



Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

**EFFICIENCY ESTIMATION OF INDUSTRIAL EQUIPMENT IN ORE-DRESSING AND
PROCESSING ENTERPRISE**

MASTER THESIS

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2. Prepare energy audit and interpret results
3. Evaluate economic efficiency of proposed technical improvements
4. Perform sensitivity analyses

Bibliography / sources:

1. Energy Saving at Industrial Enterprises: Tutorial / G.N. Klimova; Tomsk Polytechnic University. - 2nd ed. - Tomsk: Publishing house of the Tomsk Polytechnic University, 2014. - 180p.
2. Power Systems Analysis. John Grainger, William Stevenson, Jr., Gary W. Chang // McGraw-Hill Education, 1 edition, 1994, p. 784.
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ABSTRACT

The object of study is the Aikhal mining and processing plant. This enterprise is characterized by high-energy intensity and, in accordance with the legislation of the Russian Federation, requires energy audit inspections. The purpose of energy audit is to identify the inefficient use of resources by the enterprise and to propose measures to reduce it.

The aim of the work is the analysis of measurements of the real operating mode of the enterprise and, as a result, the development of measures to optimize certain equipment groups. The following indicators of the quality of electricity were considered: Steady-state voltage deviation, evaluation of the power factor for each transformer substation, displacement power factor analysis, and evaluation of the additional power losses caused by the asymmetry of the current. After evaluating these parameters, it was possible to reduce the reactive power flowing through the packaged transformer substation. As a result, the use of compensating devices was proposed. In addition, the efficiency of the use of pumping units with throttle control was analyzed. The use of variable frequency drive was proposed to reduce the consumption of active power during hours when the pumps are not fully loaded. Both measures effectively reduce the cost of paying for electricity, which is important for an energy-intensive industrial enterprise.

The following methods were used - processing and research of measurements from a real enterprise, analysis of proposed methods for optimizing the operation of equipment, comparison of technical indicators, economic comparison of options based on indicators such as Net present value, Internal Rate of return, Profitability index and Payback period.

KEYWORDS: Energy audit, energy efficiency, ore-dressing and processing enterprise, economic effect, net present value, return on investment, internal rate of return.

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LIST OF ABBREVIATIONS

Abbreviation	Russian	English
PTS	-	Packaged transformer substation
PP	-	Payback period
NPV	-	Net Present Value
VFD	-	Variable frequency drive
DPF	-	Displacement Power Factor
PFC		Power Factor Correction
TMZ	Transformator maslyanyiy zaschischennyiy	Oil sealed transformer
GRAT	Gruntovyyiy odnokorpusnyiy nasos	Single-unit soil pump
PI	-	Profitability index
CF	-	Cash flow
CAPM		Capital Asset Pricing Model
IRR	-	Internal rate of return

1. INTRODUCTION

Energy inspection (energy audit) is an integral part of the energy saving process aimed at increasing the energy efficiency of an object. The issue of increasing the efficiency of fuel and energy resources has become an important area of the state economic policy of the Russian Federation and has been formulated as a priority objective of the energy strategy of Russia according to Federal Law No. 261 “On Energy Saving and Improving Energy Efficiency”. An energy audit is necessary if the management of enterprises and institutions has taken a course to reduce energy costs and is mandatory for a number of governmental organizations [1].

The purpose of the energy audit is to optimize the costs of the enterprise’s energy system by:

- Optimization of energy consumption;
- Reducing the cost of energy.

An energy survey of enterprises is carried out in order to realistically reduce the energy consumption of the enterprise to identify the possibility of saving resources and to develop a set of measures for energy conservation.

Ore-dressing and processing enterprise is a mining enterprise for the primary processing of solid minerals in order to obtain technically valuable products suitable for industrial use. Ore-dressing and processing enterprise is a power-consuming manufacturing process. The tasks of efficient use of energy resources are especially relevant for modern industrial enterprises. This is primarily due to the continuous increase in the value of energy costs caused by a significant increase in tariffs [2, 3].

Thus, the goal of this paper is to estimate the energy audit results and, as a result, to propose the measures to increase the energy efficiency of ore-dressing and processing enterprise.

The following tasks are solved at the process of work implementation:

1. Conducting an energy survey within 24 hours;
2. Consideration of power supply features in the territory of Yakutia;
3. Identification of weaknesses in power supply;
4. Proposal of measures to increase the energy efficiency of the enterprise;
5. Investment appraisal to increase energy efficiency.

The object is ore dressing and processing enterprise located on a technologically isolated area of Russia.

2. THE BASIC INFORMATION ABOUT THE AIKHAL ORE-DRESSING AND PROCESSING ENTERPRISE

The Soviet geologist Feinstein discovered the first Yakut diamond in 1949. Therefore, a new page in history was opened the development of diamond Russia as a leader in the global diamond complex [4].

The Russian diamond mining corporation “ALROSA” was established in accordance with the decree of the Russian Federation President "On the formation of the joint-stock company Diamonds of Russia - Sakha" dated February 19, 1992. A third of all diamonds of the world's largest company ALROSA is mined at the Aikhal mining and processing plant in Yakutia. This is the largest diamond production in Russia, today it employs about four thousand people. ALROSA's forecast reserves are about one-third of the world's diamond reserves. Company provided mineral resource base for 30 years in advance.

Aikhal ore-dressing and processing enterprise was organized in 1986 based on the Sytykansky quarry, factory number 8, followed by increasing production volumes due to the commissioning of the Yubileiny quarry.



Figure 1 - Territorial location of the study object [4]

The enterprise includes the following main divisions: Komsomolsky and Yubileiny quarries, Aikhal underground mine, technological transport vehicle depot, processing plants No. 8 and No. 14. The powerful structure of Aikhal ore-dressing and processing enterprise is ore-dressing plant No. 14. It was put into operation in July 1996. According to the project, the factory processes 10 million tons of ore per year. Over the past few years, the factory has reached the level of 11.2 million tons of raw materials. The factory has three mills with a drum diameter of 10.5 meters. One of them is imported, the rest are domestic. Ore-dressing plant No. 14 is a modern enterprise with a high level of automation and mechanization of technological processes.

The ore mined by the Aikhal ore-dressing and processing enterprise is processed at plants No. 8 and No. 14, the design capacity of which is 1.7 million tons of ore and 10 million tons of ore per year respectively.

The possibility of using a new mine development system is currently being evaluated, which will reduce costs and increase production productivity. One of the proposed solutions is a chamber development filling system (the dimensions of the extraction blocks will be from 20 to 25 meters in height, 15 meters in width and 120 meters in length).

Processing plant No. 8 has again reached its design capacity of 1.5 million tons of ore per year. This is the result of modernization of the production of the Aikhal ore-dressing and processing enterprise.



Figure 2 – Diamond pipe “Mir” [4]

Careers in the Republic of Sakha (Yakutia) in terms of their combined mining and geological characteristics and parameters are unique and have no analogs in world practice. Great depths (up to 500–600 m), the presence of up to 300–500 m of permafrost, the presence of aggressive groundwater (with salinity up to 400 g per 1 liter), bitumen and oil products - all this is not an obstacle to the effective extraction of diamonds.

ALROSA's quarries use modern mining equipment and machinery of domestic and foreign production. Industrial explosives and self-made explosives are used in conjunction with soft technology to preserve diamond crystals when blasting the rock mass.

Diamond-containing raw materials are delivered for processing at the processing plants by heavy-duty mining dump trucks with a carrying capacity of up to 136 tons and road trains with a carrying capacity of up to 130 tons. After reaching the maximum depth quarries in opencast mining, mining goes to the underground method.

Today, ALROSA underground mines are modern mining enterprises provided with domestic and foreign mining equipment of world-leading manufacturers. The staff has more than 20 years of experience

in underground mining in difficult mining and geological conditions of kimberlite deposits in Western Yakutia.

The deposits were discovered by vertical and inclined trunks and horizontal underground workings, which divide the tubes into blocks of at least 100 m high. Depending on the geological and geographical conditions, the deposits are mined using a development system with laying out the developed space (Internatsionalny mine, Aikhal mine) or a development system with forced collapse (Udachny mine).

After breaking, the ore is transported to skip loading complexes using conveyor, electric locomotive, and mine dump trucks. Further, the rock mass is loaded into skips and rises to the surface along mine shafts, after which it is delivered by technological transport to concentration plants. After coarse crushing in jaw crushers, the ore is fed to wet self-grinding mills, where pieces of ore rock with size up to one and a half meters are crushed to sizes of 50 mm and less using water. The crushed rock is sent to spiral classifiers, where there is a separation of raw materials depending on its density.

Then, the ore is scattered into several parts at the screens - size classes, in the future, each fraction is processed separately. Medium-sized ore is sent to heavy medium concentration plants or to jigging machines. In these operations, due to the influence of physical processes, minerals are separated into heavy and light fractions (concentrate and tails). The material together with the addition of reagents enters the machine, where diamond crystals adhere to air bubbles, forming a foam layer, and are already sent to it for finishing operations [4].

3. ORE-DRESSING AND PROCESSING ENTERPRISE TECHNOLOGICAL PROCESS

The processing plant is a mining enterprise for the primary processing of solid minerals in order to obtain technically valuable products suitable for industrial use. Often the processing plant is part of the mining and processing plant.

Using various technologies (flotation, magnetic separation, and others), processing plants are obtained from the extracted ore at the concentration plants in which the content of the useful component is much higher than in the feedstock. Non-ferrous metal ores, ferrous metal ores, non-metallic minerals, and coal are processed (enriched) at concentration plants. The rock mass goes through the processes of crushing, screening, classification, the main enrichment of the mineral with the release of concentrates and waste, dehydration and thickening.

The final product (concentrate) is sent to bunkers or to warehouses, from where it goes for further processing or delivered to the consumer and the waste in the form of water-sand (water-clay) suspension is sent to dumps.

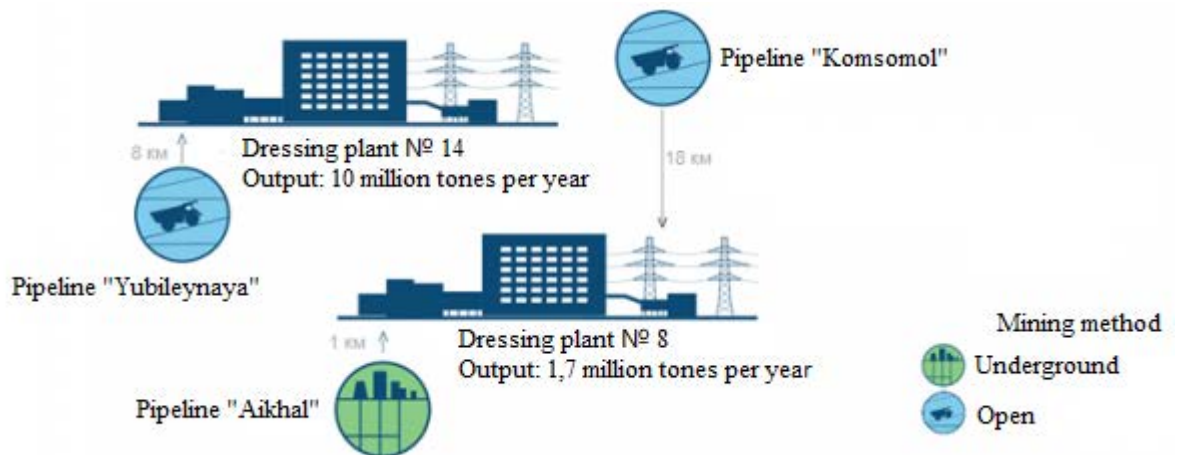


Figure 3 – Schematic diagram [4]

The enrichment production is characterized by a significant energy consumption: in non-ferrous metallurgy for the enrichment of copper ores from 15 to 70 kWh/t, in ferrous metallurgy for iron ores 60-70 kWh/t.

The main point of the enrichment process is to increase the concentration of the useful component of solid minerals. In some cases, when enriching minerals, they even get final marketable products, such as limestone, asbestos, graphite, but often it is a concentrate suitable for further processing and economically feasible for transportation.

The modern processing plant is a highly mechanized and automated enterprise with in-line technology, including hundreds of items of basic and auxiliary equipment. The prospects for the development of processing plants are associated with the use of new technological processes, high-performance equipment, integrated low-waste or non-waste mineral processing technology.

Based on the analysis of the data, the load of this enterprise has an active-inductive nature. It belongs to the first category of power supply.

The features of diamond ore technology are determined by many factors, the main of which are:

- Extremely low content of valuable component;
- The need to extract crystals of a wide range of fineness from micro to millimeters;
- The need to ensure the safety of crystals from mechanical destruction in the processes of ore preparation, transport, and enrichment;
- Physicochemical properties of diamonds.

Schematic diagrams of the enrichment of diamond-containing raw materials include the following steps:

- Ore preparation;
- Primary enrichment;
- Refinement of crude concentrates.

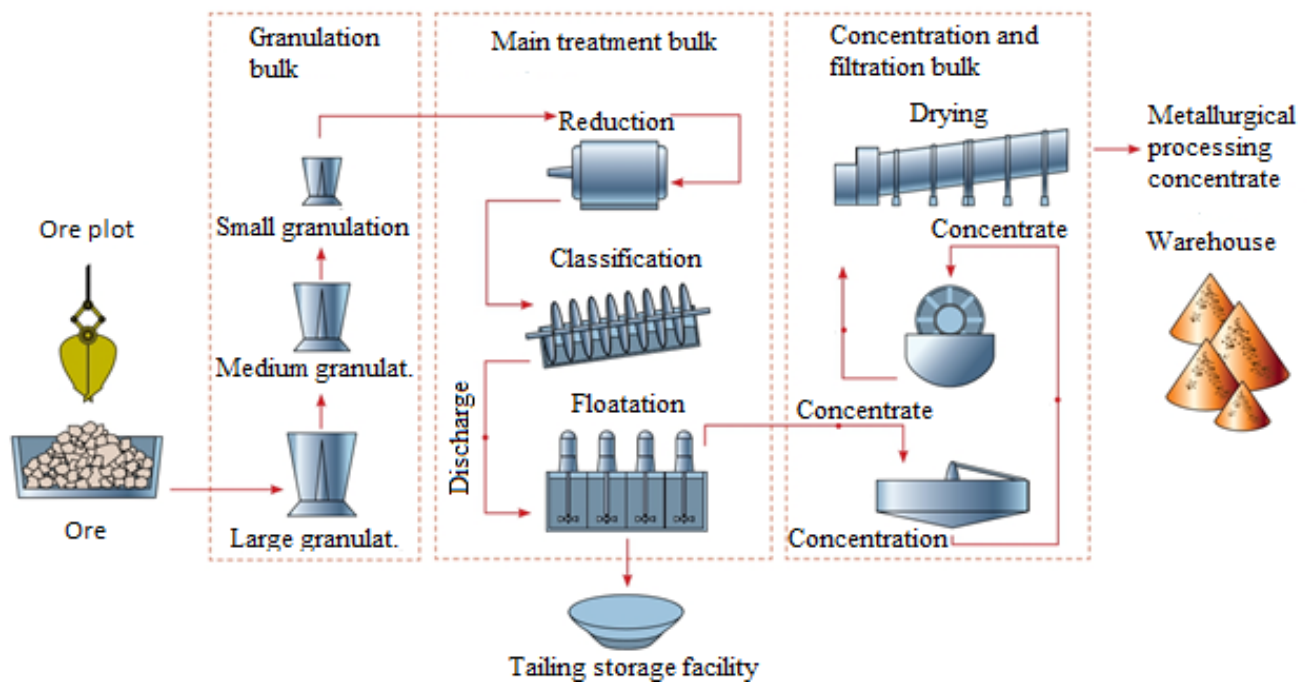


Figure 4 - The scheme of the processing plant technological process [5]

Technological equipment of the factory consists of three systems (production):

1. Auxiliary production of the factory - boiler rooms, compressor rooms, pump rooms, and dam;
2. The main production of the factory is the ore preparation section and other parts of ore processing;
3. Power supply system [5].

The composition of the main technological equipment of the ore preparation section is given in the table:

Table 1 – Equipment description [6]

Code	Name of equipment	Type, parameters
1-1	Ore preparation bunker 1	700x700 mm
1-2	Ore preparation bunker 2	700x700 mm
2-1	Apron feeder 1	*Q=350 m ³ / h
2-2	Apron feeder 2	*Q=350 m ³ / h
3-1	Classifier of base ore 1	
3-2	Classifier of base ore 2	
4-1	Circulation classifier 1	
4a	Slurry splitter	
5-1	Grinding-mill 1	*Q=110 tones/h, V=80 m ³
5-2	Grinding-mill 2	*Q=110 tones/h, V=80 m ³
6	Ore preparation sump	V=38,5 m ³
7-1	Pump 1	*Q=900 m ³ / h, **H=67 m
7-2	Pump 2	*Q=900 m ³ / h, **H=67 m
7-3	Pump 3	*Q=900 m ³ / h, **H=67 m
7-4	Pump 4	*Q=900 m ³ / h, **H=67 m
8	Sump pump	*Q=150 m ³ / h
9-1	Sump pump 1	
9-2	Sump pump 2	
10-1	Vertical conveyor	
10-2	Vertical conveyor	

*Q – flow rate, **H – pump discharge.

The ore processed by three ore deposits at the factory: Komsomolskaya, Aikhal, and Yubileinaya pipes. Ore from the quarry is transported by cars to two receiving bunkers. Ore fed by apron feeders to self-grinding mills. Apron feeders have electrical drives with regulated rotation frequency.

The receiving window of the mill is designed for pieces of ore not more than 700x700 mm. The crushed ore from the mills comes to the classifiers of the original ore. In the classifiers, pulp dehydration occurs. Then it sent through vertical conveyors to enrichment and lapping units. Vertical conveyor can work with any of two grinding-mill.

The discharge of the classifiers of the initial ore is sent to the sump pos.6. The circulation (return from subsequent nodes) is directed to the slider pos. 4a and after separated to circulation classifiers pos. 4-1 (4-2). Dehydrated pulp from circulation classifiers is sent to mills. Discharge of circulation classifiers are sent to the sump (pos. 6). From the sump pump (pos. 7.1-7.4) pulp is sent for further processing. There are also drainage pumps at the ore preparation unit (pos. 8, 9.1 – 9.2).

On the pipelines of the water supply to the mills, control valves, and flow meters should be installed (water lines are not shown in the diagram).

