.

At present, there are a significant number of classes of forecasting models [6]. Moreover, some models and relevant methods relate to individual approaches to forecasting.

Speaking of the scientific works studying to the use of ANN in forecasting processes, we should mention the works by Yu. Zaigraieva, G. Shumilova, I. Chuchueva and others [7-10].

The main requirements for forecast models include: sufficiently high accuracy of forecasting and simplicity of algorithms, which allows to minimise the decision time and volume of system memory; work in conditions of uncertain and insufficient information; ensuring the sustainability of management.

The goal of this paper is to develop a model for forecasting the electricity consumption of an enterprise using artificial neural networks to improve the accuracy of planning the operating mode and increase the reliability of the enterprise's estimates in making technical and economic decisions.

To achieve this goal, the following objectives are addressed in the paper:

- Building a structure and developing a mathematical model of ANN for power consumption forecasting.
- Investigation of neuromodels with different numbers of neurons to assess the effect of ANN configuration on prediction accuracy.

Object of research: graphs of electrical loads of the enterprise, neuron model of the process of power consumption at the enterprise.

Subject of research: characteristics of the neuron model, indicators of electricity consumption and factors that determine the enterprise's mode of operation and electricity consumption.

Presentation of the main research material

Interconnected neurons form a neural network. Network configuration is determined for each separate task. To solve some individual types of problems, there are already optimal configurations described in the academic literature on the construction and operation of neural networks [11-15].

On each cycle, all training observations are sequentially fed to the network input, the initial values are compared with the target values, and the error function is calculated. The values of the error function, as well as its gradient, are used to adjust the weights and offsets, after which all steps are repeated. The initial values of the ratios and biases of the network are chosen randomly. The learning process is terminated either after a certain number of cycles, or when the error decreases to a sufficiently small level or ceases to decrease.

Suppose a given multilayer perceptron with a smooth activation function [16] (Fig. 1).

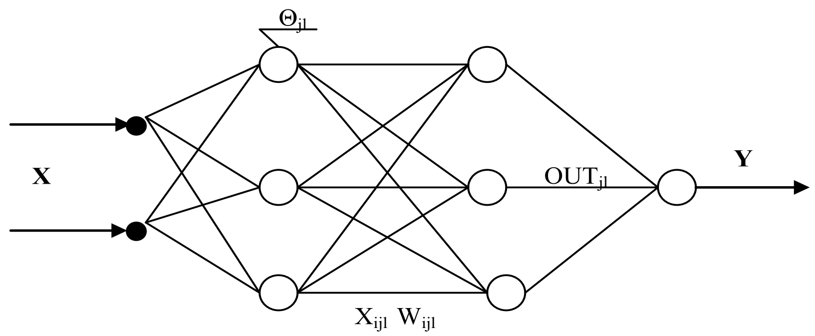

FIGURE 1. *Multilayer perceptron*

Its work is set by the equations:

$$NET_{jl} = \sum w_{ijl} \cdot x_{ijl} - \theta \tag{1}$$

$$OUT_{jl} = F\left(NET_{jl}\right) \tag{2}$$

$$x_{ij(l+1)} = OUT_{il} \tag{3}$$

We accept the total quadratic error as the objective function:

$$E = \frac{1}{2} \cdot \sum_{j} \sum_{s} \left(y_j^s - d_j^s \right)^2 \tag{4}$$

The network is defined by its parameter vector – a set of weights and threshold levels of

$$P = \begin{pmatrix} W \\ \Theta \end{pmatrix}$$

where:
W – a vector, the components of which are the weights of the network;
Θ – the vector of network threshold levels.

Therefore, if we consider the training set as given, the network error depends only on the vector of parameters: $E = E(P)$.

During training on each iteration, the parameters in the direction of antigradient E will be adjusted:

$$\Delta P = -\varepsilon \nabla E(P) \tag{5}$$

The model of the object of research is realized on the basis of ANN. Preliminary preparation of the input data vector reduces the duration of the learning process, which is important for large amounts of data in the case of multicomponent systems. The mathematical apparatus of the ANN for the implementation of the model is selected based on the fact that the network of such a structure can simulate a function of almost any degree of complexity, and the number of layers and the number of elements in each layer determine the complexity of the function. MLP network has the ability to extrapolate data and high performance after training [17].

The paper predicts the schedule of active power consumption for the day ahead on the basis of data on electricity consumption for the previous days. The total sampling consists of 168 observations (24 hourly observations per day during a week) and is provided in the form of a table and graph (Fig. 2). To verify the accuracy of the forecast, the forecast will be based on 144 observations, and the data of the last day will serve as a control sequence. The accuracy of the model will be assessed by the average value of the relative error in the control sequence and the value of the relative error in determining the daily power consumption.

A multilayer perceptron was adopted as a model for prediction. The number of perceptron inputs is determined by the length of the load schedule (24 observations per day). To obtain the predicted value, one source element is sufficient. The number of neurons in the hidden layer is set from 2 to 20 and will be adjusted depending on the accuracy of the model, which will be determined by the performance on the training and test sequences. Threshold activation functions may take linear, hyperbolic, exponential values. Network learning algorithm is BFGS.

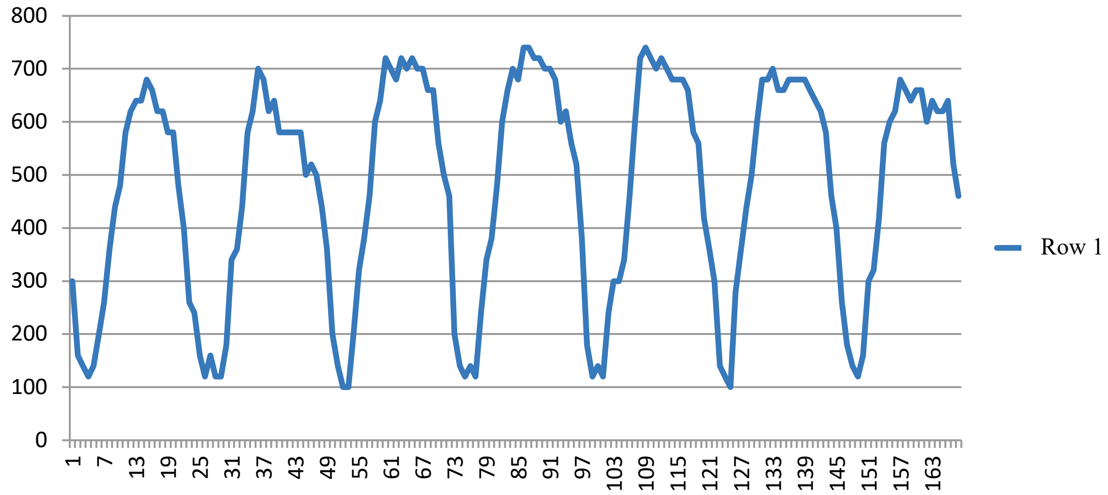

FIGURE 2. *Weekly schedule of energy consumption of an enterprise*

When training networks under given conditions, the best 2 results out of 50 options have the characteristics shown in Table 1.

TABLE 1. *Characteristics networks*

No.	Net	Training perf.	Test perf.	Training error	Test error	Training algorithm	Hidden activation	Output activation
2	MLP 24-14-1	0.974301	0.983437	804,850	646,3876	BFGS 12	Logistic	Identity
9	MLP 24-16-1	0.975561	0.982711	752,883	740,1567	BFGS 11	Identity	Logistic

The two networks with the best performance (the smallest absolute error in the training and control sequence) were used to build forecasts for the day ahead (Fig. 3).

