CSITA
ISSN 2414-9055

UDC 62.314
https://doi.org/10.31721/2414-9055.2018.4.1.13

USAGE OF HYDRO-ACCUMULATING INSTALLATIONS IN THE POWER SUPPLY SYSTEM OF MINING COMPANIES

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Abstract. Real graphs of electric energy consumption by the mining enterprises of the Kryvyi Rih Iron Ore Basin are analyzed. Uneven consumption levels of this type of energy during the day are confirmed in the article. Significant difference in payment for the energy consumed by the enterprises during a day and at daytime necessitates optimizing electricity consumption at daytime. To date, the possibilities of the enterprises to "equalize" the schedules of electric energy consumption by organizational methods are practically exhausted. The direction of implementing this process is substantiated by using power from additional energy sources in the structure of the power supply systems of iron ore enterprises. It has been established that one of the most significant losses in the consumption of electric energy is the process of pumping water from the underground mines. Water drainage consuming electrical energy in the "peak" and "half-peak" hours makes up to 90% for the individual mines. Hence, hydro-accumulating power stations are proposed to be used as an option for equalizing the schedule of electric power consumption. The analytical review of the usage of the prospective hydro accumulators and high-pressure generators in mining drainage systems, as well as organizational measures to reduce energy consumption and payment for electricity are represented. This system is optimal and can be suggested as one of the ways of energy supply system improvement for the iron ore mines such as "Oktyabrska", "Rodina", "Ternivska", "Hvardiyska" PJSC "Kyvyi Rih Iron Ore Combine". Thus, synchronous generators were implemented as a part of the energy systems for the mentioned iron ore mines. Besides,economy effect formula for using this equipment was determined, as well as an improved schedule of water pumping operation was suggested. Another way for costs optimization is to use synchronous generators as a part of ready-to-use hydrogenerators that were designed for a small electricity plants.

Keywords: electricity, mine, water drainage, hydro accumulators, energy efficiency.

Introduction. The extraction of iron ore in Ukraine has been carried out for almost 200 years in terms of both open-pit mining (career with subsequent enrichment of raw ore at the ore mining enterprises) and underground mining. In the last 7 years, after almost a decade of recession, there is a tendency to increase the output of iron ore materials. Moreover, in certain years, compared to the prior years, ore output has doubled [1]. To date, ore output by open-pit mining exceeds the production in the mines. However, the growth or rather the recovery of the production volume of commodity iron ore by underground in domestic mines is faster than in quarries. This is due to the fact that underground mining, unlike open-pit mining, is characterized by eco-friendlier environmental impact and high iron content in raw ore up to 62%, in contrast to 37% for quarry. This virtually reduces the need for an energy-intensive and time-consuming enrichment process. In Ukraine, commodity iron ore is mined at 11 underground enterprises (mines, mills). Energy consumption represents over 30% of production cost for iron ore by underground mining. In point of fact, unlike other methods of iron ore extraction, electric power accounts for around 90% of the total energy consumed by this method of production electricity (figure 1) [2,3,4]. Figure 2 shows the charts of volumes of energy consumption by a number of domestic underground mining enterprises. As established, the maximum difference for individual mines over the past five years is in the range of 40%. As a rule, the maximum power consumption is in conformity with volume production of iron ore.

Relevance of Research. The by-year analysis reveals a low correlation between iron ore production and amount of electricity consumed, that can be caused both by the technological component, namely, internal factors, and by external factors determining the synergistic components of this process. Contributing factors include volumes of inflow and pumped out water in the underground mine workings, depths of mining, installed electrical power receivers, modes of their operation, etc. [5]. Diagrams of fluctuations in levels of electric energy consumption by consumer types of iron ore enterprises are presented in Fig. 3,4,5,6,7. Having entered the new economic period, iron ore enterprises changed their attitude to the electric power component in economical spheres. Moreover, the enterprises' expenses for electric energy consumption for this period has changed significantly from two-rate tariffs to single-rate with differentiated payment depending on the time of day. Enterprises try to build a daily schedule of electricity consumption mainly in the form of organizational measures [5, 6, 7], so that the most energy-consuming units operate in the night shift like drainage, partially skip rises, while other consumers operate in offpeak time (Fig. 4,5,6,7).