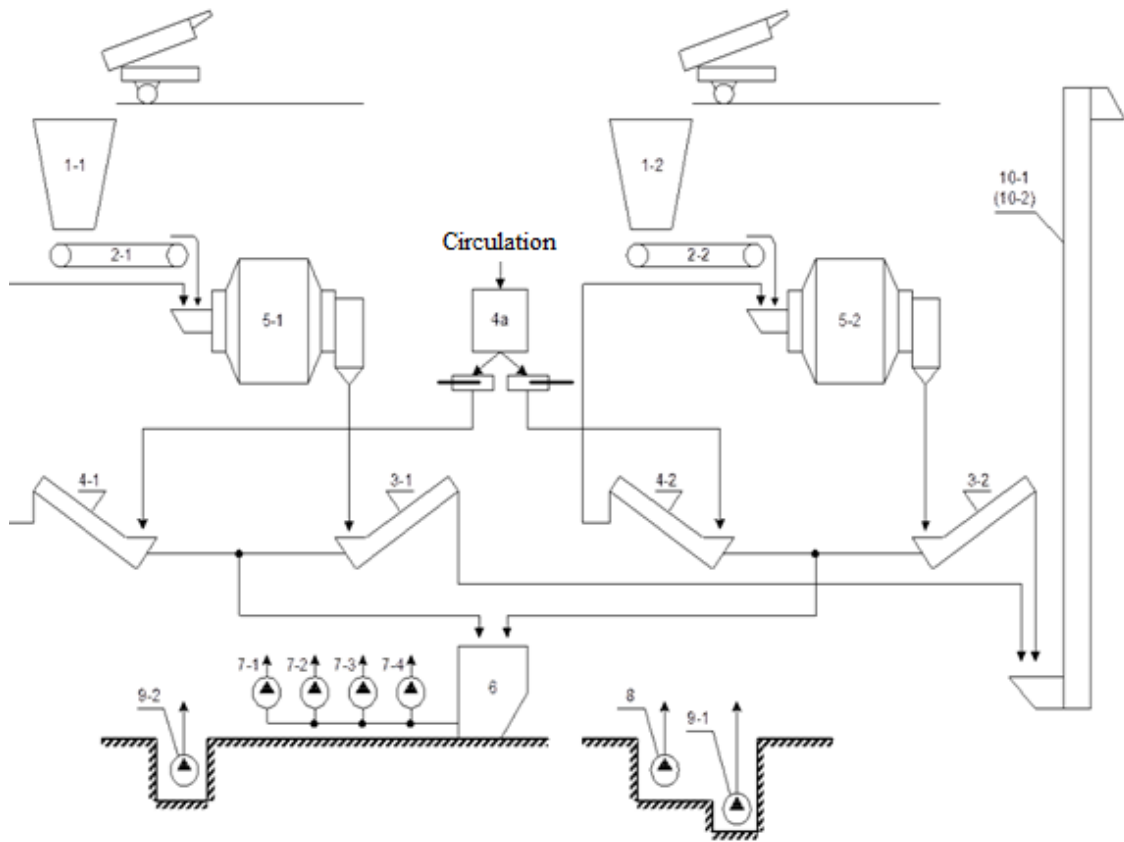


Figure 5 - Technological scheme of ore preparation part [6]

The power supply system of the processing plant consists of:

- Indoor switchgear 6 kV;
- Packaged Transformer Substation 6/0.4 kV;
- Indicator and control board 0.4 kV;
- Switchboard building 0.4 kV;
- High voltage electric drive 6 kV;
- Low voltage electric drive 6 kV;
- Power receiver 6 kV;
- Power receiver 0.4 kV;

The power supply system is designed to solve the following problems:

- Uninterruptible power supply of high-voltage electric drive, low-voltage electric drive, power receivers; 6 kV, power receivers 0.4 kV;
- Electrical protection for electrical equipment;
- Control of switching devices;
- Diagnostics of electrical equipment [6].

4. INTERPRETATION OF THE ENERGY SURVEY INSPECTION

4.1 The value of the active and reactive power in the system

The actual load characteristic can be obtained using recording devices that record changes in the corresponding parameter over time [7]. Let us analyze the real load schedules of each consumer. The measurement time for each is different. For example, we give the data about the Packaged transformer substation (PTS) no. 1.

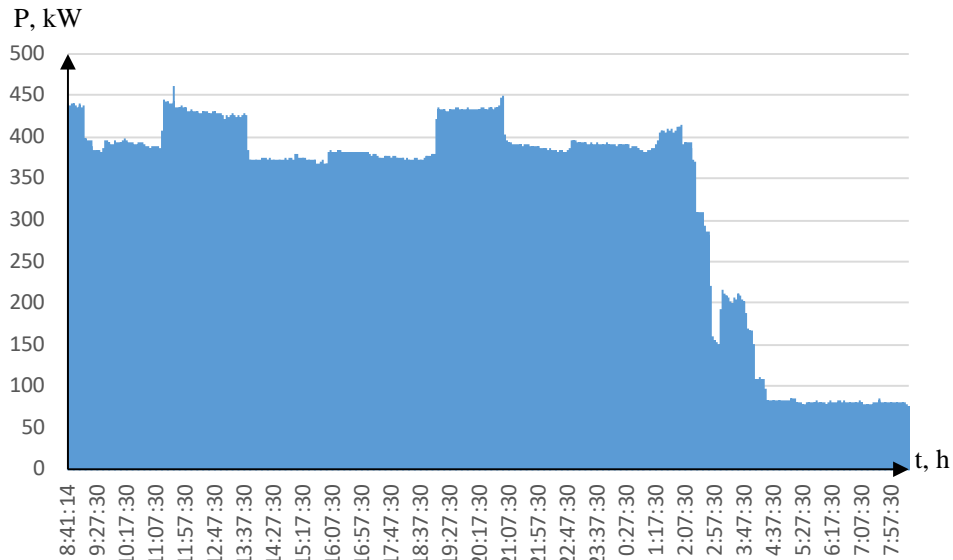


Figure 6 - Load characteristic for PTS 1 (T-1)

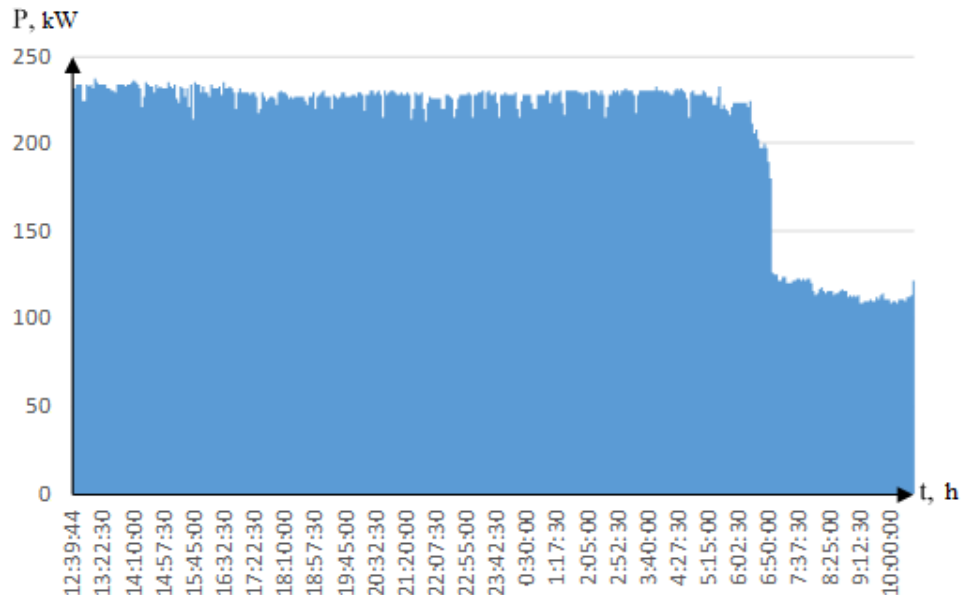


Figure 7 - Load characteristic for PTS 1 (T-2)

Based on the active power graph, it can be argued that the transformers are loaded in different ways. There was a drawdown in power at night; it can be assumed that there was a change in staff.

The software package allows us to determine the maximum and minimum values of active power for each complete transformer substation.

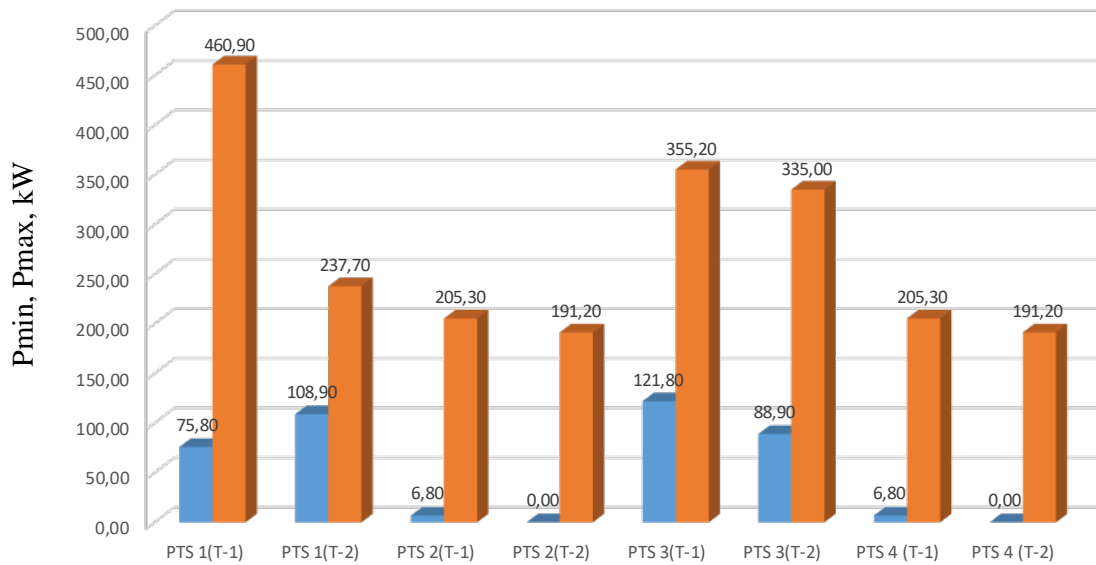


Figure 8 - Minimum and maximum active power load of consumer

The orange color correspond to maximum active power, the blue correspond to minimum active power. The minimum value of active power in a certain time interval has PTS 2 and 4. The maximum value at PTS 1.

Next, we consider the graphs of reactive power for each complete transformer substation, which allows us to clarify the amount of annual electricity consumption, outline the operation mode of transformers at substations, and choose the right compensation devices. The reactive load is inductive.

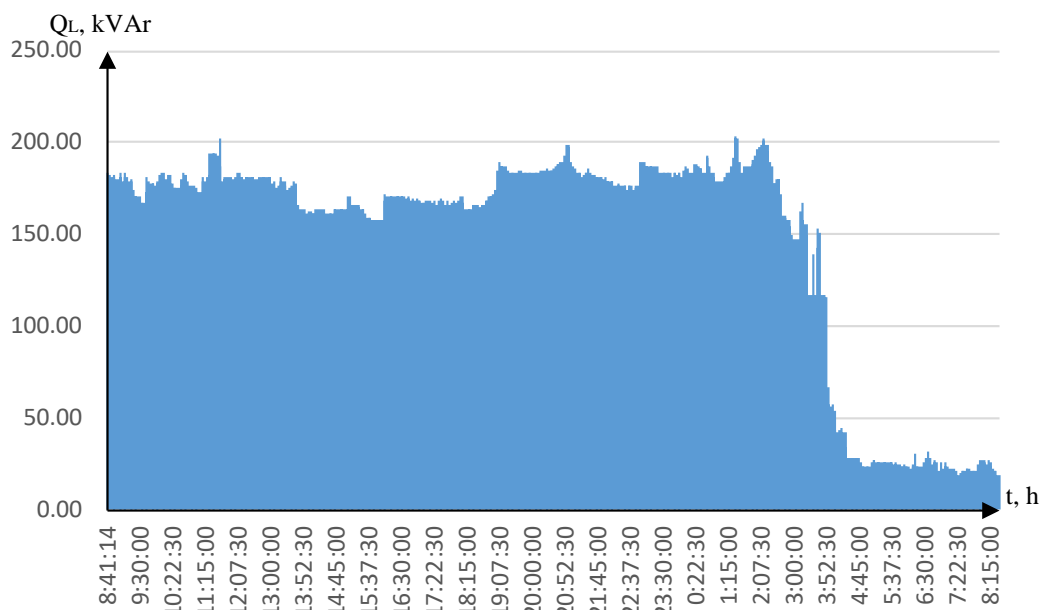


Figure 9 - Load characteristic for PTS 1 (T-1)

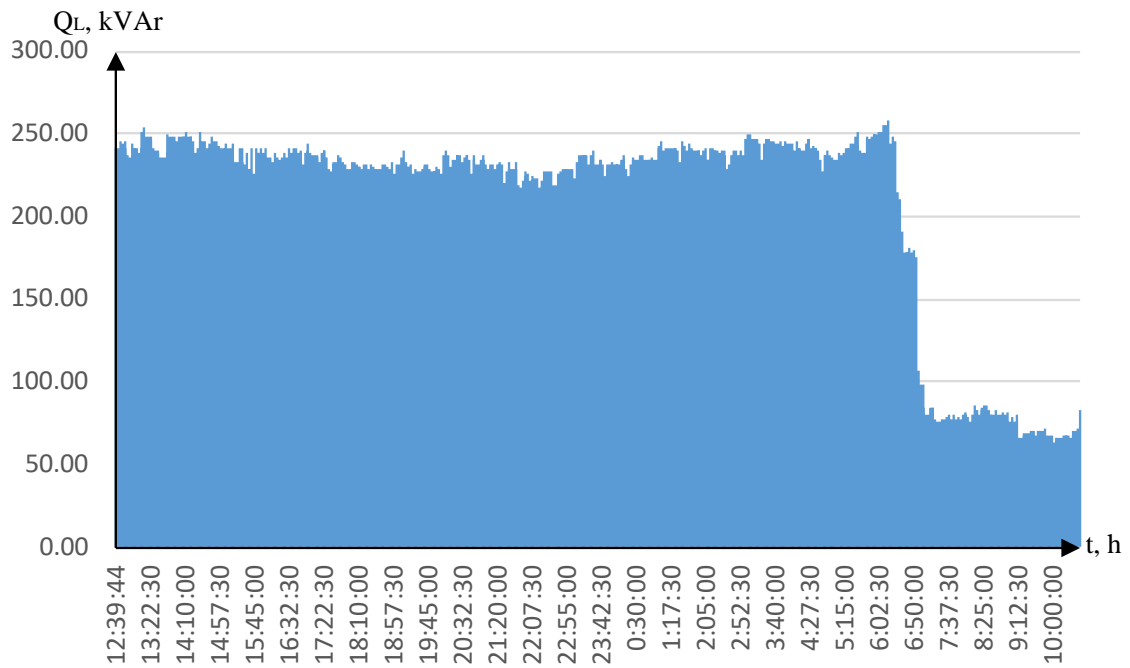


Figure 10 - Load characteristic for PTS 1 (T-2)

The results of measurements reactive power for each PTS are presented in the form of a graph below. The orange color correspond to maximum reactive power, the blue correspond to minimum reactive power.

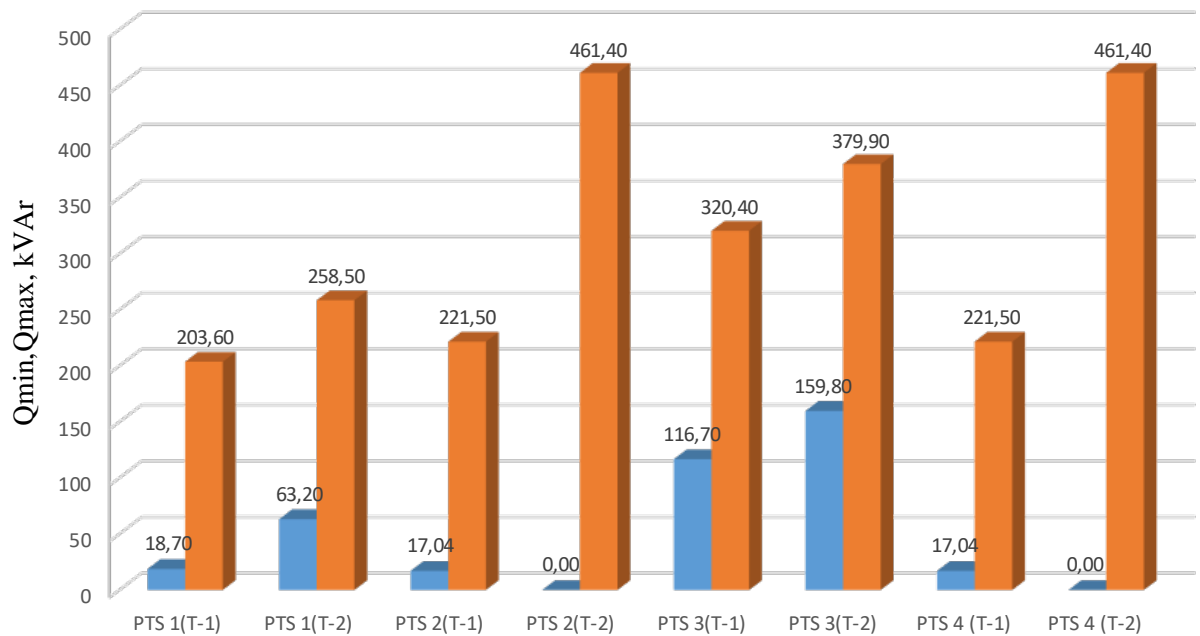


Figure 11 - Minimum and maximum reactive power load of consumer

4.2 Evaluation of the power factor for each transformer substation

The power factor is the ratio of active power (P) to total power (S). The power factor is a scalar physical quantity that shows how rationally consumers consume electrical energy. In other words, the power factor describes the electrical receivers in terms of the presence of a reactive component in the current consumption [11].

The deterioration of the power factor (disproportionate current consumption relative to voltage) leads to reactive and non-linear loads. Reactive loads are adjusted by external reactances, it is for them that the value is determined by $\cos \varphi$.

Power Factor Correction (PFC) is the process of bringing the consumption of an end device that has a low power factor when powered by an AC power network to a state where the power factor complies with accepted standards [12].

Consider the power factor for each PTS separately.