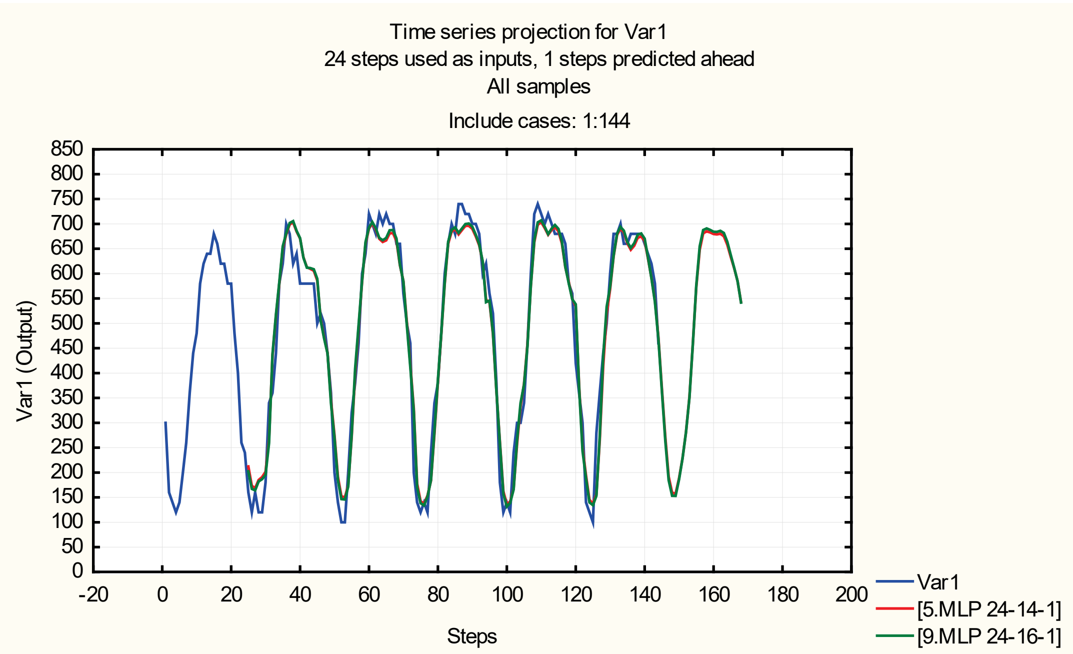

FIGURE 3. *Graphs of energy consumption by the original sequence and ANN models*

The quality of the models was assessed by relative error indicators for the predicted values of electricity consumption and the total amount of electricity consumed. The average error in forecasting the current values of active power consumption for MLP 24-16-1, MLP 24-14-1 and MLP 24-1-1 networks was 9.7%, 9.9% and 9.5%, respectively. When estimating the total amount of energy consumed, the error was 1.8%, 1.6% and 4.1%.

***TABLE 2.** Estimation of accuracy of models*

	Dimension W	24"16"1	24"14"1	Error	Error	24"1"1	Error
1:00	400	364,8682	369,8831	0.08783	0.075292	347,7334	0.130666
2:00	260	263,5233	271,1761	0.013551	0.042985	249,8743	0.038945
3:00	180	184,6158	191,9261	0.025644	0.066256	170,9807	0.050107
4:00	140	153,2481	159,4724	0.094629	0.139089	147,3600	0.052571
5:00	120	153,0187	157,3944	0.275156	0.31162	167,1893	0.393244
6:00	160	186,0898	188,3890	0.163061	0.177431	237,1377	0.482111
7:00	300	228,1412	228,5293	0.239529	0.238236	313,9695	0.046565
8:00	320	281,0085	281,0490	0.121849	0.121722	404,3978	0.263743
9:00	420	350,9698	352,1839	0.164358	0.161467	495,7506	0.180358
10:00	560	456,1922	456,8315	0.185371	0.18423	577,6940	0.031596
11:00	600	575,1257	572,1859	0.041457	0.046357	633,2087	0.055348
12:00	620	654,7844	648,0695	0.056104	0.045273	656,2832	0.058521
13:00	680	687,5770	680,9111	0.011143	0.00134	661,0392	0.027883
14:00	660	690,9127	684,9339	0.046837	0.037779	649,6118	0.01574
15:00	640	687,9962	682,8616	0.074994	0.066971	642,9487	0.004607
16:00	660	684,3566	679,8348	0.036904	0.030053	642,3883	0.026684
17:00	660	683,8430	678,9896	0.036126	0.028772	646,9048	0.019841
18:00	600	686,2046	680,1743	0.143674	0.133624	658,9881	0.098313
19:00	640	681,8390	675,1215	0.065373	0.054877	671,7496	0.049609
20:00	620	664,0817	658,0634	0.0711	0.061393	675,4060	0.089365
21:00	620	637,2844	633,5488	0.027878	0.021853	663,2066	0.069688
22:00	640	611,4985	610,2385	0.044534	0.046502	625,3585	0.022877
23:00	520	584,7224	584,8978	0.124466	0.124803	556,1733	0.069564
24:00	460	541,7731	542,5004	0.177768	0.179349	458,3088	0.003676
	Amoun W	Amoun W	Amoun W	Error	Error	Amoun W	Error
	11480	11694	11669	0.018612	0.016478	11953	0.0412598

Conclusions

Operation of the enterprise has a cyclical change of loads, repeated daily during the week. Operation of the enterprise is characterized by hours of minimum load (from 0 to 8 hours) and hours of work with a nominal load of 600 kW to 700 kW. To build a mathematical model of the function of changing the electrical load, it is advisable to use a multilayer perceptron.

The daily load schedule with hourly data recording determines the observation period and the required number of neurons (24) in the input layer, because predicting a decrease in the number of neurons will worsen the quality of the model due to period mismatch, and increase will complicate the model.

For the proposed prediction model, a network with one hidden neuron provides a more accurate prediction for individual observations, but for predicting total power consumption over a set period, networks with more hidden neurons are more accurate. The biggest forecasting errors are observed at the time of changing the operating mode.

The error of the forecast values for operation at rated mode from 10 to 17 hours (minimum value 0.4%, maximum value 5.8%) and 4.1% error of forecast daily consumption indicates sufficient accuracy of the ANN model applied for forecasting daily loads of the enterprise.

The capability of processing large data sets, self-learning based on the given data sequences, and the high accuracy of the models confirm the feasibility of using artificial neural networks to solve problems of forecasting electrical loads.

Conflicts of Interest: The author declares no conflict of interest.

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NEURAL NETWORK MODEL OF THE MECHATRON COMPLEX "CRUSHER MILL"

Abstract: *The paper discusses the use of the technology of artificial neural networks to improve technical and economic performance of crushing and milling complex. Formulated the goal and major tasks of constructing a system of automated control and monitoring to optimize the power consumption of crushing and milling complex is analyzed modes of complex mechatronic and development of multicriteria models to provide optimal technological parameters of the equipment.*

Keywords: *crushing and grinding complex, modelling, neural network*

Introduction

The technology of crushing and grinding rocks is one of the most energy intensive technologies. Effective management of crushing and grinding is possible with the most complete mathematical model of the situation. Studies show that the work of crushing and grinding complex is determined by dozens of factors, many of which are random. Each combination corresponds to a specific techno-power mode of operation. The more fully taken into account in the operational management factors and system properties that affect the characteristics of the mode, the more effective it management and lower the energy consumption of the processes of crushing and grinding. The increase in the number of considered factors complicates the model, so it is necessary to form the control action, finding a compromise solution that takes into account the degree of informativeness of the factor field and its complexity. It is necessary to solve a number of tasks such as: analysis of operation modes of the equipment of grinding to determine the parameters, which correspond to different operation modes; development of a multicriterial model of optimal technological parameters of equipment of the crushing and grinding complex subject of power consumption, productivity and quality of grinding; development of the model of crushing and grinding complex, which could provide optimal power consumption management of crushing and grinding complex.

Literature review

The simulation of crushing and grinding complex is used to optimize its energy consumption. This particular task contains a number of subtasks such as: description of kinematics and dynamics of internal processes, the establishment of energy intensive of processes of destruction of rocks, the construction of control systems for crushing and grinding complex. The analysis of works in the field of simulation of the grinding aggregates and management highlights the following researchers [1].

The most famous equation that establishes a relationship between the energy expended and the fineness of the product resulting from grinding are equations of Rittinger, Kick-Kirpichev, Bond. Comparison of the curves constructed according to the laws of Rittinger, Kick-Kirpichev, Bond, showed that the law of Rittinger can be applied in the case of high specific power consumption regardless of the size of the grains, the law of the bond – in a significant range of intermediate values of the specific energy consumption, the law Kick-Kirpichev – at low specific power consumption. Based on the works of Andreev, Davis, Perov, Tovarov, Olevskii, Kantorovich established that the greatest power consumption characterizes, however, and most work of grinding. Knowing the useful power consumed by the mill and taking into account losses occur in all elements of the system can provide a complete energy picture of the mill as a control object, thereby providing the possibility of its rational exploitation, in terms of energy consumption.