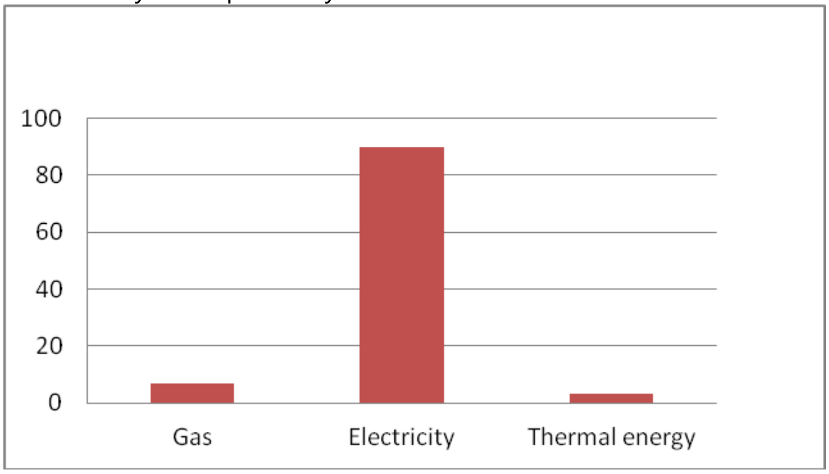
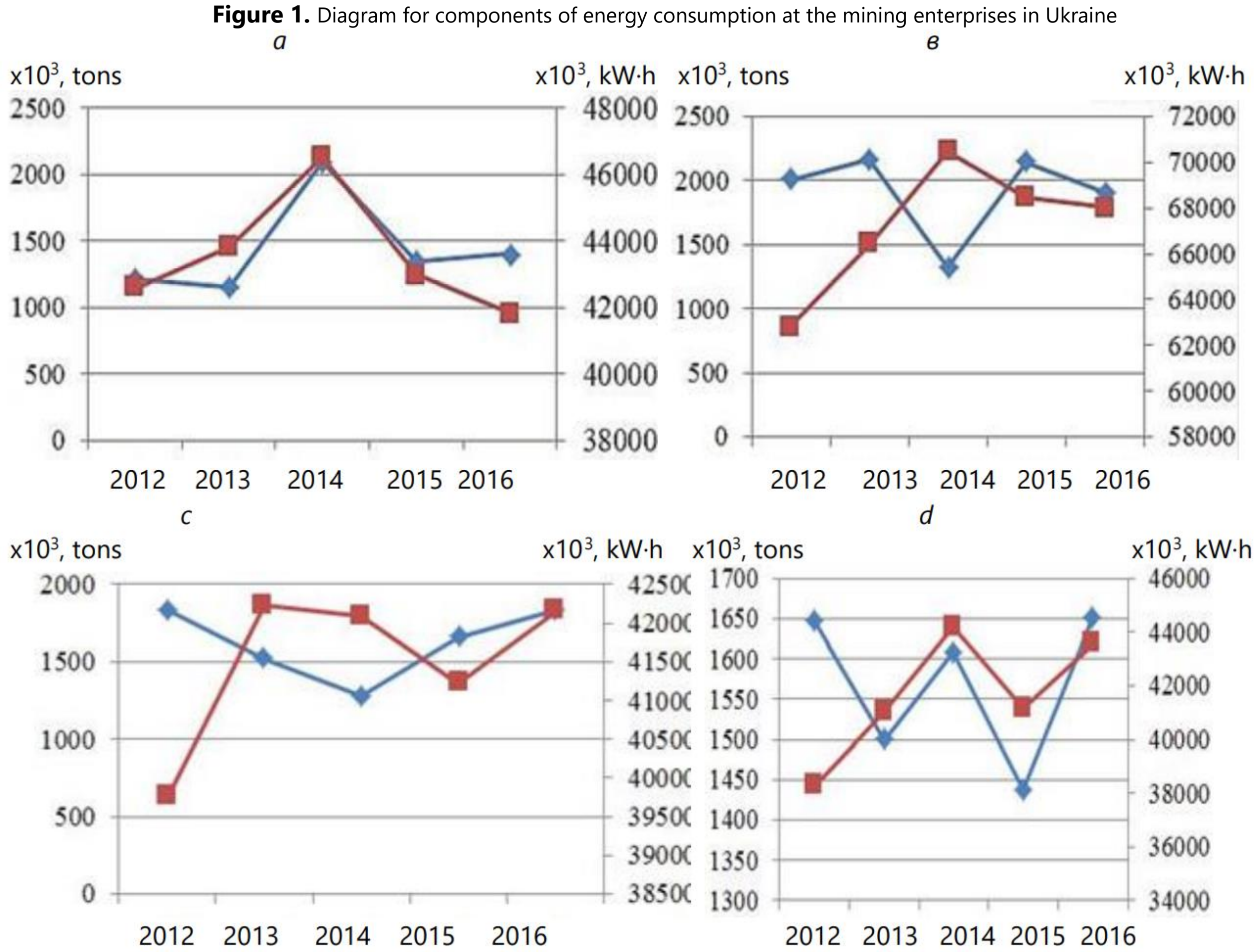