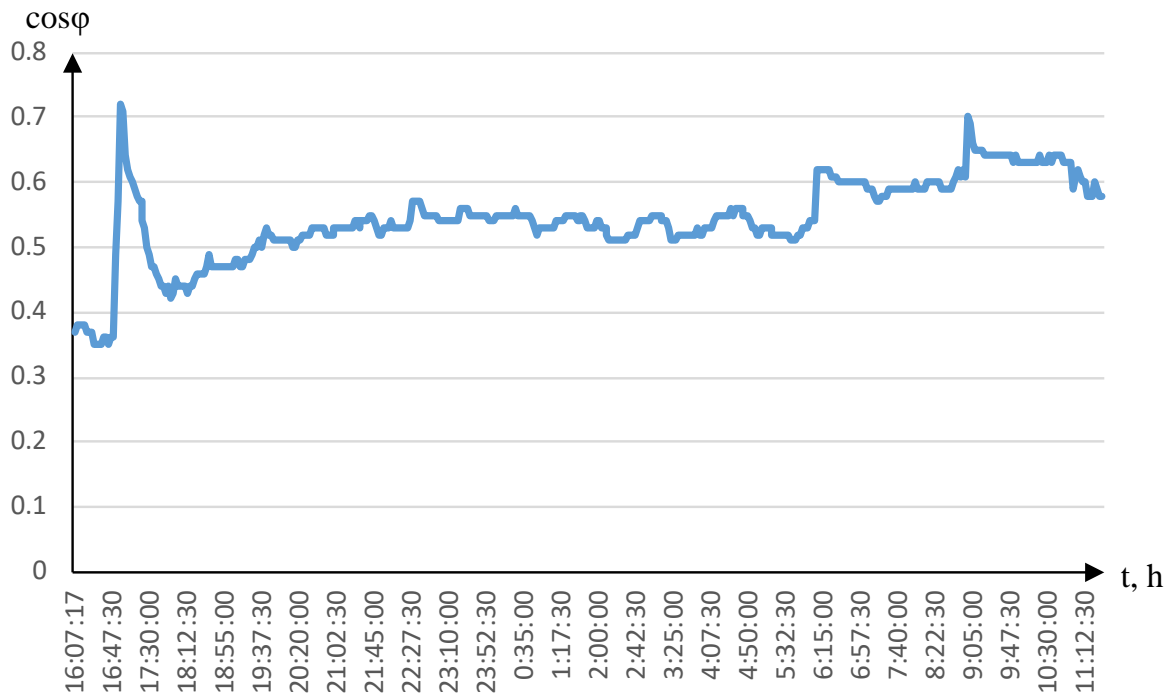


Figure 12 - Power factor PTS 2 (T-1)

The value of the power factor is calculated in the design of networks. Its low value is a consequence of an increase in the total loss of electricity. To increase it in networks, various correction methods are used, increasing its value to one.

Typical power factor values: 0.95 is a good indicator; 0.9 is a satisfactory indicator; 0.8 - bad indicator. It is a measure of the efficiency of converting electrical energy into useful work. The ideal power factor value is one. Any value less than one means that additional power is needed to obtain the desired result [13].

The flow of currents leads to losses in generating capacities and distribution systems. A load with a power factor of 1.0 most efficiently loads the source, and a load with a power factor of 0.8, for example, causes large losses in the system and higher energy costs. A relatively small improvement in power factor can lead to a significant reduction in losses, as they are proportional to the square of the current.

If the power factor is less than one, this indicates the presence of so-called reactive power. It is required to obtain the magnetic field necessary for the operation of motors and other inductive loads. Reactive power, which can also be called useless power or magnetization power, creates an additional load on the power supply system and increases the consumer's energy costs [14].

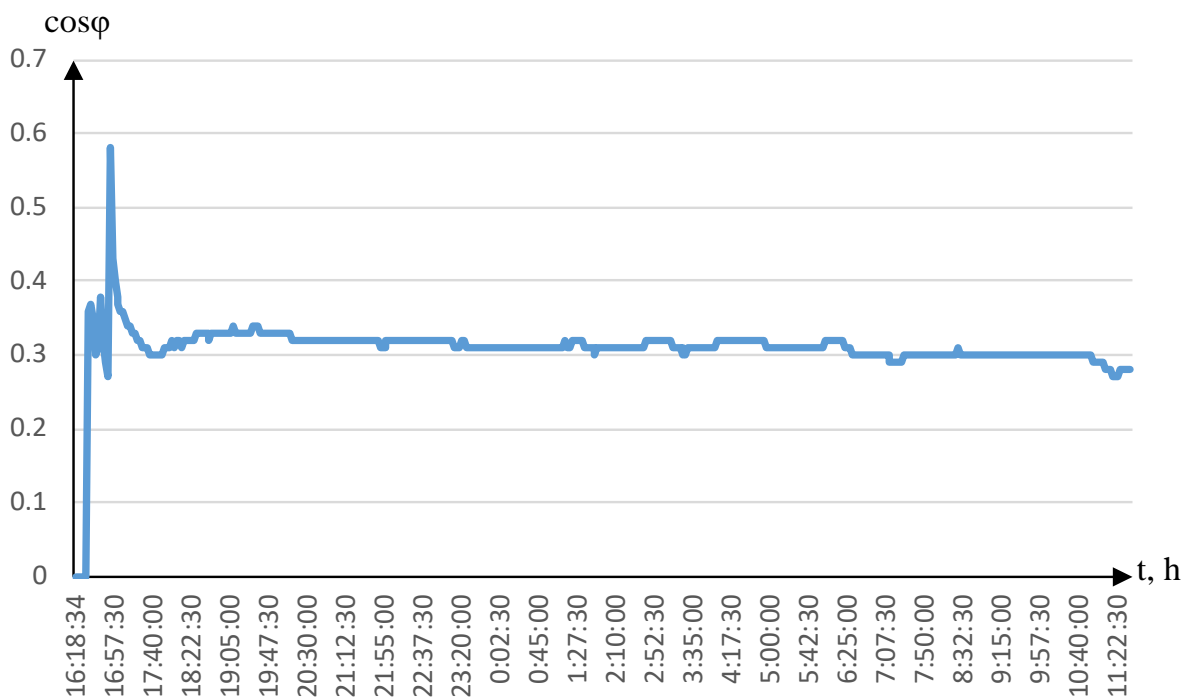


Figure 13 - Power factor PTS 2 (T-2)

4.3 Calculation of the power transformers load factor

The company uses TMZ transformers with a rated power is equal to 1000 kVA. Power oil transformers of the TMZ series are step-down, three-phase, double-winding and oil-tight transformers with power from 250 to 2500 kVA and voltage up to 10 kV are designed for installation at large industrial facilities and in packaged transformer substations for indoor and outdoor installation.

The first section of buses powers up the first transformers of four PTS, and the second section of categories respectively powers up the second group of PTS.

We determine the average value of power on the high side for each section of categories:

For PTS 1 – $P_{av1}=327.05$ kW, $Q_{av}=147.01$ kVAr,

For PTS 2 – $P_{av2}=115.36$ kW, $Q_{av}=171.8$ kVAr,

For PTS 3 – $P_{av3}=263.8$ kW, $Q_{av}=253.1$ kVAr,

For PTS 4 - $P_{av4}=115.36$ kW, $Q_{av}=171.8$ kVAr

Connections to the second bus section:

For PTS 1 – $P_{av1}=207.82$ kW, $Q_{av}=208.6$ kVAr

For PTS 2 – $P_{av2}=131.4$ kW, $Q_{av}=397.8$ kVAr

For PTS 3 – $P_{av3}=268$ kW, $Q_{av}=299.6$ kVAr

For PTS 4 – $P_{av4}=131.4$ kW, $Q_{av}=397.8$ kVAr.

Define the power loss in the transformers:

Table 2 – Catalogued data of transformer TMZ-1000

Tag	TMZ
Nominal power, kVA	1000
Voltage, kV	6; 10
Open circuit loss, W	1550
Short-circuit losses, W	10800
Short-circuit voltage, %	5.5
Open circuit current, %	1.2

Example of calculation for PTS 1-1:

$$S_{calc1} = \sqrt{P_1^2 + Q_1^2} = \sqrt{327.05^2 + 147.01^2} = 358.57,$$

where

S – apparent power, kVA,

P_1 – active power, kW,

Q_1 – reactive power, kVAr.

$$\beta_T = \frac{S_{calc}}{S_{nom}} = \frac{358.6}{1000} = 0.359,$$

where

S_{calc} – calculated value of apparent power, kVA,

S_{nom} – nominal value of apparent power, kVA,

$$\Delta P_T = P_{oc} + \beta_T^2 \cdot P_{sc} = 1.55 + 0.359^2 \cdot 10.8 = 2.939 \text{ kW},$$

where

ΔP_T – active power losses in transformer, kW,

P_{oc} – losses at the process of open circuit mode, kW,

β_T - power load factor,

P_{sc} – losses at the process of short circuit mode, kW.

$$\Delta Q_T = S_{nom} \cdot \frac{I_{os}}{100} + \beta_T^2 \cdot S_{nom} \cdot \frac{U_{sc}}{100} = 1000 \cdot \frac{1,2}{100} + 0.359^2 \cdot 1000 \cdot \frac{5,5}{100} = 19.072 \text{ kVAr},$$

where

ΔQ_T – reactive power losses in transformer, kVAr,

I_{os} – current at the open circuit mode, A,

U_{sc} – voltage at the short circuit mode, V.

$$P_{\max 1-2} = 327 - 2.9 = 324.1 \text{ kW}; Q_{\max 1-2} = 147.01 - 19.07 = 127.94 \text{ kVAr};$$

PTS 1-2

$$S_{calc1} = \sqrt{P_1^2 + Q_1^2} = \sqrt{207.82^2 + 208.6^2} = 294.45$$

$$\beta_T = \frac{S_{calc}}{S_{nom}} = \frac{364.2}{1000} = 0.294;$$

$$\Delta P_T = P_{oc} + \beta_T^2 \cdot P_{sc} = 1,55 + 0.294^2 \cdot 10.8 = 2.486 \text{ kW};$$

$$\Delta Q_T = S_{nom} \cdot \frac{I_{oc}}{100} + \beta_T^2 \cdot S_{nom} \cdot \frac{U_{sc}}{100} = 1000 \cdot \frac{1,2}{100} + 0.294^2 \cdot 1000 \cdot \frac{5,5}{100} = 16.769 \text{ kVAr};$$

$$P_{\max 1} = 205.3 \text{ kW}; Q_{\max 1} = 191.8 \text{ kVAr};$$

The other results of calculations is tabulated

Table 3 - Power transformers load factor

No.	PTS 1(1)	PTS 1(2)	PTS 2(1)	PTS 2(2)	PTS 3(1)	PTS 3(2)	PTS 4(1)	PTS 4(2)
β	0.359	0.294	0.207	0.419	0.364	0.402	0.207	0.419

The transformer load factor (β) is calculated based on the load time, comparing the actual load with the nominal one, comparing the received and transmitted power with the internal losses in the iron and windings. The efficiency of the converters also depends on this indicator.

According to normative document, we compiled a table of transformer load factors depending on the consumer category:

Table 4 – Recommended values of power factor load [15]

Power factor of transformer load	Description
0.65 ... 0.7	Two-transformer substations with a predominant load of category I
0.7 ... 0.8	Single-transformer substations with a predominant load of category II in the presence of mutual reservation through jumpers with other substations at secondary voltage
0.9 ... 0.95	Transformer substations with a load of category III or with a predominant load of category II with the possibility of using a warehouse reserve of transformers

Thus, the load factor of the transformer is lower than declared by regulatory documents. It can be assumed that this is designed to increase production capacity and connect new consumers.

4.4 Displacement power factor analysis

The technically necessary degree of displacement power factor (DPF) at each point in the network is determined by the parameters of the lines connecting this point to power sources. These parameters are individual for each point and, therefore, for each consumer. However, electricity tariffs are not set individually for each consumer but are differentiated only by four supply voltage levels: 110 kV and higher, 35 kV, 6-20 kV and 0.4 kV.

The value of the displacement power factor during hours of large daily loads of the electric network ($\tan\varphi$) is set depending on the nominal voltage of the network to which the consumer is connected.

Table 5 – Normalized values of DPF [16]

U,kV	110	35	6-20	0,4
$\tan \varphi$	0.5	0.4	0.4	0.35

For a voltage of 6-20 kV, the DPF is 0.4. We pass to $\text{tg}\varphi$ according to the formula:

$$\tan \varphi = \sqrt{\frac{1}{\cos^2 \alpha} - 1}$$

The examples of the obtained graphs are below.

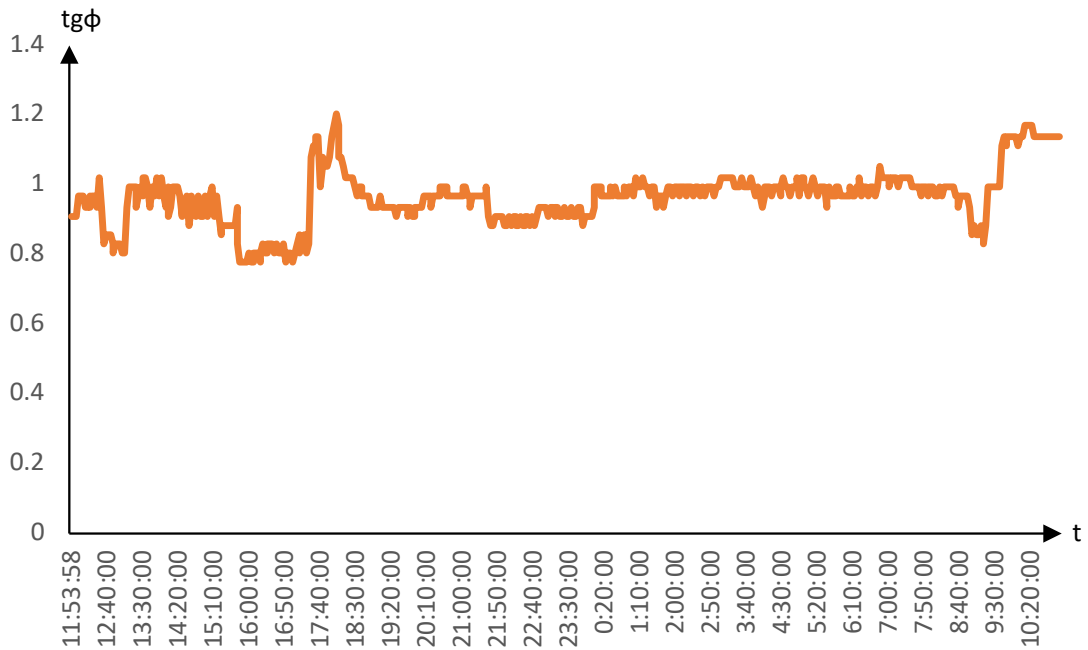


Figure 14 - Dependence of $\tan \varphi$ from time for PTS 3(T-1)

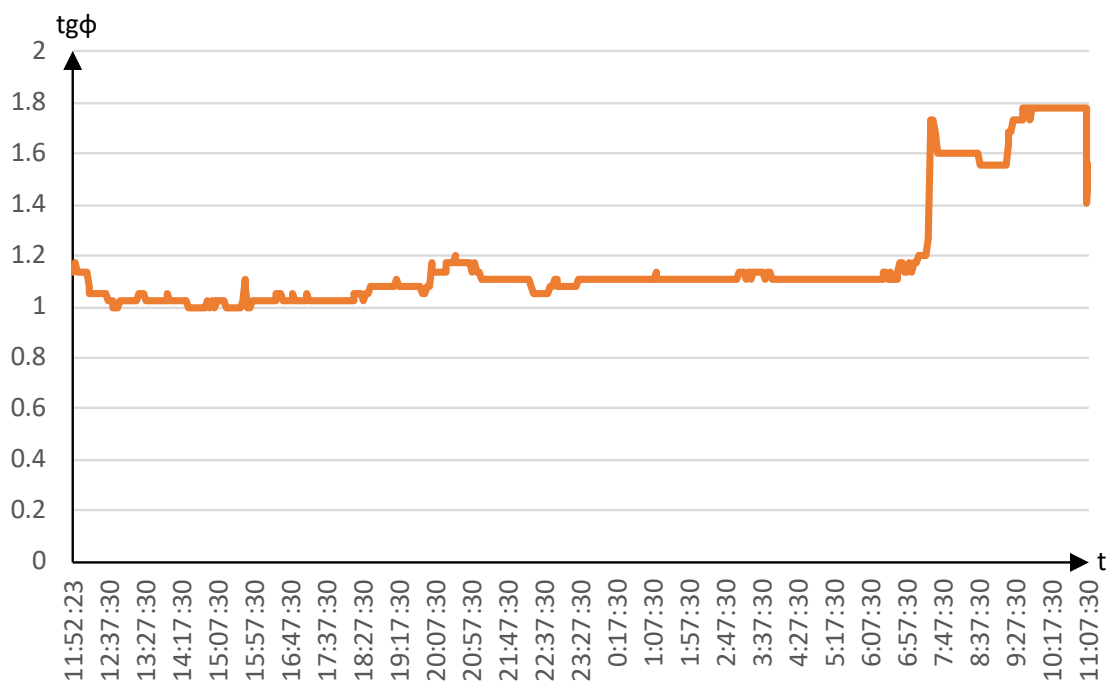


Figure 15 - Dependence of $\tan \varphi$ from time for PTS 3(T-2)

In each case considered, there is a deviation of the reactive power factor from the regulated value. In this regard, it is further advisable to consider the possibility of reactive power compensation.

4.5 Evaluation of the additional power losses caused by the asymmetry of the current

The reason for the deteriorating values of the quality indicators of electric energy and leading to an increase in losses and elements of the distribution and consumption of electric energy is the presence of long-term asymmetry modes of currents and voltages.

Voltage asymmetry is caused by the presence of an asymmetric load. Unbalanced load currents flowing through the elements of the power supply system cause unbalanced voltage drops in them. The asymmetrical voltage system appears on the terminals of electrical receivers. The voltage deviations in the electric field of the overloaded phase can exceed the permissible values, while the voltage deviations in the electric field of other phases will be within the normalized range. In addition to the deterioration of the voltage regime in the electric power supply under asymmetric conditions, the operating conditions of both the electric power supply and all network elements are significantly worsened, the reliability of the electrical equipment and the power supply system is reduced. In the case of reverse and zero sequence currents, the total currents in individual phases of the network elements increase, which leads to an increase in active power losses and may be unacceptable from the point of view of heating.