Automatic control of operation of the mills, the variables determining them, the construction of control systems for crushing aggregates considered in the works of Nazarenko V.M., Uteus Z.V., Uteus E.V., Gelfand J.E. and Ginzburg I.B.

The use of modern CAE-systems for optimizing of parameters of mechatronic systems and complexes, investigated the Pivnyak G.G., Samus V.I., Kirichenko O.E., Kirichenko V.E. [2-4].

Purpose and research objectives

The purpose of this work is to develop a model of a crushing and grinding complex. To achieve this goal, the following tasks are solved in the work: analysis of factors and parameters that determine the processes of crushing and grinding in grinding units, selection of the structure and parameters of a neural network corresponding to a multifactorial task, determination and description of the factors most affecting power consumption.

Object of research: neuron model of the crushing and grinding complex.

Subject of research: power consumption of the crushing and grinding complex.

Material and research results

Technological processes are the basis of many industries and virtually all industries. This process involves primary environment and additionally enter components used physico-chemical, mechanical or hydro-mechanical effects, which are inside of the workspaces of the devices to obtain the final products. Technological processes in grinding equipment belong to the group of mechanical processes that determines the regularities of the processes that are common to the group. Crushing and grinding stands out as a separate subgroup, which characterizes the specifics of the processes and their characteristics.

The technology of crushing and grinding is one of the largest and most energy intensive, therefore costly operations. In concentrating factories and production of building materials, crushing and grinding operations account for up to 50-70% of the total capital expenditure and the same share of total operating costs. The ways to solve the problem of optimal energy consumption of crushing grinding complexes can be further improvement of the grinding and crushing, the use of the most efficient and economical methods of grinding, the simplification of the scheme of layout of crushing plants.

One of the ways to ensure rational operating modes of technological mechanisms of crushing and sorting factories is the use of adaptive control systems, which relate to robotic systems, the element base of which is microprocessor technology. To operate the process control system, the technological process requires mathematical support, which adequately describes the technological processes and the operation of certain types of equipment participating in them. In choosing the mathematical description of technological processes, it is necessary to take into account the regular connections that are repeated in time, and random ones, caused by the variability of process parameters.

The task of constructing an automated control system for simplification can be divided into a number of sub-tasks such as:

1. The definition of the factor of the field system and the allocation of the main factors.
2. Establishment of regularities of changing factors.
3. Identify the relationships between dependent variables.
4. Identification of the current state of the object (nominal, pre-emergency, emergency, ineffective mode).
5. Prediction of the state of the managed object based on its current state.
6. Formation of the control action depending on the available data on the system and their projected values.

As an example, the technological process of production of silicate bricks in the construction industry enterprises is considered, which is a sequence of the following operations:

- delivery of raw materials for making bricks (lime and sand);
- lime burning;
- transportation of burned lime with a conveyor belt to the feed hopper of the crusher;
- crushing of lime in hammer crushers up to size 1 mm;
- transportation of the crushed product by pneumatic transport to the mill feed hopper;
- grinding in the ball mill of cooked lime and sand (binder preparation);
- transportation of ready-made binder by pneumatic transport to a molding shop for manufacturing bricks from prepared raw materials;
- warehousing of finished products.

At each stage of the technology, the physical state of the substance changes at a certain energy expenditure. Changes in the physical state can be both positive (necessary for technology changes, such as reducing the size of the material, giving the necessary properties of lime by burning it, forming the finished product) and negative (re-grinding of the substance, undesirable change in humidity, loss during transport). Regardless of whether a technologically useful or harmful effect occurs, the amount of energy consumed during the transition from one stage to another is constantly increasing, therefore, in order to ensure rational energy-efficient management of the complex, it is necessary to take into account how energy-intensive each stage of production is and how much this energy expenditure is justified. At the same time, for each stage it is necessary to identify the factors determining its energy consumption and those indicators by which its energy state can be estimated.

From the given technological chain of greatest interest are the factor fields of the crusher and mill, as the key objects of the complex.

Research carried out at concentrating plants and enterprises for the production of building materials have made it possible to identify a number of factors that have the most significant effect on the nature of the power consumed. These factors include the magnitude of the ball load, the mill speed and the productivity of the grinding unit. The mode of operation of the mill and the amount of power consumption depend not only on the factors listed, but also on the magnitude of the frictional force between the inner surface of the drum (lining and ball loading) and the type of lining. For the electric drive of such a mill, it is characteristic that the power consumption depends little on the productivity, that is, the specific costs of producing the binder are significantly reduced with increasing productivity.

In the practice of grinding a substance has the following properties density, strength, abrasiveness, moisture content, flowability, lumpiness, specific surface area of mineral raw materials crushability and grindability.

The researches have shown, that the specific expenses of the electric power on binder production essentially change depending on the above mentioned factors (up to 30%). The change in the fineness of the grinding occurs intensively at the beginning of the mill, at a time when there are practically no changes at the last meters, which indicates an inefficient grinding of the material.

In addition to the physical properties of matter, there are a number of technological variables that determine the operation of grinding aggregates. These include fineness of grinding; number of grinding media; the size of grinding bodies; the presence of inter-chamber partitions; state of armor; intensity of aspiration; resistance of the material to grinding; introduction of an intensifier of the grinding process. The factorial field of the ball mill can be represented by the Ishikawa diagram (Fig. 1) [5].

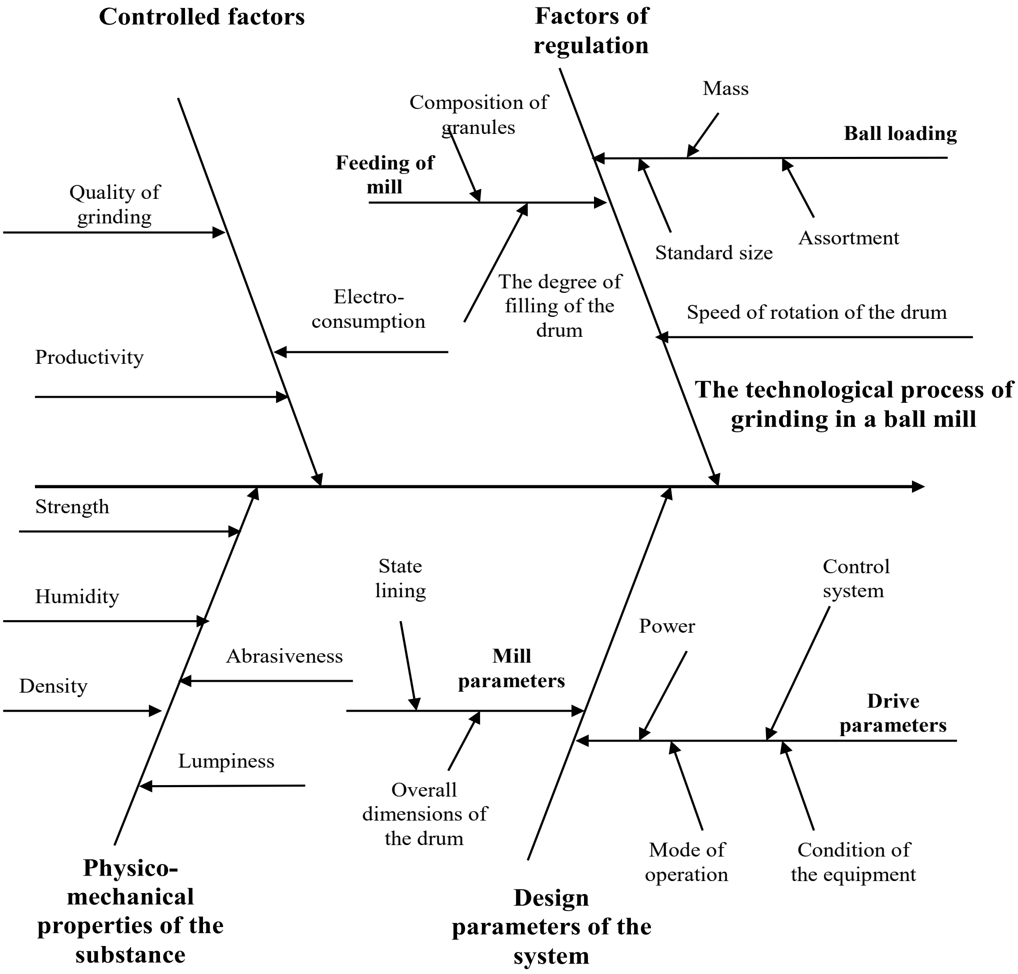

FIGURE 1. *Factor field of a ball mill*

The main positions in the diagram are assigned to four groups of factors that determine the technological process (Table1). The breakdown and sorting of factors within each group makes it easier to assess the impact of a factor.