Additional losses in electric machines are divided into main and additional. The main losses occur in electric machines due to the electromagnetic and mechanical processes. These losses include losses in copper of windings and in steel from the main power flow and mechanical losses [17].

The values of additional power losses in individual elements of the distribution network that arise as a result of asymmetry allow us to estimate their total value and determine the economic damage caused by the decrease in the quality of electric energy. It is necessary for preliminary calculations of the economic feasibility of applying measures to improve the quality of electric energy:

$$\Delta P_{av} = \frac{1}{3} \frac{P_{av}^2 (1 + \tan^2 \varphi_{av})}{U_{av,ph}^2} \cdot R_{ph} \cdot k_{add,los,av},$$

where

$k_{add,los,av}$ – coefficient taking into account the average for the calculation period the uneven distribution of loads by phase, p.u.:

$$k_{add,los,av} = 3 \cdot \frac{I_a^2 + I_b^2 + I_c^2}{(I_a + I_b + I_c)^2} \cdot \left(1 + 1,15 \frac{R_{zero}}{R_{ph}}\right) - 1,5 \frac{R_{zero}}{R_{ph}},$$

R_{ph} – phase wire resistance, Ohm,

R_{zero} – resistance of a neutral wire, Ohm,

$U_{av,ph}$ – the average value of the voltage over a period of time T in phase n, V,

$I_{a,b,c}$ – currents in phases A, B, C [18].

The calculation was made according to the formula above, the resistance of the neutral conductor was taking equal to the phase, based on this, for the first PTS, we have:

$$I_a = 45.022 \text{ A}$$

$$I_b = 45.145 \text{ A}$$

$$I_c = 46.289 \text{ A}$$

The calculation example is illustrated below:

$$k_{add,los,1} = 3 \cdot \frac{45.022^2 + 45.145^2 + 46.289^2}{(45.022 + 45.145 + 46.289)^2} = 1.000157$$

The average value of the coefficient of additional losses for the first transformer is equal to $k_{add,los,av} = 1.001493$

The value of the losses were found in the corresponding section taking into account the coefficient of additional losses of loads on phases:

$$\Delta P_{I1} \cdot k_{add,los,av} = 0,354 \cdot 1,001493 = 0,3545 \text{ kW}$$

The coefficient of additional losses can be neglected.

The remaining calculations were performed using the Excel software package. In all cases, $k_{add,los,av}$ we do not take into account. Nevertheless, PTS 2 is characterized by the presence of asymmetric load in phases. The unevenness coefficient varies within. This fact can be explained by the fact that for some time the current in one of the phases is zero. This phenomenon is possible due to check out and start-up activity.

All values are summarized in the table:

Table 6 – Calculation results of additional losses coefficient

$k_{add.los}$	PTS 1(1)	PTS 1(2)	PTS 2(1)	PTS 2(2)	PTS 3(1)	PTS 3(2)	PTS 4(1)	PTS 4(2)
Max	1.009304	1.009304	1.000049	1.001554	1.009304	1.009304	1.000049	1.001554
Min	1.000049	1	1.003616	1.000049	1.000049	1.000049	1.003616	1.000049
Average	1.001493	1.01004	1.000189	1.000179	1.001366	1.001395	1.000189	1.000179

Power losses increase with increasing coefficient of uneven phase currents. According to the calculation, the value of the coefficient of additional losses does not exceed the value of 1.15, in further calculations its influence is not taken into account.

4.6 Estimation of steady-state voltage deviation

Deviations of voltage from nominal values occur due to daily, seasonal and technological changes in the electrical load of consumers; changes in the power of compensating devices; voltage regulation by generators of power plants and at substations of power systems; changes in the circuit and parameters of electric networks.

The steady-state voltage deviation is determined according to the formula [19]:

$$\Delta\delta = \frac{U_{nom} - U_{fact}}{U_{nom}} \cdot 100\% ,$$

where

U_{nom} – nominal value of voltage,

U_{fact} – current value of voltage.

The calculated values are summarized in the table:

Table 7 – Calculation of voltage deviation

	PTS 1(1)	PTS 1(2)	PTS 2(1)	PTS 2(2)	PTS 3(1)	PTS 3(2)	PTS 4(1)	PTS 4(2)
$U_{average}$	6.13	6.25	6.02	6.2	6.09	6.23	6.02	6.2
$\delta U, \%$	2.65	0.77	4.38	1.6	3.19	0.97	4.38	1.6

According to [19], positive and negative voltage deviations at the point of transmission of electric energy must not exceed 10% of the nominal or agreed voltage value during 100% of the time interval of one week. Analyzing the calculated values of the steady-state voltage deviation, we can conclude that all the numerical values do not exceed 10%, which corresponds to the quality standards of electric energy.

4.7 Energy efficiency of pumping units

The share of pumping equipment for a significant part of the electricity cost consumption in many industries. In the vast majority of pumping systems, the energy spent by the pump on pumping the working medium significantly exceeds the level actually needed for this. Excessive energy transferred to the system (for example, as a result of throttling of the pressure by the control valves) leads to increased heat and noise generation, excessive vibration and, as a result, to an increase in the cost of equipment maintenance. In addition, the excess energy reserve laid in the design of the system entails an overestimation of the weight-dimensional parameters of the equipment included in it. In particular, pumps, load elements, and control valves, which in turn leads to an increase in capital costs for repairs and maintenance.

The manufacturer must indicate the values of the following indicators for the nominal mode in the passport for the pump:

Flow rate, Q , m^3/h ;

Pump discharge, H , m;

Pump speed, n , rpm;

Performance efficiency, η , %;

Positive suction head, Δh_{adm} , m.

The pumps used at the Aikhal Mining and Processing Plant are connected to distribution point No. 2. Analyzing the single-line power supply scheme, conclude that three types of pumps GRAT 900, GRAT 1400, GRAT 1800 are used. The characteristics of the pumps will be considered.

The GRAT pumps are designed for pumping abrasive mixtures in processing plants. Soil pumps pump abrasive hydraulic mixtures with a density of up to 1600 kg/m^3 , a temperature of up to $700 \text{ }^\circ\text{C}$, a maximum size of solids from 1 to 200 mm and a volume concentration of up to 30%. The flowing part of the soil pump is made of superhard alloys, abrasive material on an organic bond, rubber, and polyurethane [20].

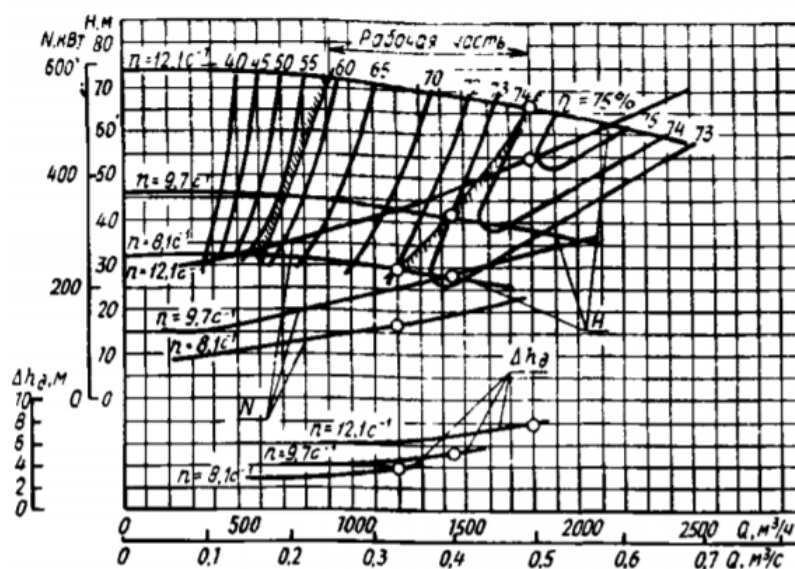


Figure 16 – Performance curve of pump [21]

Legend:

кВт - power units, kW,

м³/час – pumped liquid volume, m³/h,

м³/с – pumped liquid volume, m³/s,

с⁻¹ – cycles per second, s⁻¹,

м – units of length, m,

Рабочая часть – Operating area.

The analysis of the operating mode of pumping units is performed using the characteristics of the pumps. The characteristics of the pump are called the dependences of the head H , power N , efficiency η and permissible vacuum gauge suction lift or cavitation reserve on the pump supply Q at a certain number of revolutions n of the impeller with a diameter D .

The pump efficiency is zero at two points: at zero flow and at zero pressure. Efficiency has a maximum value at a nominal pump flow, for which the impeller geometry is designed. It is important to select a pump when operating conditions correspond to the middle part of the pump characteristics [21].

Example of pumping plant operating schedules and its specific energy consumption is considered:

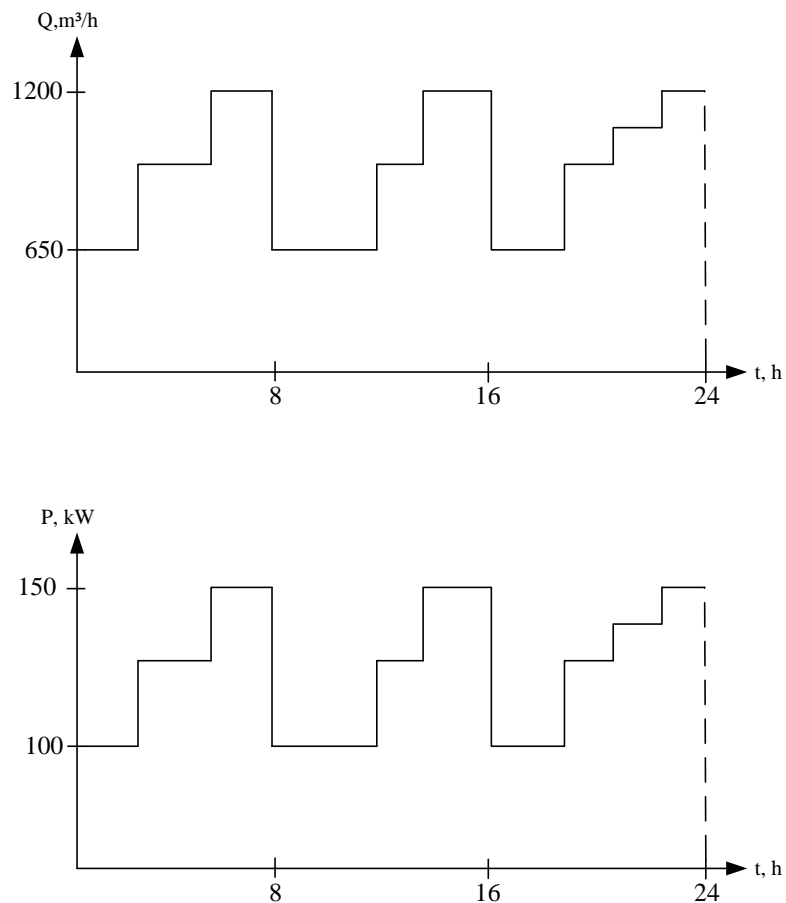


Figure 17 - Operating schedule

Specific energy consumption measured in kilowatt hours per unit of production, the value is an integral indicator of the consumption of electric energy per unit of production.

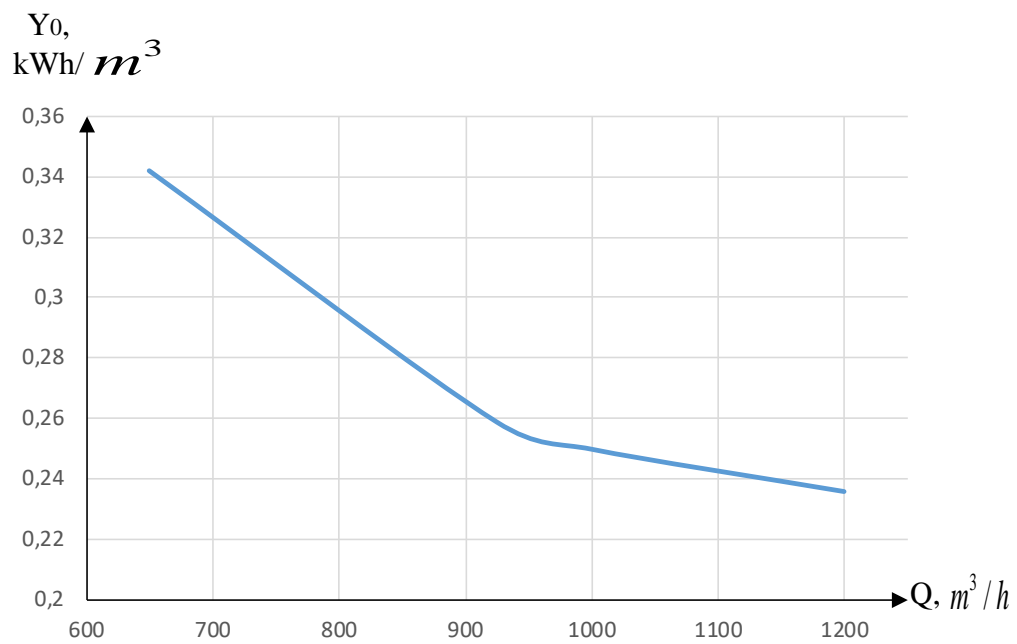


Figure 18 – Specific energy consumption

The lowest specific energy consumption for water supply is observed at maximum pump flow.

5. REACTIVE POWER COMPENSATION

Compensation of reactive power allows you to increase the efficiency of energy use in three main directions: increasing the throughput of lines and transformers, reducing losses of active energy, normalizing voltage.

It can be estimated how much of the energy consumed is useful for performing work by the magnitude of the reactive power coefficient.

$$\text{PTS 1-1: The power factor before installing capacitor banks is: } \cos \varphi = \frac{P}{S_1} = \frac{324.1}{369.346} = 0.893,$$

where

P – active power, kW,

S_1 – apparent power, kVA

The power factor value satisfies the regulated value.

$$\text{PTS 1-2: The power factor before installing capacitor banks is: } \cos \varphi = \frac{P}{S_1} = \frac{205.3}{280.95} = 0.731$$

$$\text{After installing the capacitor banks, it will rise to: } \operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{191.8 - 100}{205.3} = 0.447,$$

where

Q – reactive power, kVAr,

Q_{cb} – reactive power of capacitor bank, kVAr.

The following step is to express the value of the power factor $\cos \varphi = 0.91$. Accept for installation KRM-0,4-100 UZ IP20.

$$\text{PTS 2-1: The power factor before installing capacitor banks is: } \cos \varphi = \frac{P}{S_1} = \frac{113.35}{193.99} = 0.584. \text{ After}$$

$$\text{installing the capacitor banks, it will rise to: } \operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{157.44 - 100}{113.35} = 0.507 \text{ express the value of the}$$

power factor $\cos \varphi = 0.89$. Accept for installation KRM-0,4-100 UZ IP20.

$$\text{PTS 2-2: The power factor before installing capacitor banks is: } \cos \varphi = \frac{P}{S_1} = \frac{127.95}{397.32} = 0.32. \text{ After}$$

$$\text{installing the capacitor banks, it will rise to: } \operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{376.15 - 325}{127.95} = 0.42, \text{ express the value of the}$$

power factor $\cos \varphi = 0.91$. Accept for installation KRM-0,4-325-7-25 UZ IP20.

$$\text{PTS 3-1: The power factor before installing capacitor banks is: } \cos \varphi = \frac{P}{S_1} = \frac{260.82}{348.94} = 0.747. \text{ After}$$

$$\text{installing the capacitor banks, it will rise to: } \operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{231.8 - 100}{260.8} = 0.505, \text{ express the value of}$$

the power factor $\cos \varphi = 0.893$. Accept for installation KRM-0,4-100-4-25 UZ IP20.

PTS 3-2: The power factor before installing capacitor banks is: $\cos \varphi = \frac{P}{S_1} = \frac{264.71}{384.94} = 0.689$. After

installing the capacitor banks, it will rise to: $\operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{278.7 - 150}{264.71} = 0.486$, express the value of the

power factor $\cos \varphi = 0.89$. Accept for installation KRM-0,4-150-6-25 UZ IP20.

PTS 4-1: The power factor before installing capacitor banks is: $\cos \varphi = \frac{P}{S_1} = \frac{113.35}{193.99} = 0.584$. After

installing the capacitor banks, it will rise to: $\operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{157.44 - 100}{113.35} = 0.507$ express the value of the

power factor $\cos \varphi = 0.89$. Accept for installation KRM-0,4-100 UZ IP20.

PTS 4-2: The power factor before installing capacitor banks is: $\cos \varphi = \frac{P}{S_1} = \frac{127.95}{397.32} = 0.32$. After

installing the capacitor banks, it will rise to: $\operatorname{tg} \varphi = \frac{Q - Q_{CB}}{P} = \frac{376.15 - 325}{127.95} = 0.42$, express the value of the

power factor $\cos \varphi = 0.91$. Accept for installation KRM-0,4-325-7-25 UZ IP20.

6. OPTIMIZATION OF OPERATING MODES OF PUMPING UNITS

The main consumers of electricity at the processing plants are pumping units. This is due to their multiplicity and low efficiency of use.

The intensive development of cavitation and the increase in hydrodynamic and dynamic loads, leading to a decrease in the structural strength of the centrifugal pump, it is due to its operation in non-stationary modes [20].

6.1 Variable frequency drive of motor`s pump

The basic element that ensures the functionality of the pump is an electric motor. Previously, the adjustment of the working process was due to automation, now a frequency converter for pumps solves this problem.

According to the principle of operation, the frequency converter is quite simple. An electric current wave is applied to the board of the device. The inverters and stabilizers located there ensure its alignment. At the same time, the sensor reads pressure data and other relevant information. All information is redirected to the automation unit. Further, the frequency converter carries out their assessment, determining the power level that must be supplied, and, in accordance with this, supplying the amount of electricity necessary to continue working.

The control system is represented by a microprocessor, which simultaneously performs the protection functions (turns off the pump during strong current fluctuations in the mains) and control. In borehole water pumps, the control element of the converter is connected to a pressure switch, which allows the pump station to operate in a fully automatic mode. The use of frequency converters, due to the reduction in engine speed and, as a consequence, the supplied power, allows changing the “pump curve” by adapting it to the “system curve” [20].

The regulatory characteristics for the pumps is built:

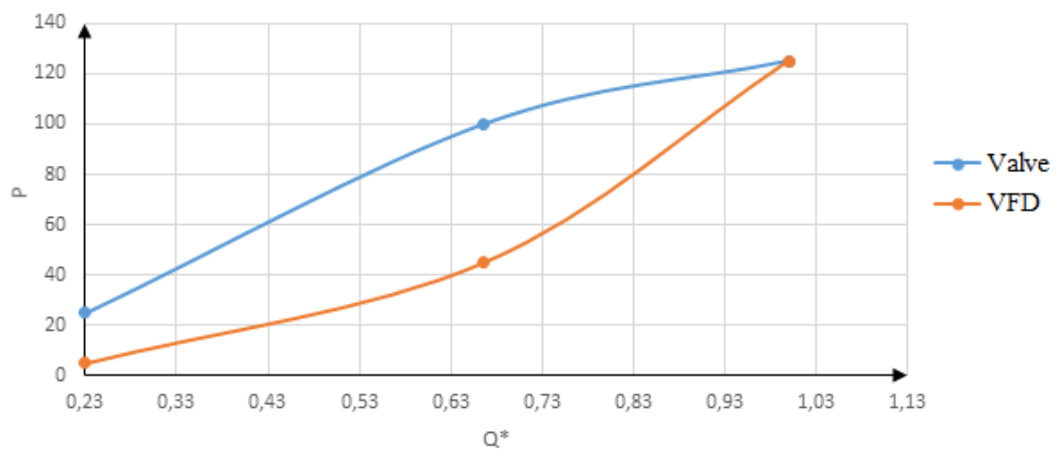


Figure 19 – Regulating characteristic of the pump GRAT 900

A similar construction is possible for other pumps:

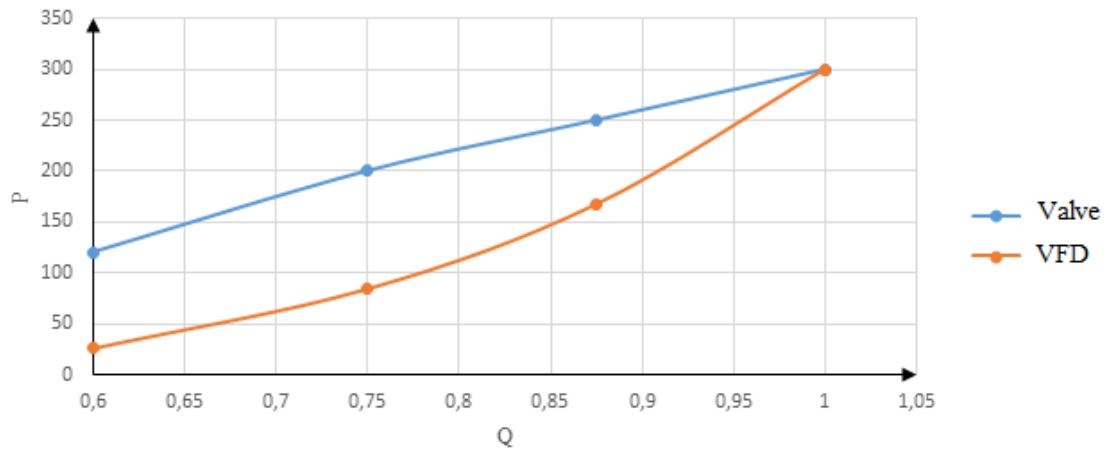


Figure 20 – Regulating characteristic of the pump GRAT 1400

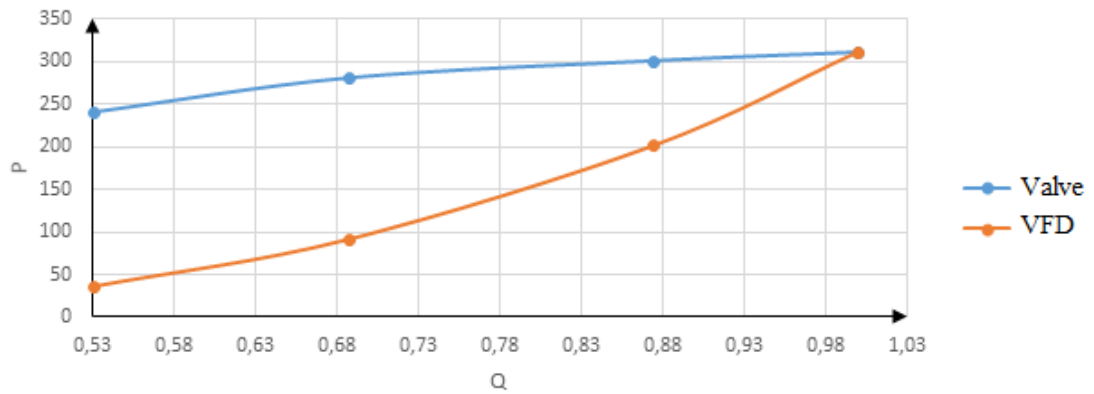


Figure 21 – Regulating characteristic of the pump GRAT 1800

Based on the obtained values, the work schedules of pumping units were built taking into account power regulation.

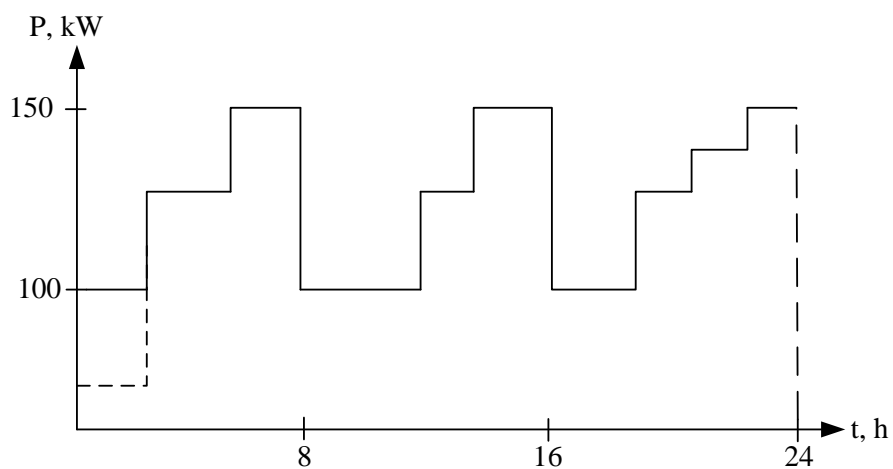


Figure 22 – Power graph for the GRAT 900 pump when using VFD

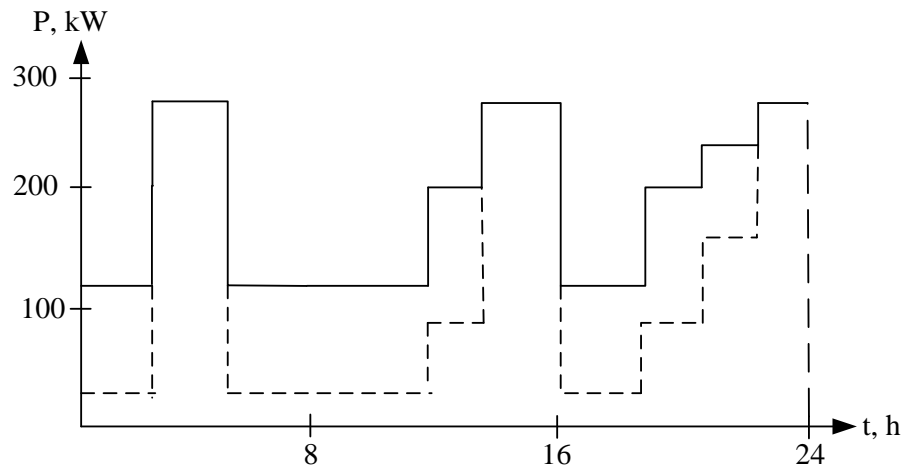


Figure 23 – Power graph for the GRAT 1400 pump when using VFD

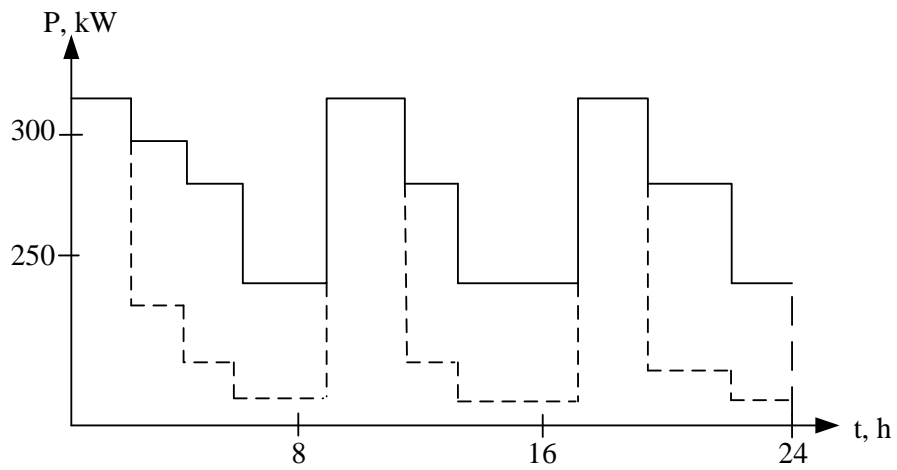


Figure 24 – Power graph for the GRAT 1800 pump when using VFD

The calculation of energy saved using frequency adjustment of the drive was performed.

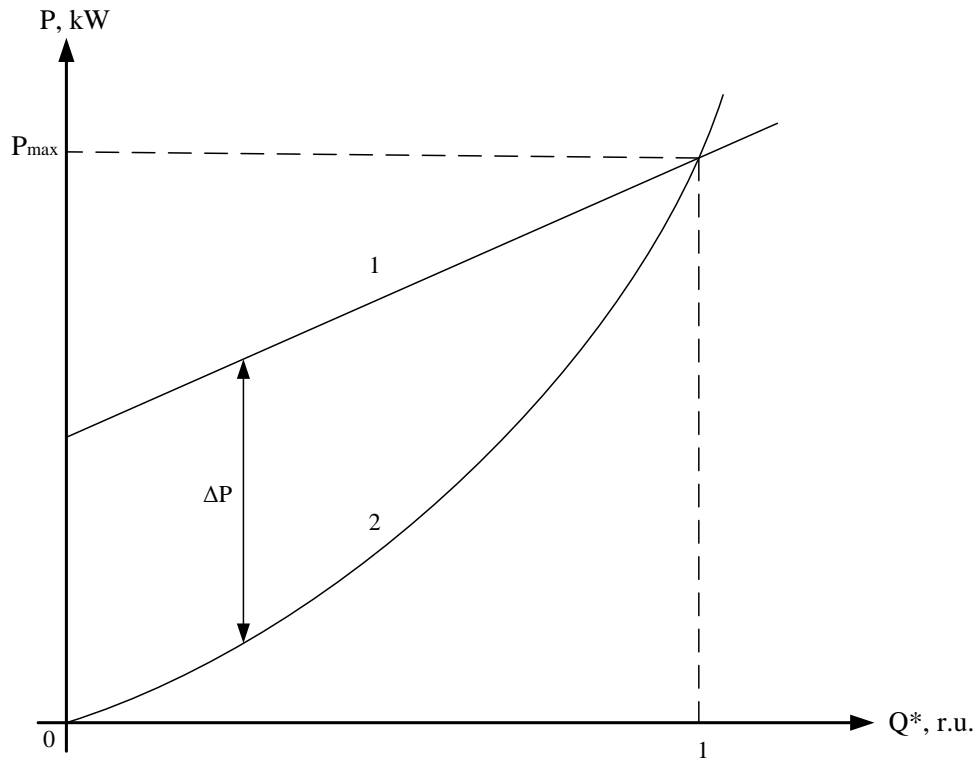


Figure 25 – Saved energy

$$\Delta W = \sum_i^m \Delta P_i \cdot t_i,$$

where

m is the number of sections of the cycle with different ΔP_i ,

ΔP_i – power consumed for time is equal to t , kW.

Table 8 – Saved energy

Pump	ΔW_{year} , kW · h
GRAT 900	37 917
GRAT 1400	114 662
GRAT 1800	175 841

7. ECONOMIC ANALYSIS

The adoption of certain decisions in the activities of the enterprise should be supported by a justification in the form of economic calculations. It gives an assessment of the state of the economy of a given facility and its current economic activities. Thus, in this chapter, the appropriateness of applying the proposed measures will be considered.

7.1 Choosing the optimal price category for the Aikhla mining and processing plant

The costs of the electric power system consist of the costs of generating electricity for the entire complex of power plants, the costs of transmitting and distributing electricity to consumers, and other system-wide costs of ensuring the stability and reliability of power supply, the maintenance of general power reserves, intersystem power lines and regulation of the load schedule.

According to the Decree of the Government of the Russian Federation No. 442, there are currently six price categories of electricity in the retail electricity market [22]. According to the law, the choice of a price tier is an obligation and the right of the consumer of electric energy; the final price of electricity for a consumer depends a lot on the right price category.

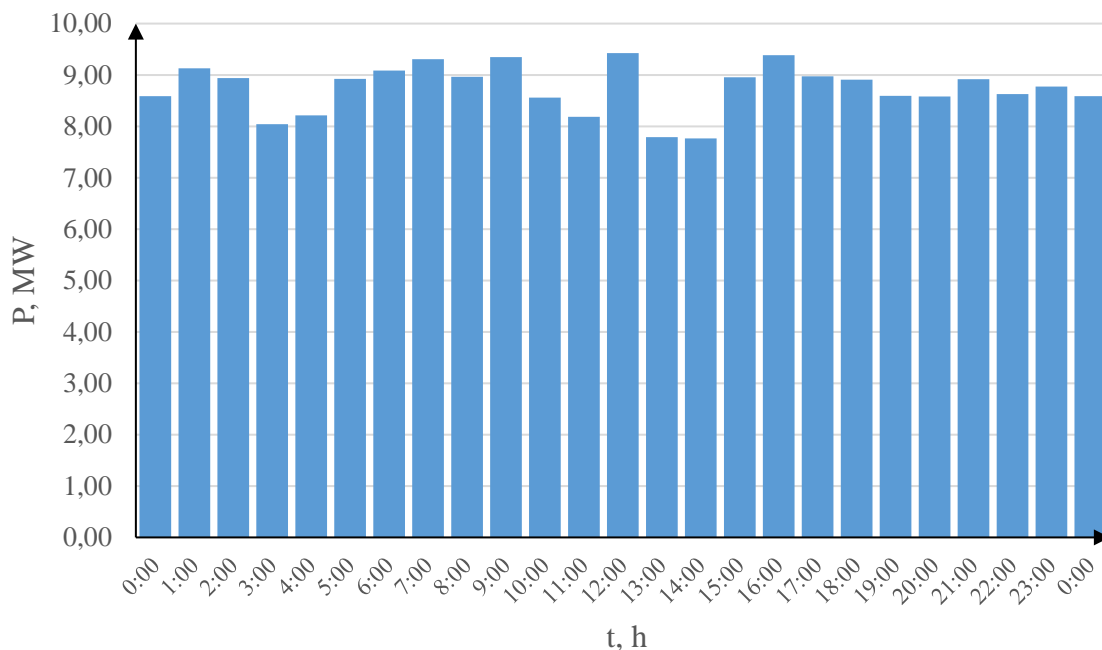


Figure 26 – Distribution point active load graph

7.2 Calculation according to the daily schedule of electric loads of the enterprise of average and maximum loads

Consumption group: Consumers with max power from 670 kW to 10 MW. At a voltage of 110 kV. The calculation is simplified, as it analyzes the characteristic schedule of the enterprise.

Table 9 – Active power

Hour	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
P, MW	8.59	9.13	8.94	8.04	8.21	8.92	9.09	9.31	8.96	9.35	8.56	8.18
Hour	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
P, MW	9.43	7.79	7.77	8.96	9.39	8.97	8.91	8.59	8.58	8.92	8.63	8.77

Active electricity consumed per day:

$$W = \sum_{i=1}^n P_i \cdot t_i = 218.57 \text{ MWh},$$

where $i = 1-n$ - number of steps in the load graph,

P_i – active power for one hour, kW,

t_i – period of time, h.

First price category

Annual consumption:

$$W_{year} = \sum_{i=1}^n (P_i \cdot t_i) \cdot 365 = 218.57 \cdot 365 = 79840.1 \text{ MWh}.$$

Payment for the first price category is defined as for a simple flat-rate tariff:

$$P_{ee} = W_{year} \cdot T \cdot (1 + VAT) = 79840.1 \cdot 1960.3 \cdot 1.2 = 187\,812\,657 \text{ RUB},$$

where

VAT – Value Added Tax

Second price category

The table shows the recommended durations of the zones of the daily load schedule and active capacities in each zone of the day.

Table 10 – Duration of the daily load schedule zones and active capacities in each zone of the day

Zone of daily schedule of loading	Duration, h	P, MW	C, RUB
night	23-07	79.01	1304.02
peak	07-11	103.28	2886.17
	18-21		
intermediate	11-18	123.27	1872.95
	21-23		

Payment in the second price category will be:

$$P = (W_{pk} \cdot T_{pk} + W_{int} \cdot T_{int} + W_n \cdot W_n) \cdot 365 \cdot (1 + VAT) =$$

$$= (103.3 \cdot 2886.2 + 123.27 \cdot 1872.95 + 79.01 \cdot 1304.02) \cdot 365 \cdot 1.2 = 276\,839\,488.5 \text{ RUB},$$

where

W_{pk} – energy during peak loading,

W_{int} – energy during intermediate value of loading,

W_n – energy during night.

Third price category

To determine the power paid to the wholesale market, you need to know the hours of maximum total electricity consumption. Table X presents the monthly report on peak hours and the corresponding capacities.

Table 11 – Monthly peak hours report

Date	Hour	P , MW
02.2018	6-7	9.09
03.2018	7-8	9.31
04.2018	9-10	9.35
05.2018	7-8	9.31
06.2018	6-7	9.09
09.2018	6-7	9.09
10.2018	6-7	9.09
11.2018	7-8	9.31
12.2018	6-7	9.09
13.2018	7-8	9.31
16.2018	9-10	9.35
17.2018	6-7	9.09
18.2018	7-8	9.31
19.2018	6-7	9.09
20.2018	7-8	9.31
23.2018	7-8	9.31
24.2018	7-8	9.31
25.2018	7-8	9.31
26.2018	7-8	9.31
27.2018	9-10	9.35
30.2018	7-8	9.31
Total		194.09

Power paid to the wholesale market:

$$P_{p.opt} = \frac{\sum P_i}{N_w} = \frac{194.09}{21} = 9.24 \text{ MW},$$

where

N_w – working days during a month ($N_w = 21$).