TABLE 1. *The main groups of the factor field of crushing and grinding equipment*

Output Vector	Vector of input measurable control variables	Vector of input measured uncontrolled variables	Vector of input non-measurable variables
Electroconsumption (*W*), productivity (*Q*), quality of grinding (*T*)	Ball and raw materials, rotational speed (*n*) of the working body	Physical and mechanical properties of incoming raw materials	Condition and operating conditions of equipment (lining, balls, drive)

Based on the above data, it is possible to construct a neural network to control the crushing and grinding complex. The controlled parameters act as the output vector, and the corresponding values of the regulated quantities, the parameters of the equipment and the crushed material are the input vector.

In the generalized model, the selected factors will be used as inputs, and as output values, the process parameters or those control actions that will regulate them. A similar network is shown in Figure 2.

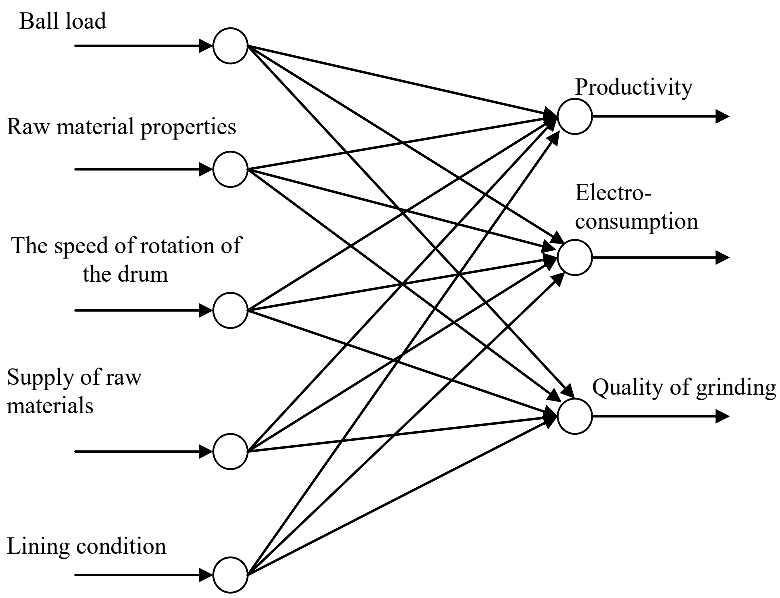

***FIGURE 2.** The grinding control model*

The mathematical model describes a real object with some approximation. The degree of correspondence of the description to the real process is determined, first of all, by the completeness of the calculation of disturbing influences. In the absence or insignificance of disturbances, it is possible to unambiguously determine the influence of the input and control parameters on the output.

An objective model of the grinding object can be created under the condition of good awareness of the properties of the object under study, the main groups of which are represented in the factor field. According to the degree of completeness of information about real objects and processes occurring within them, we can distinguish:

- objects with a zero level of information; in this case the object is represented as a "black box", its mathematical model is constructed by statistical tests of a real object on the basis of regression, dispersion and correlation analysis and factorial design of the experiment;
- objects whose behavior has empirical information; when creating models of such objects, physical modeling methods are used; a complete closed model is obtained by methods of experiment planning;
- objects with known basic deterministic regularities; their models are formulated by methods of mathematical modeling; deterministic dependencies are partially complemented by empirical relationships, the values of constants are established from experience.

The objects of the crushing and grinding complex belong to the first group.

The power consumed by the mill depends on its load and the speed of rotation, so the mill's power consumption model can be represented in the form of two interacting components: the speed n and intra-milling filling (IF). The speed component is unambiguous, not below a certain value at which grinding is generally possible and is easily controlled by means of an adjustable drive. On the other hand, intramural filling is a function of many variables. First of all, this value is determined by the set productivity and quality, then it must take into account as much as possible the number of perturbations and, in addition, be a function of time – to perform the functions of the predictor (PR) – to determine the influence of the previous values of the factors on their current values. Such a notion of intramelic filling will allow to take into account the multifactority of the object and eliminate the influence of its inertia.

Separately, it should be noted systems consisting of several working together crushers or mills. In a sense, they are a model of a single multi-chamber mill (in operation in series), which makes it possible to optimize their operating mode not only by regulating the rotational speed, but also by regulating the stage of grinding.

The considered model of the mill as a component element is included in the multi-stage grinding scheme: successive operation of two objects. In this case, we have a system of two power consuming objects and the task will be to select a combination of speeds that ensure minimum power consumption. In this case, the first mill will perform for the second function of the feeder, but in addition to the productivity there will be the possibility of regulating the fineness of grinding and there is an additional condition: selection of the degree of grinding by the first mill for optimal system operation (Fig. 3). That is, if in the case of single work speed was a regulating parameter, and productivity and quality of grinding are internally calculated, then when working together, all three variables for the first mill become adjustable.

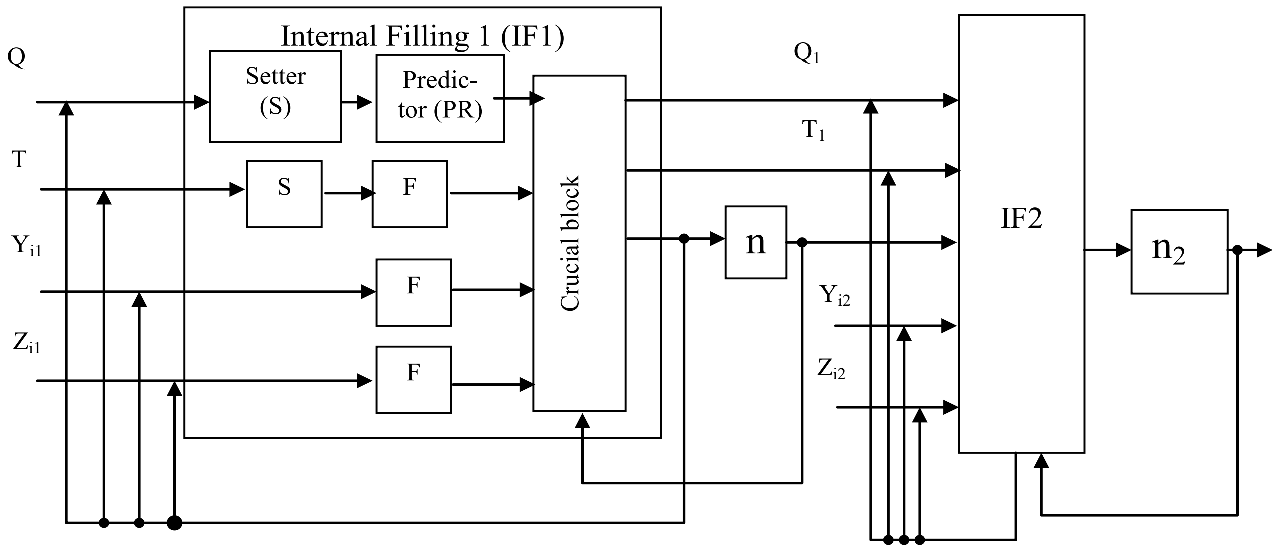

FIGURE 3. *Simulation of the joint work of mills*

Let the crushing complex consist of several grinding aggregates, included in the sequential work (Fig. 4). Each unit that is part of the complex is characterized by a certain amount of power consumption or power consumption per ton of ground material, the value of which depends on a number of factors (we take into consideration such factors as the mass of grinding bodies *M*, the productivity of the aggregate *Q* and the size of the raw material *T*) and size of the finished product. The size of the finished product is determined by the mode of operation of the unit and the grinding time, which affects the amount of power consumed).

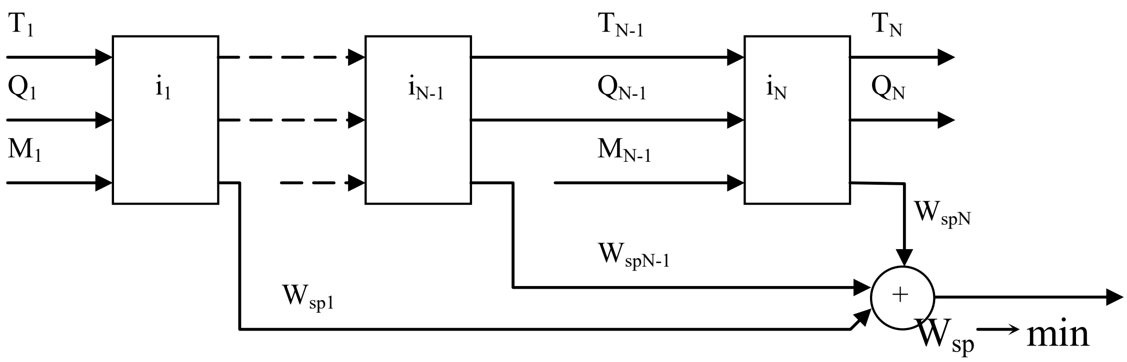

FIGURE 4. *Model of crushing and grinding complex*

The ratio of the size of the product at the inlet to the size of the product at the outlet determines the degree of crushing of the product *i*. For *N* consecutive objects, the total degree of grinding is determined by multiplying the degrees of grinding at each stage [6]:

$$i = \prod_{K=1}^{N} i_K \tag{1}$$

The value of the power consumption for the complex consists of the sum of the power consumption of individual units:

$$W = \sum_{K=1}^{N} w_K \tag{2}$$

Using the specific power consumption as an optimization function, it should be taken into account that this value is determined not only by the value of the received power, but also by the productivity. Summation of specific power consumption is possible only for quantities characterizing the same mode of operation of the complex. Then the total specific power consumption of a group of objects (for a material flow that does not vary from an object to an object-the condition for the joint operation of the elements of the complex included in series) is determined by summing the specific power consumption of each stage:

$$W_{sp} = \sum_{K=1}^{N} w_{sp\_K} \tag{3}$$

Then, the optimization problem for a crushing complex with a performance varying in a narrow range will be written in the form

$$\begin{aligned} & W_{sp}(Q, i, k_N) \to \min \\ & \begin{cases} Q = \text{const} \in [Q_{\min}, Q_{\max}] \\ i \geq i_{permiss} \end{cases} \end{aligned} \tag{4}$$

With this representation of the complex, the specific power consumption is represented by a nonlinear function determined by the state of each element of the complex, each of which in turn is a function of many variables. Two possible solutions are possible here: the first is the reduction of all variables to one, artificially introduced (the expression of all variables through one of them) and the second is the numerical solution of the problem, by sequentially supplying to the inputs of the model possible states of the system. The second option is more labor-intensive, however, its accuracy will be determined by the accuracy of its models. At the initial stage of solving the problem with the help of a numerical model, it is sufficient to identify zones of local minima of a function with the aim of more detailed investigation of them in the future, since each of them can be a minimum in one of the incoming variables and characterize only certain operating modes. Since the objects of the crushing complex are inertial and multi-variable, there may be some discrepancy between the calculated optimal mode and the "real" optimal mode, therefore, one must take into account the accuracy constraints imposed by the properties of the object. In addition, depending on the selected priorities, preference can be given to a particular local minimum.

To implement the monitoring and management system, it is advisable to use neural networks with the help of which it is possible to implement a model of the system and regulator. Neural networks are trained, designed to work with a large number of variables, successfully perform predictions. The task of grinding control using neural networks is implemented as follows (Fig. 5).

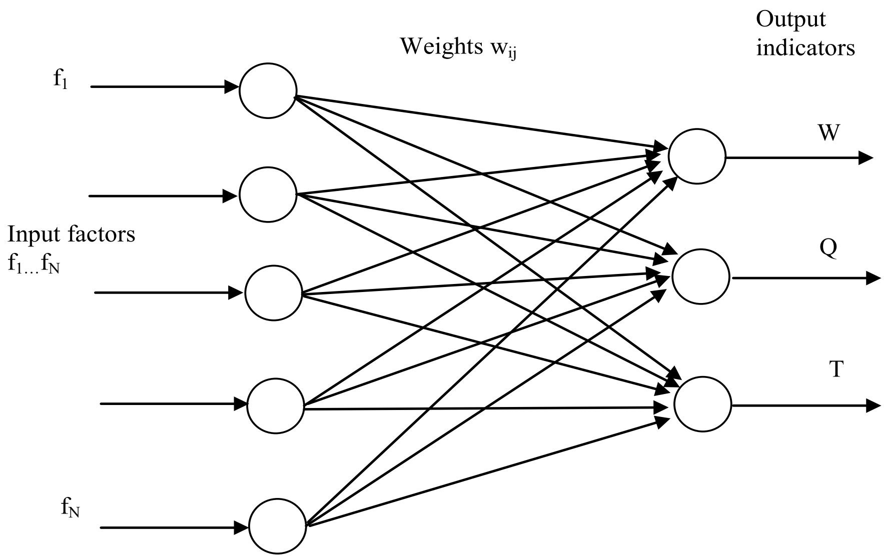

FIGURE 5. *Neural network model for grinding control*

Each input of the network corresponds to one of the factors. The network outputs correspond to performance, subtlety and power consumption. Network weights determine the significance of factors. In addition to identifying the factors, the network can detect the forecasted state of the system based on the available data and optimize the work for a given parameter. As optimization parameters, we can take T, W and Q, or the introduced generalizing indicator that reflects all three criteria, depending on their significance.

System control using neural networks provide an alternative to the control systems, constructed according to the classical methods of management. This possibility is based on the fact that a neural network consisting of two layers and containing in the hidden layer is arbitrarily large number of nodes can approximate any function of real numbers with a given degree of accuracy [7].

To ensure monitoring system with the prediction function, it is necessary to build a neural network model of the form [8]:

$$y(k+d) = N\begin{bmatrix} y(k), y(k-1),..., y(k-n+1), u(k), \\ u(k-1),...,u(k-n+1) \end{bmatrix} \tag{5}$$

where:

$y(k)$ – the output of the model;

d – the number of prediction cycles;

$u(k)$ – the output of the model.

To design a tracking system that provides a given trajectory of the form

$$y(k+d) = y_r(k+d) \tag{6}$$

it is necessary to design a nonlinear controller of the following general form

$$u(k) = G\begin{bmatrix} y(k), y(k-1),..., y(k-n+1), \\ y_r(k+d), u(k-1),...,u(k-m+1) \end{bmatrix} \tag{7}$$

In Figure 6 shows the structure of the corresponding controller in the form of a neural network. Here we should pay attention to the sections of the network that performs the approximation of non-linear operators g and f in outputs $\hat{g} = a_2(t)$ and $\hat{f} = a_4(t)$.

The controller outputs are the signals $y(t+1)$ and $u(t+1)$, the latter is implemented as a feedback and a reference signal $y(t+2)$. The delay units include remembering the relevant entry and exit, and then used a two-layer neural networks, which form estimates of the nonlinear operators and compute the control signals.