Payment for capacity paid to the wholesale market:

$$P_{P.opt} = P_{P.opt} \cdot T_{P.opt} = 9.24 \cdot 553306.14 = 5\,112\,548.73 \text{ RUB}$$

The total payment for the third price category will be:

$$P = (P_{year} + m \cdot P_{P.opt}) \cdot (1 + VAT) = \\ = (86\,066\,891 + 12 \cdot 5\,112\,548.7) \cdot 1.2 = 176\,900\,970.13 \text{ RUB}$$

Fourth price category

Electricity is paid on an hourly basis, a separate fee for capacity is charged, as in the third and fifth price categories.

Total payment for the fourth price category:

$$P = (P_{year} + 12 \cdot P_{P.opt} + 12 \cdot P_{Net}) \cdot (1 + VAT) = \\ = (86066891 + 12 \cdot 5112548 + 12 \cdot 13860004) \cdot 1.2 = 376\,485\,030.6 \text{ RUB,}$$

where

P_{Net} – payment for network power, kW.

The fifth price category

In the fifth price category, the consumer is obliged to plan his hourly consumption a day in advance and pay for the deviations; they are included in the price of electricity.

Total payment for the fifth price category:

$$P = (P_{year} + 12 \cdot P_{P.opt} + P_{dev}) \cdot (1 + VAT) = \\ = (61\,890\,234 + 12 \cdot 5\,112\,548.73 + 397\,120) \cdot 1.2 = 148\,365\,526.57 \text{ RUB,}$$

where

P_{dev} – power deviation, kW.

The final payment in the fifth price category depends on the accuracy of the estimated consumption.

The sixth price category

There are obligations to plan hourly consumption and pay for deviations. These price categories are available to all legal entities - consumers of electricity.

Total payment for the sixth price category:

$$P = (P_{year} + 12 \cdot P_{P.opt} + 12 \cdot P_{Net} + P_{Dev}) \cdot (1 + VAT) = \\ = (61\,890\,234 + 12 \cdot 5\,112\,548.7 + 12 \cdot 13\,860\,004.2 + 87457.7) \cdot 1.2 = \\ = 3\,475\,777\,991.9 \text{ RUB}$$

Table 12 – A summary sheet for each price category

Price category	Total price P , RUB
1 category	187 812 657
2 category	276 839 488
3 category	176 900 970
4 category	376 485 030
5 category	148 603 798
6 category	3 475 777 991

Consumer with a maximum power of more than 670 kW can choose one among price tier from three to six.

The necessity for daily planning of hourly consumption for 5-6 price tier is the difference from 3-4. At the same time, for 3-4 price tier the deviations of the guaranteeing supplier per the volume of consumption of the enterprise are used at the process of calculating the final cost of power supply [23].

7.3 Initial data for obtaining economic model

7.3.1 Inflation

Inflation - is the rising prices for goods and services. There is a depreciation of money, reduced purchasing power of the population. The value of inflation was analyzed for Russian Federation. Information about average inflation level was analyzed by the state statistics website [24]. The result value was adjusted using inflation targeting.

Inflation targeting is a central banking policy that revolves around adjusting monetary policy to achieve a certain annual inflation rate. Inflation targeting is a monetary policy regime whose ultimate goal is price stability. Through the interest rate policy, the Central Bank takes measures to ensure it and is publicly responsible for the results of its policy. Monetary authorities establish and publicly announce a quantitative inflation target, which is recognized as the main (final) goal of monetary policy. The Central Bank relies on interest rate policy (short-term interest rate management), which distinguishes inflation targeting from other monetary policy regimes. Monetary policy decisions are based on a wide array of information, including forecasts of economic development and inflation. The central bank within the framework of the objective function minimizes the deviation of current inflation from its target and current GDP from its potential long-term level. The objective function is based on a macroeconomic model that takes into account the inertia and lags of monetary policy, through which the use of the central bank instrument is reflected in the aggregate demand and supply. Monetary policy can be described by the response function of the central bank, which shows how it should optimally respond to changes in macroeconomic variables in order to achieve the objectives [25].

The Bank of Russia maintains inflation close to the target of 4% [26].

7.3.2 Taxes of Russian Federation

The amount of tax is one of needed aspects for calculation. According to the tax code of the Russian Federation, this value is equal to 20% [27].

7.3.3 Investments

Investments are process of investing in any object that after a certain period will give the expected income (and not necessarily in material terms). It is necessary to calculate investments in Capacitor banks installing and Variable frequency drive.

First of all, the calculation of capacitor banks installing were obtained. The capacitor banks were chosen based on nominal voltage and value or reactive power contributed. The automatic capacitor units have been selected to reduce reactive power. An automatic installation is considered an electrical installation consisting of capacitors, a busbar and related auxiliary electrical equipment. The prices were borrowed from site for the sale of electrical equipment [34]. Expenses estimates are shown below.

Table 13 – Expenses budget for capacitor banks

Name	Nominal Power	Number	Price
Capacitor banks	100	1	55 169
	100	1	55 169
	325	1	119 589
	100	1	55 169
	150	1	60 397
	100	1	55 169
	325	1	119 589
Total			520 251

The cost of delivery, selection of equipment, consulting services, commissioning, changes to the system of operation of automatic equipment were also taken into account.

Secondly, the expenses for VFD were considered. They were chosen based on nominal power of pumps. Expenses estimates are shown below.

Table 14 – Expenses budget for VFD

	Pump GRAT 1400	Pump GRAT 900	Pump GRAT 1800
Nominal power	40	67	67
VFD (Frequency variable drive)	+	+	+
Price	189381	263756	263756
Number	2	2	2
Price according to number of units	378762	527512	527512
Total			1433787

There are exist some cons of the VF circuit such as initial investments for the purchase of the device; the specialist is needed to connect and configure the equipment.

In addition, the following work was carried out to introduce this equipment into operation: consulting services, equipment selection, box settings, frequency equipment programming, and settings of the existing automatic control system for introducing new equipment into it, start-up and commissioning.

These shortcomings are quickly compensated for by cheaper maintenance. As a result, maintenance and repair costs are reduced, the cost of ownership as a whole is reduced, and comfort is markedly increased [28].



Figure 27 – Example of installed equipment [36]

In addition, installation, maintenance costs are included.

Every year there is an increase in prices, so it is necessary to take into account the escalation in the calculation of investments and paying for energy. The electricity tariff is changing every year with a growth.

7.3.4 Depreciation

Russian depreciation in English breaks down into two types: depreciation for tangible assets and amortization for intangible assets.

The enterprise needs to know three things to account for depreciation: the initial cost of an asset (cost), its residual value (residual value is the value expected at the end of its life) and useful life.

According to Russian accounting standards, there are four main ways of calculating depreciation for accounting for fixed assets:

Linear method - there is a uniform accrual of depreciation from the initial to the residual value (at the end of the service life) during the entire period of use. The current residual value is determined by subtracting the total accumulated depreciation of the fixed asset from the initial cost.

Declining balance method - the amount of depreciation for each period is equal to the residual value multiplied by a certain percentage. Each year depreciation is charged on the residual value at the beginning of the year.

The method based on the write-off of value in proportion to the volume of products - depreciation is calculated based on some natural indicator (for example, the machine-hour of equipment use).

The method of writing off value according to the sum of the digits of the years of useful life [29].

The declining balance method is used in this work. The depreciation charges based on non-linear methods are calculated for the depreciation group as a whole. The declined balance method is characterized by an accelerated depreciation process, which is based on the terms of the residual value of the property. The main steps if this method:

1. To determine the depreciation group from one to ten based on useful lifetime of the equipment;
2. To choose monthly depreciation rate for nonlinear method;
3. To calculate the annual depreciation amount.

$$N_a = \frac{100\%}{T} = \frac{100}{20} = 5\%$$

N_a – annual norm of amortization;

T - equipment useful life.

4. To calculate amortization for the first year taking into account annual depreciation amount and depreciation rate for nonlinear method.
5. The further depreciations are recalculated based on taking into account the amount of money from the last year. So as a result, depreciation will be decreasing. The final year will be characterized with the lowest amount of money in comparison with first year.

Table 15 – Amount of depreciation for VFD equipment

Year	1	2	3	4	5	6	7	8	9	10
Value of depreciation	93 196	87 138	81 474	76 179	71 227	66 597	62 268	58 221	54 437	50 898
Year	11	12	13	14	15	16	17	18	19	20
Value of depreciation	47 590	44 497	41 604	38 900	36 371	34 007	31 797	29 730	27 798	25 991

The further step is to obtain the same type of calculation for capacitor banks investments. The results of calculation are presented in the following table:

Table 16 – Amount of depreciation for Capacitor banks equipment

Year	1	2	3	4	5	6	7	8	9	10
Value of depreciation	33 816	31 618	29 563	27 641	25 845	24 165	22 594	21 126	19 752	18 468
Year	11	12	13	14	15	16	17	18	19	20
Value of depreciation	17 268	16 146	15 096	14 115	13 197	12 340	11 538	10 788	10 086	9 431

The method of reduced balance allows you to write off most of the value of the object at the beginning of operation, which also correctly reflects the economic sense of calculating depreciation. Indeed, almost any object loses its value most quickly at the beginning of use. This happens not only due to physical wear and tear, but also due to obsolescence.

7.3.5 Discount rate

The discount rate is used for calculation the present value of future cash flows. The cost of capital is the minimum rate that let to justify the value of a new enterprise. Many companies use the weighted average cost of capital (WACC) as the discount rate. The discount rate is usually has higher value due to taking into consideration risk premium. The cost of capital shows the level of return on invested capital

necessary to ensure the maximum market value of the company. The weighted average cost of capital organization integrates information about the specific composition of the elements of the capital. It determines the relative level of expenses (in the form of interest payments, dividends etc.) for the use of financial resources invested in the activities of the enterprise. This indicator characterizes the balance of the debt, if the company will send all its available money to pay off debts [29].

The PJSC ALROSA has debt that is way the more appropriate way is to use WACC as a discount rate. The using of WACC let to get more proper results. The use of R_e as a discount rate would be acceptable, if the company did not have debts.

CAPM model

The discount rate is the rate of return used to discount future cash flows to their present value. This value was calculated using CAPM model. It is an idealized depiction of how financial markets value securities and thereby determine the expected return on capital investment. The model provides a methodology for quantifying risk and translating this risk into an estimate of the expected return on equity [29].

$$E(R_i) = R_f + \beta(E(R_m) - R_f),$$

Where

R_f – risk-free rate (6,58%) [31]

β – beta ratio of stocks, for Metals and Mining sector this value is equal to 1.31 [30];

$E(R_i)$ – expected market risk premium (10,04%) [33];

$$E(R_i) = R_f + \beta(E(R_m) - R_f) = 6.58 + 1.31 \cdot 10.04 = 19.73\%$$

Weighted average cost of capital for PJSC ALROSA

Weighted average cost of capital (WACC) - This is the average interest rate for all sources of financing a company. The indicator characterizes the relative level of the total cost of providing each source of financing and represents the weighted average cost of capital. WACC characterizes the cost of capital in the same way as the bank interest rate - the cost of attracting a loan. Only in contrast to the bank rate, the weighted average cost of capital does not imply uniform payments, but requires that the investor's total present income be the same as would ensure uniform payment of interest at a rate equal to WACC. That is, the weighted average cost of capital characterizes the minimum acceptable rate of return on investment [29].

The weighted average cost of capital is defined as the sum of the indicator of the cost of borrowed funds multiplied by their share in the structure of total capital and the indicator of the cost of equity, multiplied also by their share in the structure of total capital [29]:

$$WACC = \frac{E}{D+E} \cdot r_e + \frac{D}{D+E} \cdot r_d \cdot (1 - tax) = \frac{247,6}{164,9 + 247,6} \cdot 19,73\% + \frac{130,7}{164,9 + 247,6} \cdot 7,82\% \cdot (1 - 20\%) = 13,85\%,$$

where

E – Market value of the firm's equity [32];

D – Market value of the firm's debt [32];

r_e – Cost of equity from CAPM model;

r_d – Cost of debt [32].

Invested money should give no less than 13,85 % per annum on the amount of investments if we want to provide the required return on equity and pay the bank on borrowed funds. That is why when investment projects are considered and calculate the return on investment, in most cases WACC is chosen as a discount indicator. If the NPV of the project with the calculated WACC (as a discount) is more than zero, then the project is effective and we can invest in it. If below zero, then there is no point in doing this project - we will not be able to pay the bank and secure the required profitability.

8. ECONOMIC EVALUATION OF SUGGESTED MEASURES USING DISCOUNT RATE BASED ON CAPM MODEL

8.1 Net present value

During implementation the economic estimation of suggested measures, the following indicators will be considered:

- Net present value (NPV);
- Internal Rate of return (IRR);
- Profitability index (PI);
- Payback period (PP);

Net present value is the sum of the discounted values of the payment reduced to today. NPV is the difference between all cash inflows and outflows reduced to the current point in time (the moment the investment project is evaluated). It shows the amount of cash that the investor expects to receive from the project, after the cash inflows will pay back its initial investment costs and periodic cash outflows associated with the implementation of the project [27].

$$NPV = \sum_{t=1}^T \frac{CF_t}{(1+r)^t} - INV,$$

where

CF_t – cash flow in the period t ;

r – discount rate;

INV – initial investment in the project;

t – number of time periods;

T – lifetime of the project.

The investment is effective with a positive NPV. The concept of net present value (NPV) is widely used in investment analysis to evaluate various types of investments.

The several cases were considered during calculation implementation. First of all, the pumps consumption without any measures. The NPV was equal to $NPV = -125\,340\,158$ ₺. After that, the situation for PTS without compensating devices was considered.

The second part of calculation connected with NPV was about installing of VFD and their influences on saved energy for pump units working and as a result final payment for electricity. The same measure was obtained and for PTS working but using capacitor banks. The same value of tariff was used for all cases. After that the positive value of saved energy for installing capacitor banks and for variable frequency drive were considered.

According to final results, suggested measures let to save amount of money such as these measures imply decreasing of consuming. The final results of NPV calculation were illustrated on the table.

Table 17 – NPV according to different measures using CAPM result as a discount rate

Case description	NPV
Saving energy from using CB	1 465 485 ₺
Saving energy from using VFD	5 943 232 ₺

The installing Variable frequency drives let us to save the big amount of energy of industrial enterprise. The energy price is quite high, that is way it reflect the savings in money and make the process of ore-dressing cheaper. The NPV value as a result of saving energy due to installing Variable frequency drive is 5 943 232 rubles.

The installing of Capacitor banks also lead to decreasing of energy consumed amount and, as a result, decreasing of payment from the enterprise to the distributed organization. The NPV value as a result of saving energy due to installing Capacitor banks is 1 465 485 rubles.

As we can see, the proposed measures reduce the amount of electricity consumed. In addition, as a result, reduce the payment for electricity. All NPV calculations are presented in Appendices.

The Cash flow of saved energy and, as a result, saved money after supposed measures was plotted for both cases. The Cash flow is an ongoing process. Cumulative cash flow is net cash flow over an extended cycle.

This project also gain the positive NPV but starting from the first year such as this measure is very profitable as from technological point of view, as from economic point of view.

8.2 Internal rate of return

The internal rate of return is the amount of interest rate when the present value of future cash receipts and the cost of the initial investment are equalized; the net present value is zero. The IRR determines the maximum cost of capital at which the investment project remains profitable. In another formulation, this is the average return on invested capital provided by this investment project, i.e. the effectiveness of capital investments in this project is equal to the efficiency of investing under IRR percent in any financial instrument with a uniform income.

$$\sum_{t=1}^T \frac{CF_t}{(1 + IRR)^t} = 0,$$

where

CF_t – cash flow in the period t ;

IRR – Internal Rate of Return (discount rate) [29].

In this case, the Cash flow is negative as there is payments for electricity consumption.

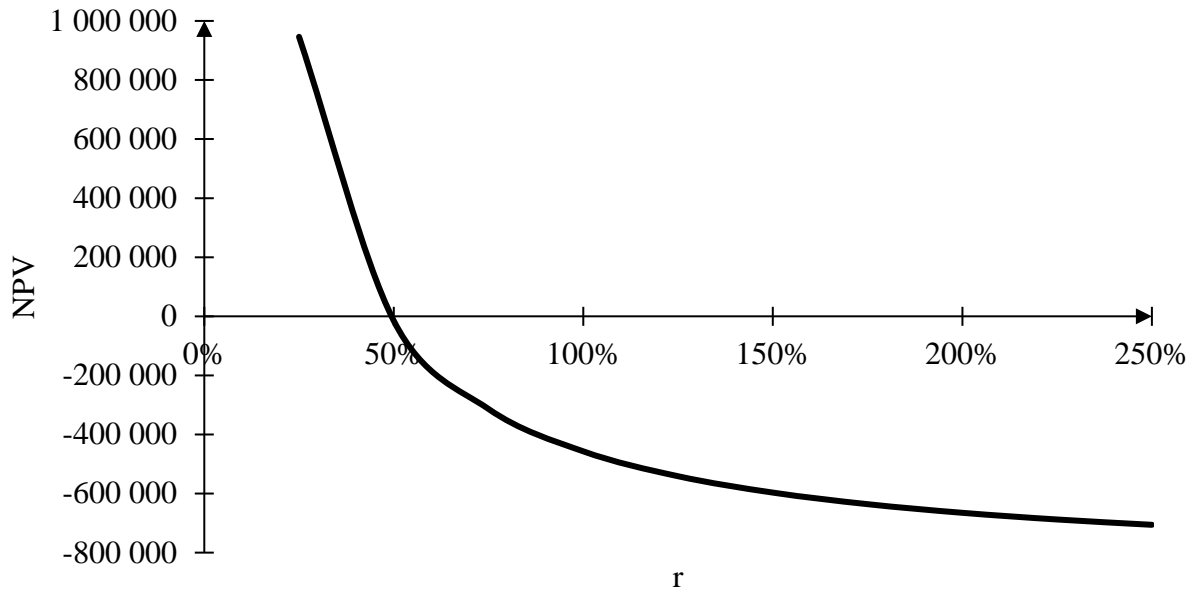


Figure 28 – IRR of the project with CB installation

In this case, the value of IRR is closer to 50%. This allows us to say that the project is profitable. The IRR of the second project is equal to 80%. This value correspond to highly profitable project.