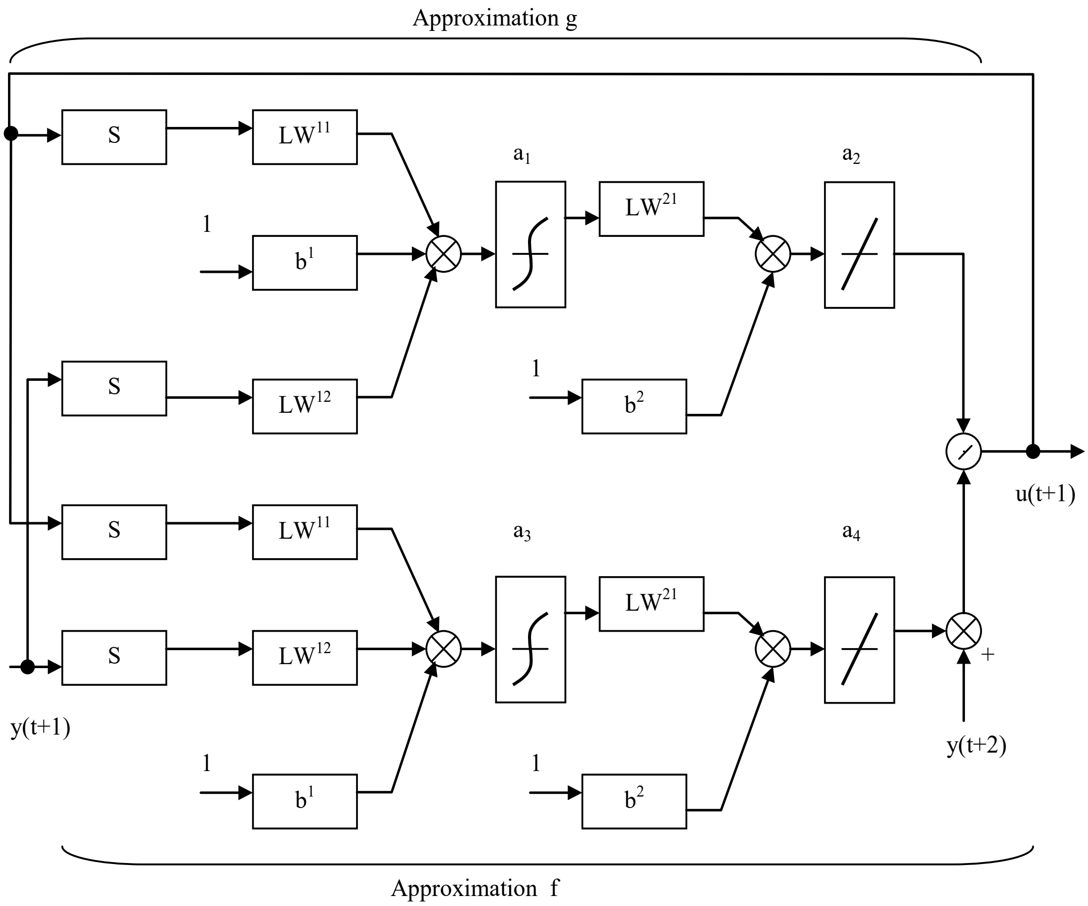

FIGURE 6. *Model of the neural network controller*

The result of the operation of the system with a trained controller is shown in Figure 7 where curve 1 shows the input stimulus; and curve 2 is the output signal.

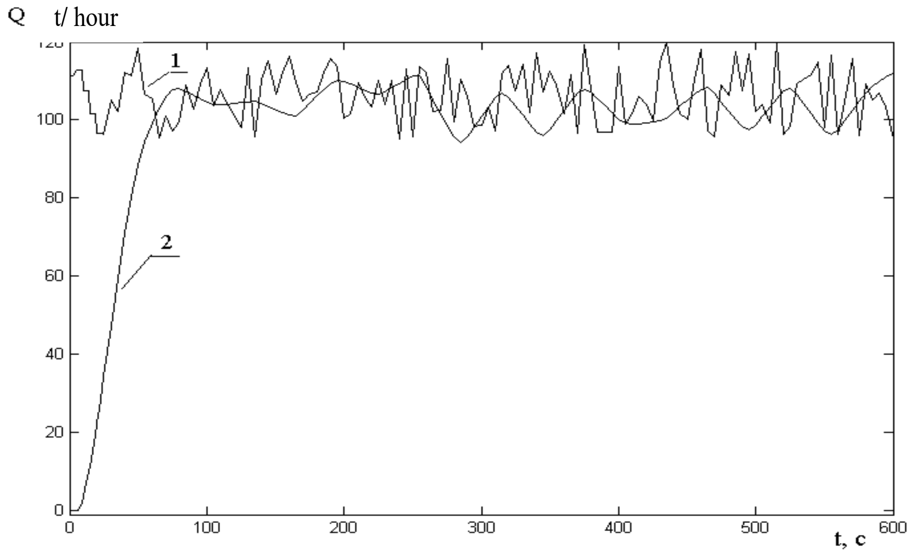

FIGURE 7. *Learning outcomes of the neuromodel*

Comparison charts of the input (random) signal and output of the system shows that the use of the controller allows to achieve a more stable work area for the output product, in case of random changes of the input traffic.

Conclusions

The technological process at the enterprises of the crushing and grinding complex is a sequence of operations, each of which changes the physical state of the substance and increases the amount of energy consumed by the complex.

Qualitative indicators of the change in the state of a substance and the amount of energy expended on it are determined by factors whose totality forms the factor field of the object. The factor field of the complex includes four groups of factors: controlled, regulating, equipment characteristics and substance characteristics.

The proposed new model of the crushing and grinding complex, which takes into account multi-factor field of the system and displays its internal links based on the mathematical apparatus of artificial neural networks lies in accounting for the formation of the objective function components that determine energy consumption and other technical and economic indicators of the complex “crusher mill” that allows you to increase the energy efficiency of the system by ensuring operation at the optimum power consumption mode.

The energy-saving effect in crushing and grinding complex is achieved by optimal power consumption mode, which is characterized by the calculated grinding fineness at which the transition from grinding from one grinding stage to the next (thinner) is carried out.

The developed model of crushing and grinding complex, which consists of several crushing units, which operate sequentially to determine the optimal parameters for a given criterion the operation mode of the complex, which reduces the power consumption of the complex by selecting an optimal mode for reducing the substance.

Application of neural networks in the implementation of the algorithm for finding the optimal operating mode.

Conflicts of Interest: The author declares no conflict of interest.

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USE OF BURSHTYN TPP ASH FOR THE PRODUCTION OF EXPANDED GAS CONCRETE

Abstract: *Production of not autoclave porous concrete, including small enterprises, industry of wall materials, which is now the most dynamically developing. One of the main problems in the production of gas concrete and concrete products is a comprehensive savings of cement, while ensuring high quality designs. Technology of gas concrete to date has at its disposal wide range of techniques that allow in specific conditions to reduce the specific consumption of cement without compromising technical properties of concrete. In recent years, for this purpose proposed in plasticized concrete mixtures using active mineral fillers. In this area gained considerable practical experience of application additives ash – removal, slags, carbonaceous materials, silica sand. Classical technology of these concrete based mainly on cement and unground sand. The use of TPP ash for cellular concrete is recommended by most of normative documents. The greatest effect is achieved by using high calcium ash.*

Keywords*: ash, porous material, thermal insulation*

Introduction

The impact of thermal power plants on the environment depends largely on the type of fuel. Coal is most polluted of all energy sources and making the largest contribution to global climate change. In coal power plants account for the biggest share of greenhouse gas emissions in the energy sector, as they have the highest rate of release of carbon dioxide per unit of electricity produced compared with all other fossil fuels. When burning coal into the atmosphere large quantities of solid particles containing not burned carbon oxides and heavy metals emitted as carbon monoxide (CO) and toxic organic compounds, including dioxins and benzopyrene, have carcinogenic effect, fly ash, sulfur and sulfuric anhydride, nitrogen oxides, some amount of fluoride and gaseous products of incomplete combustion. So especially harmful condensation power plants working on low-grade fuels. Among these stations applies Burshtyn TPP.

Solid waste production BTPP is the main fuel slag and ash. Laboratory studies show that in 2015 was formed 526,335 tons of ash and 125,583 tons of slag, which in large near BTPP form parts of ash dumps (Fig. 1).

Most European TPP do not form ash dumps because their rational use, given the content of the ash, useful for technologies manufacturing of building material chemical elements.