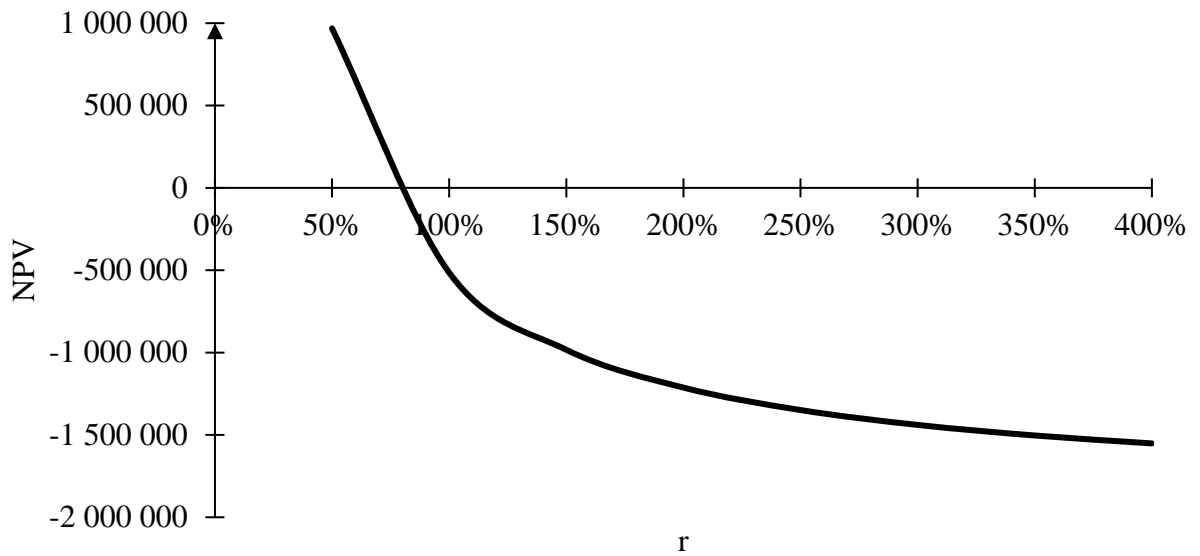


Figure 29 –IRR of the project with VFD installation

8.3 Profitability index

The profitability index (or profitability) is an important financial indicator that determines the return on investment. It is used to identify the effectiveness of the turnover of funds, calculate their quantitative increase or decrease.

$$PI = \frac{\sum_{t=1}^T (CF_t / (1+r)^t)}{INV}$$

The indicator can take three options:

1. $PI > 1$. In this case, the project is potentially or really effective.
2. $PI = 1$. The project is neutral, in this case, the company's actions can be aimed at its implementation if it has other obvious benefits, for example, it raises the status of the company, makes it possible to use any benefits and leads to an increase in production volumes.
3. $PI < 1$. In this case, the project is not effective [37].

The two type of investments were considered: installing of capacitor banks and Variable frequency drive.

As a result of Capacitor bank installing, the profitability index:

$$PI = \frac{\sum_{t=1}^T (CF_t / (1+r)^t)}{INV} = \frac{2\,330\,736}{345\,000 + 520\,251} = 2.69$$

Based on this value, the project is potentially or really effective.

As a result of Variable frequency drive installing, the profitability index:

$$PI = \frac{\sum_{t=1}^T (CF_t / (1+r)^t)}{INV} = \frac{7\,827\,020}{450\,000 + 1\,433\,787} = 4.15$$

Based on this value, this project is also potentially or really effective.

8.4 Payback period

This is the minimum period of time for the return of invested funds in an investment project, business or any other investment. The payback period is a key indicator of assessing the investment attractiveness of a business plan, project and any other investment object. The payback period of an investment project is the ratio of the initial investment in the project to the average annual return on the project.

$$\sum_{t=0}^{PP} CF_t = 0,$$

where

CF – cash flow during the considered period [38].

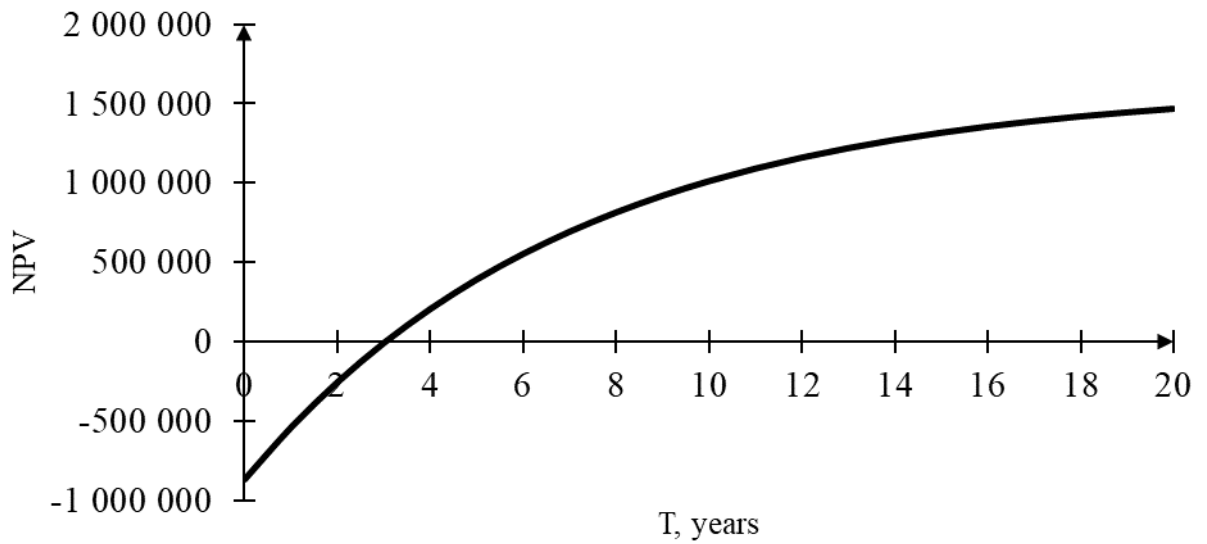


Figure 30 – NPV of saved energy after installing Capacitor banks

This NPV graph illustrates the ability for gain positive NPV after time less than four year. The project lead to saving money during all lifetime of this kind of equipment. The payback period based on the graph for project with Capacitor banks installing is equal to 3 years.

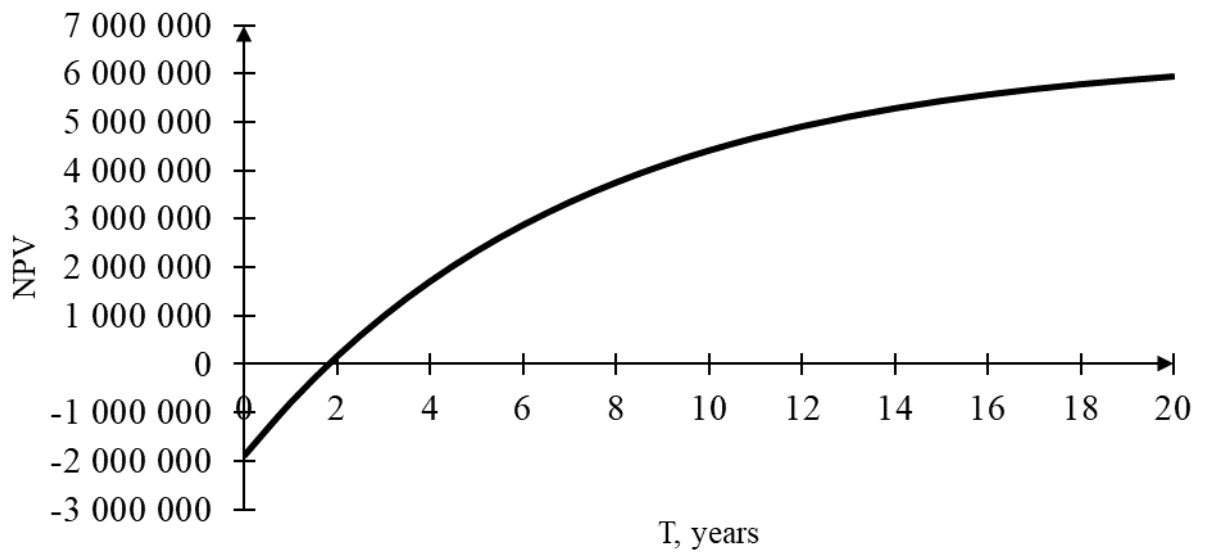


Figure 31 – NPV of saved energy after installing VFD

. The payback period based on the graph for project with VFD installing is equal to 2 years.

9. ECONOMIC EVALUATION OF SUGGESTED MEASURES USING PARAMETER WACC

9.1 Net present value

The NPV as a result of discounting by WACC parameters were considered. The results of calculation are presented in the table:

Table 18 – NPV according to different measures using WACC as a discount rate

Case description	NPV
Saving energy from using CB	2 441 746 ₺
Saving energy from using VFD	9 223 964 ₺

In case of using WACC parameter, the NPV is increase such as the discount factor is decrease. Nevertheless, in this situation the results show the savings of energy as a result of implementation of both projects. These changes allow to unload the equipment, improve the technological process and save money on electricity bill.

9.2 Profitability index

Profitability index for both cases also was recalculated based on WACC parameters. The following calculation are presented bellow:

As a result of Capacitor bank installing, the profitability index:

$$PI = \frac{\sum_{t=1}^T (CF_t / (1+r)^t)}{INV} = \frac{3\,306\,997}{345\,000 + 520\,251} = 3.82$$

Based on this value, the project is potentially or really effective.

As a result of Variable frequency drive installing, the profitability index:

$$PI = \frac{\sum_{t=1}^T (CF_t / (1+r)^t)}{INV} = \frac{11\,107\,752}{450\,000 + 1\,433\,787} = 5.9$$

Based on this value, this project is also potentially or really effective. Profitability index as a result of using WACC are higher in comparison with using the discount rate as a result of CAPM model. This valuation method is expressed in relative units.

9.3 Payback period

The payback period using WACC parameter are also considered.

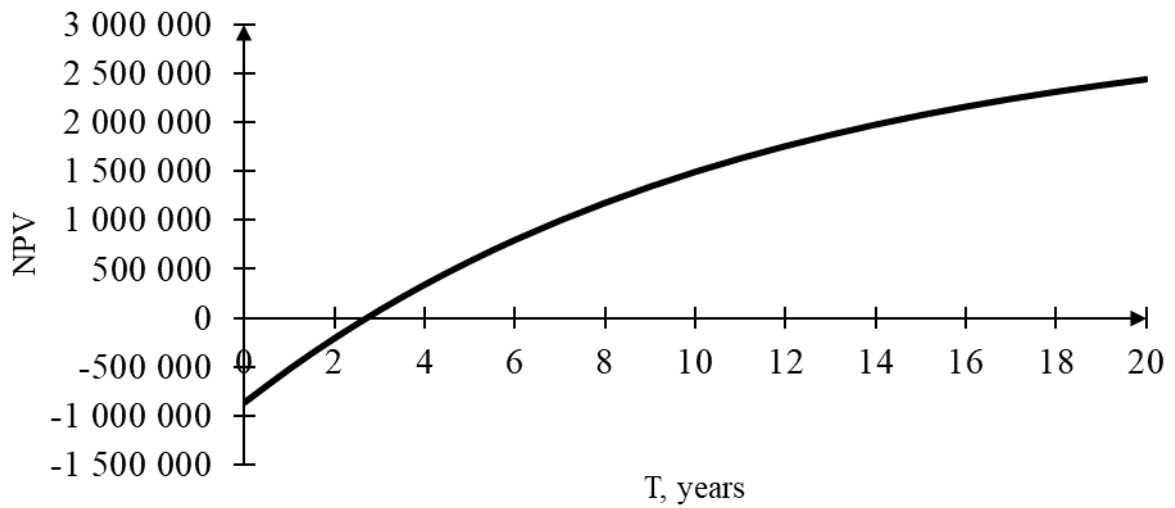


Figure 32 – NPV of saved energy after installing Capacitor banks

The project with Capacitor banks implementation reach to getting positive NPV values after two years of using

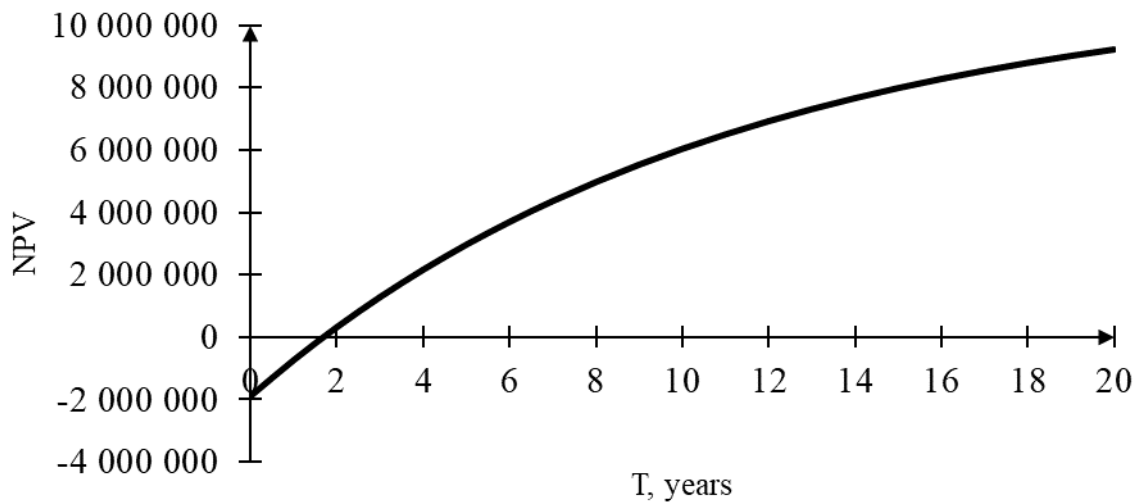


Figure 33 – NPV of saved energy after installing VFD

The project with VFD implementation reach to getting positive NPV values after first years of using. These results correspond to the literature review about consequences of VFD using. This measure is quite effective and let to save a big amount of energy.

As we can see from the calculation, using WACC allows to get more accurate results for this enterprise. Using WACC as a discount factor allows you to adequately evaluate the cost of project taking into account information about debts which company has now. In another case, if the company had no debts, it would be appropriate to use R_e as discount rate.

10. SENSITIVITY ANALYSIS

Sensitivity analysis of an investment project is an assessment of the impact of changes in the initial parameters of an investment project (investment costs, cash inflows, discount rate, operating expenses, etc.) on its final characteristics, which are usually used as IRR or NPV.

In the course of analyzing the sensitivity of an investment project, the initial parameters (indicators) are first determined by which the sensitivity of the investment project is calculated. Then carry out a sequentially single change of each selected indicator.

The relative change in the criterion with respect to the base case is evaluated and the sensitivity indicator is calculated. The sensitivity indicator is the ratio of the percentage change in the criterion to the change in the value of the variable by the predicted percentage (elasticity of the change in the indicator). Similarly, sensitivity indicators are calculated for each of the remaining selected variables.

At the next stage, using the results of the calculations performed, the parameters are ranked according to the degree of importance (for example, very high, medium and low) and an expert assessment of the predictability (predictability) of the indicator values (high, medium or low) is also carried out.

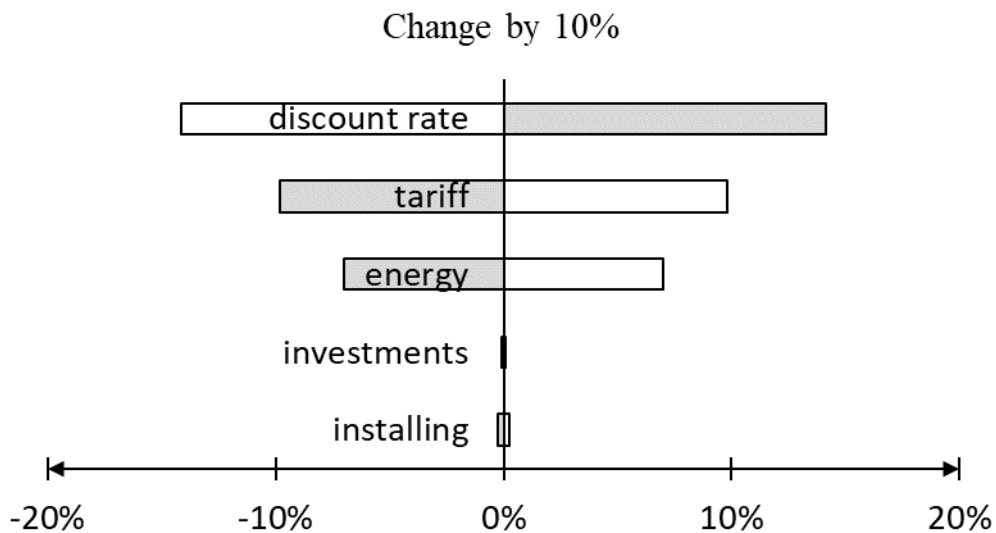


Figure 34 – Tornado diagram for VFD installing project

According to Tornado diagram, the project is quite sensitive to the change of discount rate. The second one place is correspond to the tariff changes, this result is logical, such as considered enterprise is very energy consumed. The payment for electricity is one of tremendous expenditures for them. The energy amount is correspond to the final amount of payment. The dependence is linear – more consuming, more money need to pay for electricity. Investments and installing are also influenced but in less amount.

The second Tornado diagram was built for Capacitor banks installing project.