FIGURE 1. *Burshtyn TPP (ash storage No. 3)*

Analysis of recent sources research and publications

In the publications [1-10] shows the advantages of using high-calcium ash in the production of cellular concrete.

The use of ashes in the production of cellular concrete in reality presented in various versions, from using it as a main component to the introduction of ash in the raw material as an additive. Since the high-calcium ash has all the source characteristics of materials for the production of cellular concrete (dispersion and binder potential) to the same cellular structure softens degradation expansion ash pore space without developing cracks.

The main barrier using ash as a raw material for the production of building materials is its content of free calcium and magnesium oxides in a state of burnout. Other impediment – is the wide range the composition of highly-calcium ash defining significant fluctuations in the properties (strength, medium density, frost resistance, etc.) of the finished material.

According to literature data, it was found that neutralize the negative impact of CaO ash possible in different ways: physical, chemical, and by sharing with cement or other "diluents".

For the production of high-quality non-autoclave gas concrete, complex and energy-intensive solutions should be used:

- Constantly changing technological modes in accordance with fluctuations in the properties of ash. Thus, in [47] established the optimum mixing time ash and water mass, depending on the timing of grasp the high-calcium ash.
- All the researchers recommend the use of compulsory steaming and grind in some decisions of high-calcium ash [49] or drying of products [51].

At the same time, some researchers are concerned with the question the use of high-calcium ash for the production of cellular concrete, not only take into account the factor of variability of composition and properties of the ash. Therefore, developed technology, ash gas concrete are characterized by a significant percentage of defective products due to variations in the properties of finished products, and other problems. The latter is often impossible to organize a sustainable manufacturing process using raw materials with a large variation of its composition and properties without correction (composition mass, technological processes parameters, etc.). In addition, the proposed technology is almost impossible to use in small production.

Therefore it is necessary to develop such schemes, the production of non-autoclaved gas concrete based on high-calcium ash TPP that will provide a stable material with high construction and technical properties on technology that does not require steaming, grind and other difficult-to-small enterprises process stages.

Emphasis previously unsolved parts of the general problem

For production non-autoclave cellular concrete, including small enterprises – the most rapidly developing sector of wall materials today. Classical technology of these concrete is based mostly on cement and sand unground. The use of ash TPP for cellular concrete recommended by the majority of regulatory documents. The greatest effect is achieved by using high-calcium ash.

All the previous decisions on the development of technologies of non-autoclaved aerated concrete based on high-calcium ash TPP on coal were sent to the maximum of their introduction to the raw mixture. This resulted in unnecessarily complex and energy-intensive technologies (permanent change dosages and technological modes in accordance with fluctuations in the properties of ash, mandatory steaming, and some decisions grind components or drying products). All this did not allow to widely implement the proposed technology, especially in small enterprises. Therefore, it required the development of non-autoclave gas concrete technology based on high-calcium ash TPP gives the material with consistently high construction and technical properties on technology that does not require steaming, grind and other complex for small productions process stages.

Problem statement

The aim of this work is to study the technology of production of expanded concrete possibility of replacing cement ash Burshtyn thermal power station, strength of the samples and kinetics of hardening.

The main material and results

Due to the content in the study ash of basic oxides (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O) it can be attributed to the high-calcium mineral resources, which typically use a raw mixture before thermal swelling in the production of TPM. A result we get a solid porous materials [9-12].

Therefore considering the significant share of coal in the fuel balance of Ukraine should use the experience of these countries and explore the possibility of recycling ash taking into account specific features of the product.

The use of ash in pure form in building materials compounded by the negative impact of calcium oxide, which is present in free form in a state of burnout.

Hydration of CaO particles, often covered with a vitreous shell leading to cracking and fracture of hardened material. Neutralize the negative impact of CaO, perhaps in different ways: physical, chemical, and by sharing with cement. The positive effect of in the latter case will occur both due to dilution effect and deterrent effect of destructive phenomena solid cement stone. In our work we use both methods. Since calcium oxide in the ash BTPP not much (4%), each of the methods may be appropriate. The most widely, to eliminate the destructive effects of ash are hardening additive calcium chloride or other chlorides. In our technology for the production of porous concrete to intensify the gassing requires the presence of alkali NaOH, which can be synthesized as a result exchange reactions (alkali in our technology can be added to the raw material mixture as a separate component).

It is possible also to its gradual formation of ash elements BTPP, which would control chemical transformations in the raw mixture in step swelling. New dual compound promote rapid formation of a mixture of plasticity and its early hardening. These properties can be the basis of the controlled process of forming a given structure, which is the aim of this study.

Therefore in the interaction these chemical elements, accelerated hydration CaO and accelerated the process of formation hydrates mixture.

When interacting with lime in the presence of aluminum phases of Portland cement clinker and ash, the reaction to form the hydro-sulfo aluminate and hydro-chlor-aluminate of calcium:

$$nCaO + Ca_3\,(A1O_3)_2 + 2nNaCl + (m + 1)H_2O \rightarrow$$
$$\rightarrow 3Ca_3(AlO_3)_2 \cdot nCaCl_2 \cdot mH_2O + 2nNaOH \quad (1)$$

$$nCaO + Ca_3\,(A1O_3)_2 + 2Na_2SO_4 + (m + 1)H_2O \rightarrow$$
$$\rightarrow 3Ca_3(AlO_3)_2 \cdot nCaSO_4 \cdot mH_2O + 2nNaOH \quad (2)$$

It will accelerate the hydration of CaO and ash released alkaline solution NaOH.

As a result exchange reactions that occur between sodium sulphate and cement hydration products formed additional quantity of gypsum and alkali NaOH (reaction (2)). Then NaOH easy carbonization by carbon dioxide that enters the solution from the air by the reaction:

$$2NaOH + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O \quad (3)$$

Sodium carbonate is primarily interacts with gypsum, as it is most soluble product of cement hydration and under the influence of NaOH, it significantly increased solubility:

$$CaSO_4\,2H_2O + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4 + aq \quad (4)$$

Is well soluble sodium sulfate again reacts with calcium oxide to form gypsum and alkali (2). Reactions (2) and (3) intermediate and (4) main.

Because of the fact that Burshtyn ash contains up to 61% aluminosilicate glass phase in the ash-cement compositions will be similar to the reaction between with sodium sulfate. This is certainly a positive moment, since in theory we have the ability to influence the kinetic parameters of swelling. Also, carbonated shrinkage that occurs during the use of products will partly compensate for their expansion deformation due to quenching of free lime.

In the DTA curves hydrated mixture based on fly ash, Portland cement, silicate recorded four endothermic effects, accompanied by a decrease in weight (Fig. 2).

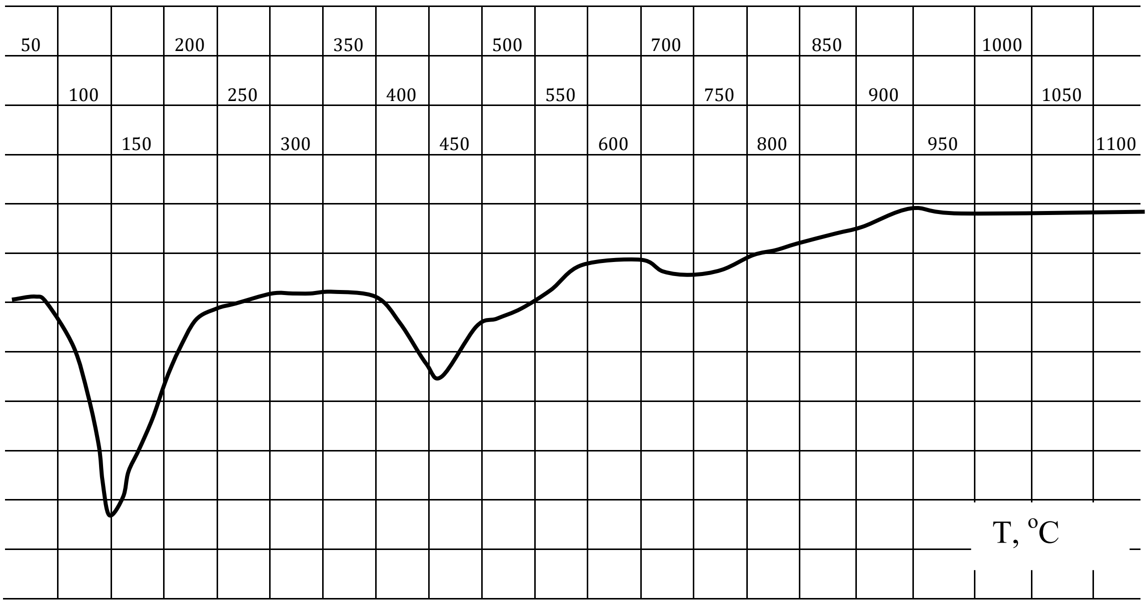

***FIGURE 2.** DTA raw mix with the addition of 70 wt. parts of BTPP ash and 5 wt. parts of Portland cement*

All endo-effects, as the differential – thermal analysis associated with weight loss in a wide temperature range. Significant endo-effect occurs at temperatures 50-250°C extremes of from 115°C to 123°C and is associated with the removal of adsorbed water with helium-like hydration products, such as calcium hydrosilicates type CSH (I), as well as water of crystallization of hydro- sulfo-aluminate of calcium AFt - phase.