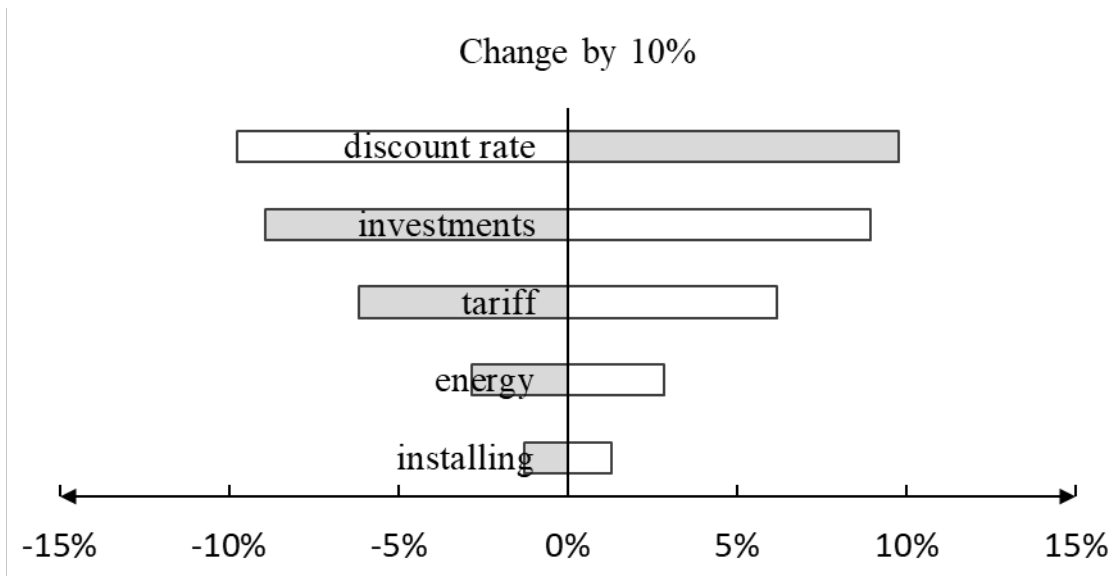


Figure 35 – Tornado diagram for Capacitor banks installing project

The indicators were the same as in the previous example. The project is more sensitive to the discount rate changes. Investments in this project are bigger so their influence now is brighter than in previous one project. The tariff and energy are also make sense on this project NPV because of their linear influence on the final payment.

CONCLUSION

In this final work, the goal was to estimate effectiveness of equipment usage in the technological process of Aikhal mining and processing plant. This enterprise is subsidiary of PJSC ALROSA.

The first step during implementation of this work was to collect necessary technical information from this company. The results was obtained in the form of data array.

The second step was to prepare energy audit and interpret results. The following activities are carried out during the energy survey (energy audit): energy monitoring - tracking established and actual parameters of energy consumption; measurements – with the help of special instruments (measuring instruments, accounting devices) of parameters at control points. The following technical indicators of power quality were analyzed and estimated based on normative documentation of Russian Federation – the value of the active and reactive power in the system, evaluation of the power factor for each transformer substation, calculation of the power transformers load factor, displacement power factor analysis, evaluation of the additional power losses caused by the asymmetry of the current, estimation of steady-state voltage deviation and etc. The actual load characteristic can be obtained using recording devices that record changes in the corresponding parameter over time. This information helps us to understand how each transformer is loaded and to choose correctly capacitor banks.

The following step was to suggest measures for increasing efficiency. The first one was to install capacitor banks at low side for decreasing the power losses and also decrease the amount of reactive. The second one was to use Variable frequency drive for pump units with the goal to reduce inrush currents and adjust the power consumption of the motor depending on the actual load.

The next step was to evaluate economic efficiency of proposed technical improvements. The initial economic data were obtained – the target inflation (4%), the discount rate (19.73%) based on CAPM model, the WACC value of the whole ALROSA (13.85%). The amount of investments was evaluated for both projects. The Capacitor banks installing contributes 520 252 rubles for equipments, the installing of Variable frequency drive contributes 1 433 787 rubles. The amount of depreciation was also considered. The method of reduced balance allows you to write off most of the value of the object at the beginning of operation.

The economic calculation was prepared using discount rate based on CAPM model and WACC. The using of discount rate shows the following results. The both cases show us ability to decreasing bill for electricity. The NPV value as a result of saving energy due to installing Capacitor banks is 1 465 485 rubles. The payback period for Capacitor banks installing equal to 3 years, the profitability index is 2.69, the IRR value is equal to 50%. The NPV value as a result of saving energy due to installing Variable frequency drive is 5 943 232 rubles. The payback period equal to 2 years, the profitability index is 4.15, The IRR value is equal to 80%.

The usage of WACC shows the following results. The NPV value as a result of saving energy due to installing Capacitor banks is 2 441 746 rubles. The payback period for Capacitor banks installing equal to 3 years, the profitability index is 3.82. The NPV value as a result of saving energy due to installing Variable frequency drive is 9 223 964 rubles. The payback period equal to 2 years, the profitability index

is 5.9. In this case, using WACC is more proper as PJSC ALROSA has debt. The both cases also show us ability to decreasing bill for electricity.

The IRR value shows that both projects are highly profitable. The payback period is quite short for both projects. The profitability indexes show that both projects are effective.

The sensitivity analysis was also prepared for both projects. The Variable frequency drive installing project are the most sensitive to the changing of discount rate, tariff, and energy. The Capacitor banks installing project are the most sensitive to the changing of discount rate, investments, tariff, and energy.

Finally, it can be concluded that both projects are profitable and suggested for implementing in Aikhal mining and processing plant. The proposed activities have a positive impact on the enterprise both from a technical point of view and from an economic.

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APPENDICES

Appendix 1 – Summarizing of energy audit results

Investigated parameter	Standard value or description of influence	Measurement/calculation result	Necessity of carriage preventing measures	Proposed measures
Power factor, $\cos\phi$	Power factor must be about 0,9 for the more efficiency of equipment	PTS 1(1) – 0,893 PTS 1(2) – 0,731 PTS 2(1) – 0,584 PTS 2(2) – 0,32 PTS 3(1) – 0,747 PTS 3(2) – 0,689 PTS 4(1) – 0,584 PTS 4(2) – 0,32	+	Installing capacity banks. Reduced reactive power allows more efficient use of electricity Power factor after installing capacity banks: PTS 1(1) – 0,893 PTS 1(2) – 0,91 PTS 2(1) – 0,89 PTS 2(2) – 0,91 PTS 3(1) – 0,89 PTS 3(2) – 0,89 PTS 4(1) – 0,89 PTS 4(2) – 0,91 <i>My suggestion for economic part:</i> <ul style="list-style-type: none"> ○ economic effect calculation of the capacitor units installation; ○ the price of installing capacitor banks.
Displacement power factor, $\text{tg}\phi$	The value of the reactive power coefficient during hours of large daily loads of the electric network ($\text{tg}\phi$) is set depending on the nominal voltage of the network to which the consumer is connected. 110 kV – $\text{tg}\phi=0,5$ 35 kV - $\text{tg}\phi=0,4$ 6-20 kV - $\text{tg}\phi=0,4$ 0,4 kV - $\text{tg}\phi=0,35$	PTS 1(1) – 0,43 PTS 1(2) – 0,98 PTS 2(1) – 0,74 PTS 2(2) – 3,01 PTS 3(1) – 0,96 PTS 3(2) – 1,18 PTS 4(1) – 0,98 PTS 4(2) – 0,74	+	Installing capacity banks. The influence of installing capacity bank shares two aspects such as power factor($\cos\phi$) and displacement power factor ($\text{tg}\phi$) The bank capacity for each PTS: PTS 1(1) – no need PTS 1(2) – 100 kVAr PTS 2(1) – 100 kVAr PTS 2(2) – 325 kVAr PTS 3(1) – 100 kVAr PTS 3(2) – 150 kVAr PTS 4(1) – 100 kVAr PTS 4(2) – 325 kVAr

Utilization rate, β	Utilization rate in normal mode for consumers of the first category should be no more than $0.65 \div 0.7$	PTS 1(1) – 0,359 PTS 1(2) – 0,294 PTS 2(1) – 0,207 PTS 2(2) – 0,419 PTS 3(1) – 0,364 PTS 3(2) – 0,402 PTS 4(1) – 0,207 PTS 4(2) – 0,419	-	
Active losses in power lines, kW		PTS 1(1) – 0,315 PTS 1(2) – 0,175 PTS 2(1) – 0,12 PTS 2(2) – 0,396 PTS 3(1) – 0,358 PTS 3(2) – 0,37 PTS 4(1) – 0,128 PTS 4(2) – 0,507	Insignificant	
Reactive losses in power lines, kVAr		PTS 1(1) – 0,081 PTS 1(2) – 0,04 PTS 2(1) – 0,028 PTS 2(2) – 0,091 PTS 3(1) – 0,079 PTS 3(2) – 0,085 PTS 4(1) – 0,018 PTS 4(2) – 0,069	Insignificant	
Coefficient of additional losses, k_{add}	This ratio is taken into account when the value is higher than 1.15. The values of additional power losses in individual elements of the distribution network that arise as a result of asymmetry allow us to estimate their total value and determine the economic damage caused by the decrease in the quality of electric energy. All this is	PTS 1(1) – 1,001493 PTS 1(2) – 1,01004 PTS 2(1) – 1,000189 PTS 2(2) – 1,000179 PTS 3(1) – 1,001366 PTS 3(2) – 1,001395 PTS 4(1) – 1,000189 PTS 4(2) – 1,000179	-	

	necessary for preliminary calculations of the economic feasibility of applying measures to improve the quality of electric energy.			
Voltage deviation, %	± 10%	PTS 1(1) – 2,65 PTS 1(2) – 0,77 PTS 2(1) – 4,38 PTS 2(2) – 1,6 PTS 3(1) – 3,19 PTS 3(2) – 0,97 PTS 4(1) – 4,38 PTS 4(2) – 1,6	-	
Energy efficiency of pumping units	<p><i>Goal:</i> reduction of energy consumption</p> <p><i>Solutions:</i> The basic element that provides pump functionality is an electric motor. The energy flow of a substance held back by a valve is lost without doing any useful work at the process of throttling. The use of an inverter as part of a pumping unit or fan allows you to set the required pressure or flow rate. It will provide not only energy savings but also a decrease in losses of the transported substance.</p> <p><i>My suggestion for economic part:</i></p> <ul style="list-style-type: none"> ○ determine the payback period of Frequency drive regulation; ○ capital investment for installing Frequency drive regulation; 			

Appendix 2 – Using pump units without any additional equipment

Year	1	2	3	4	5	6	7	8	9
Energy payment+Escalation	3 800 195	3 952 203	4 110 291	4 274 703	4 445 691	4 623 518	4 808 459	5 000 797	5 200 829
EBT	-3 800 195	-3 952 203	-4 110 291	-4 274 703	-4 445 691	-4 623 518	-4 808 459	-5 000 797	-5 200 829
Tax (20%)	-760 039	-790 441	-822 058	-854 941	-889 138	-924 704	-961 692	-1 000 159	-1 040 166
EAT	-3 040 156	-3 161 762	-3 288 233	-3 419 762	-3 556 553	-3 698 815	-3 846 767	-4 000 638	-4 160 663
DCF	-2 539 176	-2 205 582	-1 915 815	-1 664 117	-1 445 487	-1 255 581	-1 090 624	-947 339	-822 879

10	11	12	13	14	15	16	17	18	19	20
5 408 862	5 625 217	5 850 226	6 084 235	6 327 604	6 580 708	6 843 937	7 117 694	7 402 402	7 698 498	8 006 438
-5 408 862	-5 625 217	-5 850 226	-6 084 235	-6 327 604	-6 580 708	-6 843 937	-7 117 694	-7 402 402	-7 698 498	-8 006 438
-1 081 772	-1 125 043	-1 170 045	-1 216 847	-1 265 521	-1 316 142	-1 368 787	-1 423 539	-1 480 480	-1 539 700	-1 601 288
-4 327 090	-4 500 174	-4 680 180	-4 867 388	-5 062 083	-5 264 567	-5 475 149	-5 694 155	-5 921 921	-6 158 798	-6 405 150
-714 770	-620 864	-539 296	-468 443	-406 900	-353 442	-307 007	-266 673	-231 638	-201 205	-174 771

NPV= -18 171 609 RUB.

Appendix 3 - Using PTS without any additional equipment

Year	1	2	3	4	5	6	7	8	9
Energy+Escalation	990 712	1 030 340	1 071 554	1 114 416	1 158 993	1 205 353	1 253 567	1 303 709	1 355 858
EBT	-990 712	-1 030 340	-1 071 554	-1 114 416	-1 158 993	-1 205 353	-1 253 567	-1 303 709	-1 355 858
Tax (20%)	-198 142	-206 068	-214 311	-222 883	-231 799	-241 071	-250 713	-260 742	-271 172
EAT	-792 570	-824 272	-857 243	-891 533	-927 194	-964 282	-1 002 853	-1 042 968	-1 084 686
DCF	-661 964	-574 996	-499 454	-433 836	-376 839	-327 330	-284 326	-246 972	-214 525

10	11	12	13	14	15	16	17	18	19	20
1 410 092	1 466 496	1 525 156	1 586 162	1 649 608	1 715 593	1 784 216	1 855 585	1 929 808	2 007 001	2 087 281
-1 410 092	-1 466 496	-1 525 156	-1 586 162	-1 649 608	-1 715 593	-1 784 216	-1 855 585	-1 929 808	-2 007 001	-2 087 281
-282 018	-293 299	-305 031	-317 232	-329 922	-343 119	-356 843	-371 117	-385 962	-401 400	-417 456
-1 128 074	-1 173 197	-1 220 124	-1 268 929	-1 319 687	-1 372 474	-1 427 373	-1 484 468	-1 543 847	-1 605 601	-1 669 825
-186 341	-161 859	-140 595	-122 123	-106 079	-92 142	-80 037	-69 522	-60 388	-52 454	-45 563

NPV= -4 737 344 RUB.

Appendix 4 - Using pump units with VFD

Year	0	1	2	3	4	5	6	7	8	9
Investment	1 433 788									
Depreciation		93 196	87 138	81 474	76 179	71 227	66 597	62 268	58 221	54 437
Installing		450 000								
Service		10 000	10 400	10 816	11 249	11 699	12 167	12 653	13 159	13 686
Maintenance		10 000	10 400	10 816	11 249	11 699	12 167	12 653	13 159	13 686
Energy+Escalation		2 158 100	2 244 424	2 334 201	2 427 569	2 524 672	2 625 658	2 730 685	2 839 912	2 953 509
EBT		-2 271 296	-2 352 362	-2 437 307	-2 526 245	-2 619 296	-2 716 589	-2 818 260	-2 924 452	-3 035 317
Tax (20%)		-454 259	-470 472	-487 461	-505 249	-523 859	-543 318	-563 652	-584 890	-607 063
EAT		-1 817 037	-1 881 890	-1 949 846	-2 020 996	-2 095 437	-2 173 271	-2 254 608	-2 339 561	-2 428 253
CF	- 1 433 788	-1 723 841	-1 794 751	-1 868 371	-1 944 817	-2 024 210	-2 106 674	-2 192 339	-2 281 340	-2 373 817
DCF		-1 439 773	-1 251 983	-1 088 565	-946 383	-822 698	-715 121	-621 565	-540 215	-469 484

10	11	12	13	14	15	16	17	18	19	20
50 898	47 590	44 497	41 604	38 900	36 371	34 007	31 797	29 730	27 798	25 991
14 233	14 802	15 395	16 010	16 651	17 317	18 009	18 730	19 479	20 258	21 068
14 233	14 802	15 395	16 010	16 651	17 317	18 009	18 730	19 479	20 258	21 068
3 071 649	3 194 515	3 322 296	3 455 187	3 593 395	3 737 131	3 886 616	4 042 081	4 203 764	4 371 914	4 546 791
-3 151 014	-3 271 710	-3 397 581	-3 528 812	-3 665 596	-3 808 136	-3 956 642	-4 111 337	-4 272 452	-4 440 228	-4 614 919
-630 203	-654 342	-679 516	-705 762	-733 119	-761 627	-791 328	-822 267	-854 490	-888 046	-922 984
-2 520 811	-2 617 368	-2 718 065	-2 823 050	-2 932 477	-3 046 509	-3 165 314	-3 289 070	-3 417 962	-3 552 183	-3 691 935
-2 469 913	-2 569 778	-2 673 568	-2 781 446	-2 893 577	-3 010 137	-3 131 306	-3 257 273	-3 388 231	-3 524 385	-3 665 944
-407 992	-354 538	-308 074	-267 690	-232 591	-202 088	-175 581	-152 547	-132 532	-115 140	-100 029

NPV= -12 228 377 RUB.

Appendix 5 - Reactive power of PTS was compensated due to using of capacitor banks

Year	0	1	2	3	4	5	6	7	8	9
Investment	520 251									
Depreciation		33 816	31 618	29 563	27 641	25 845	24 165	22 594	21 126	19 752
Installing		345 000								
Service		10 000	10 400	10 816	11 249	11 699	12 167	12 653	13 159	13 686
Maintenance		10 000	10 400	10 816	11 249	11 699	12 167	12 653	13 159	13 686
Energy+Escalation		488 643	508 189	528 517	549 657	571 644	594 509	618 290	643 021	668 742
EBT		-542 460	-560 607	-579 712	-599 796	-620 886	-643 007	-666 190	-690 466	-715 866
Tax		-108 492	-112 121	-115 942	-119 959	-124 177	-128 601	-133 238	-138 093	-143 173
EAT		-433 968	-448 486	-463 769	-479 837	-496 708	-514 406	-532 952	-552 372	-572 693
CF		-400 151	-416 868	-434 206	-452 195	-470 864	-490 241	-510 358	-531 247	-552 940
DCF		-334 212	-290 799	-252 981	-220 046	-191 373	-166 415	-144 695	-125 798	-109 358

10	11	12	13	14	15	16	17	18	19	20
18 468	17 268	16 146	15 096	14 115	13 197	12 340	11 538	10 788	10 086	9 431
14 233	14 802	15 395	16 010	16 651	17 317	18 009	18 730	19 479	20 258	21 068
14 233	14 802	15 395	16 010	16 651	17 317	18 009	18 730	19 479	20 258	21 068
695 492	723 312	752 244	782 334	813 627	846 172	880 019	915 220	951 829	989 902	1 029 498
-742 427	-770 184	-799 179	-829 451	-861 044	-894 003	-928 378	-964 217	-1 001 574	-1 040 505	-1 081 066
-148 485	-154 037	-159 836	-165 890	-172 209	-178 801	-185 676	-192 843	-200 315	-208 101	-216 213
-593 941	-616 148	-639 343	-663 560	-688 835	-715 203	-742 702	-771 374	-801 259	-832 404	-864 853
-575 473	-598 880	-623 197	-648 464	-674 720	-702 005	-730 363	-759 836	-790 472	-822 317	-855 422
-95 059	-82 624	-71 811	-62 409	-54 235	-47 130	-40 953	-35 585	-30 920	-26 865	-23 341

NPV= -3 271 859 RUB.