A clear endothermic effect is observed in the temperature range 370-420°C and describes the process of dehydration of calcium hydroxide scheme:

$$Ca(0H)_2 \rightarrow CaO + H_2O$$

The small endo-effects at 652°C and 780°C associated with the processes of decomposition hydrosilicates calcium (CSH (II)) and calcination calcite. At temperatures of about 930°C, small exo-effect is caused by crystallization tobermo-barito-like gel in wollastonite.

Since the swelling and the formation of structural strength aerated concrete array depend significantly on water-solid ratio (WSR), the first stage searched the optimal amount of water for mixing in ash-cement gas concrete compositions.

For the purpose of determine the effect of water-solid ratio on swelling aerated concrete, aerated concrete mixtures were manufactured with WSR in the range of 0.2 to 0.6. In this case, aerated concrete mixture made based on cement and sand or based on cement and ash Burshtyn TPP using chemical additives.

The mixture was prepared as follows: samples of ash and sand mixed with water at a temperature of 20-30°C, added cement and stirred for 2 minutes. Further, in each test was injected the same number of aluminum suspension of the calculation of obtaining the average density of aerated concrete 700 kg/m^3, stirred for a further 1 minute and poured in volumetric capacity, which was swelling the mixture at an ambient temperature of 20°C. After the complete swelling mixture controlled its height as a percentage of the height of the fill. Then found the perfect amount of water and chemical additives to the maximum height of swelling. The results are presented in Table 1.

TABLE 1. *Effect of PTS on percentage swelling of concrete (%)*

Mix	WSR				
	0.2	0.3	0.4	0.5	0.6
Cement + Sand	120	195	220	225	225
Cement + Ash	200	280	350	370	360
Cement + Ash + Na_2SO_4, 1%	200	290	350	376	370
Cement + Ash + Na_2SO_4, 2%	205	290	355	380	380
Cement + Ash + NaCl, 1%	210	295	370	385	380
Cement + Ash + NaCl, 2%	205	295	370	390	370

Researches have shown that the studied range with increasing WSR height of expanded cement-sand aerated concrete increases. For ash-cement aerated concrete is the optimum ratio for WSR, which is 0.5. With the use of chemical additives NaCl and Na_2SO_4 amount of water does not change except for warehouses in which these additives are used in small amounts (0.5%). Decrease WSR in this case is probably due to "dilution" mixture through peptization effect of fine particles that can get aerated concrete with uniform porosity with less water. But the additives do not affect the process of swelling as a dry ash (it prolonged storage) by chemical reactions, these compounds are formed, and adding or increasing their number does not change the quantitative results of this process (as seen also from Table 1).

The use of Burshtyn ash instead of sand can increase the height of the swelling by 70% and the use of chemical additives – an additional 3% to 7% due to the intensification of processes of gas emission as a result of the gradual formation of NaOH in exchange reactions, which activates processes gassing.

The use of chemical additives can reduce the terms of hardening concrete mass as they provide fast water binding and accumulation of solid phase with maximum density filling space frame. In our opinion this is achieved through additional intensive synthesis and AFt AFm phases associated increased amount of H_2O, with a high growth rate and ensure the quick formation of structural strength.

Increasing the WSR, more than 0.5 leads to the separation of the initial mixture to form large cavities with a diameter of 2 cm. This is usually due to swelling induction processes and prehension gas. In addition, the increase in WSR promoted extension of swelling and prehension of gas mass since it was accompanied by a decrease in the limiting stress and shear under plastic strength of porous concrete. The introduction of additional quantities of water reduces the strength of concrete, increase their deformation and final moisture content of the material.

The main properties of gas-concrete mixtures directly dependent on the rheology-ash cement and cement-sand aerated concrete. Under the influence of physical and chemical processes occurring in the interaction of cement, coal ash BTPP and water, rheological properties of such mixtures vary. Changes viscosity and maximum stress displacement increases strength plastic systems. The degree of change rheological characteristics depend on the type of raw mixture aerated, water-solid ratio and additives used. From the velocity structure formation gas concrete mixtures depends time of stay in array form. Therefore, the study of rheological characteristics of such systems is an urgent task.

For determination of strength of aerated concrete have been selected compositions with the largest percentage of swelling (Table 1). The results are presented in Figure 3. Slow structure formation, apparently a slow set of structural strength and increase shrinkage, has a classic cement-sand aerated concrete. It is characterized by slow growth strength, which is to end grasp cement (4 hours) 0.8 Pa, and in 10 hours – a total of 1.8 Pa, while for subsequent technological processes an array of aerated concrete should be 2.50-3.0 Pa.

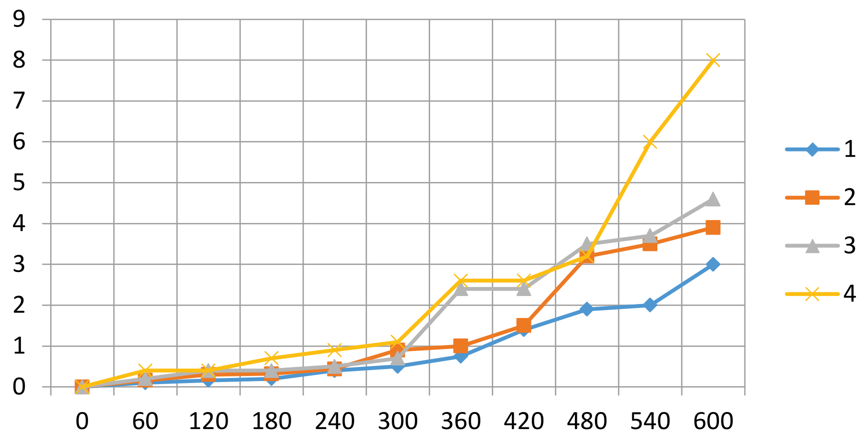

Figure 3. *The strength of the aerated concrete arrays, depending on the type of raw material mixture: 1 – cement-sand aerated concrete; 2 – cement-ash aerated concrete; 3 – cement-ash aerated concrete with the addition of sodium sulphate (1%); 4 – cement-ash aerated concrete with the addition of sodium chloride (1%)*

For ash-cement aerated concrete typical slow rate of recruitment strength, even after 10 hours you can perform various operations that provides technology for manufacturing gas concrete structures. It should be noted that after 1 day strength of cement-ash aerated concrete is higher on average 50-70%.

Conclusions

Accelerated structure formation and high strength material provides chemical additives NaCl and Na_2SO_4. The intensification of the processes of hydration and structure formation in ash-cement formulations with additives, including in its composition ion Na+, is reflected in the rapid formation of structures with an earlier date grasp array. It should be noted that after mixing all the components, the temperature of the mixture was about 30°C, and after the swelling temperature rose to 60°C. Later mixture raised its temperature to 70-80°C. This in turn also leads to accelerated recruitment of early strength.

Thus, the use of high-calcium ash Burshtyn thermal power plants and chemical additives allows you to adjust the properties of aerated concrete, at the stage of maturation of the array, and the final material.

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