Figure 1. Diagram for components of energy consumption at the mining enterprises in Ukraine



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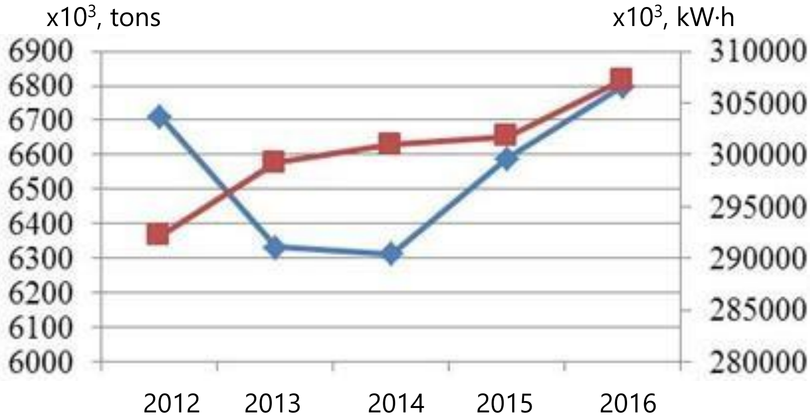


Figure 2. Charts of annual production rate of iron ore raw materials and consumption of electric energy in the mines PJSC "Kryvyi Rig Iron Ore Basin": *a* - The Octyabrska-mine; *b* -The Rodina-mine, *c* - The Ternivska-mine; *d* - The Gvardiyska-mine; *e* - amount of PJSC "Kryvyi Rih Iron Ore Basin" (red line represents amounts of consumed energy in kW·h, blue represents amounts of mined ore in thousands of tons)

Aim of research is to improve the efficiency of electricity consumption in terms of iron ore mines using hydro accumulators equipped with pumps.

Materials and methods. In order to solve the tasks and to analyze the adopted schematic and algorithmic solutions were used the methods as follows: method of mathematical statistics aimed to studying the energy consumption of pumping installations in the mines; methods of electric circuits aimed to calculating the power of hydro generator settings while converting fluid energy of water into electrical energy.

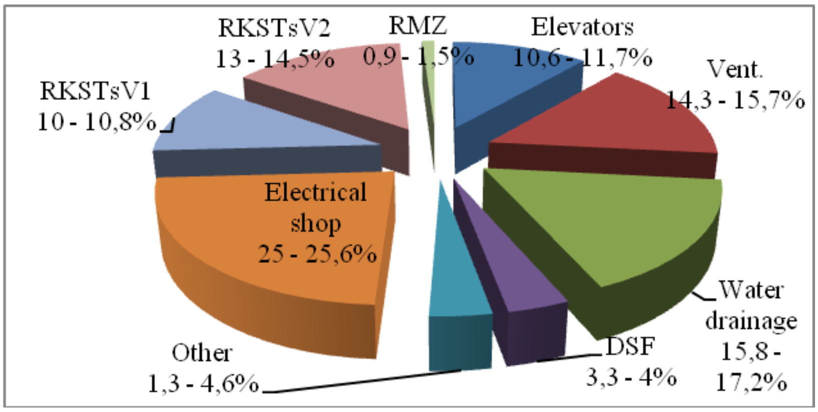


Figure 3. Diagram for levels of electric energy consumption by consumer type of the mining enterprises in Ukraine

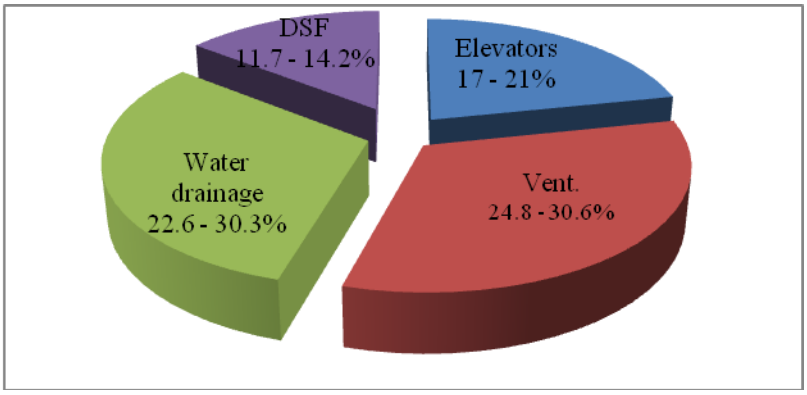


Figure 4. Diagram for levels of electric energy consumption by consumer type of the Octyabrska-mine (Kryvyi Rih)

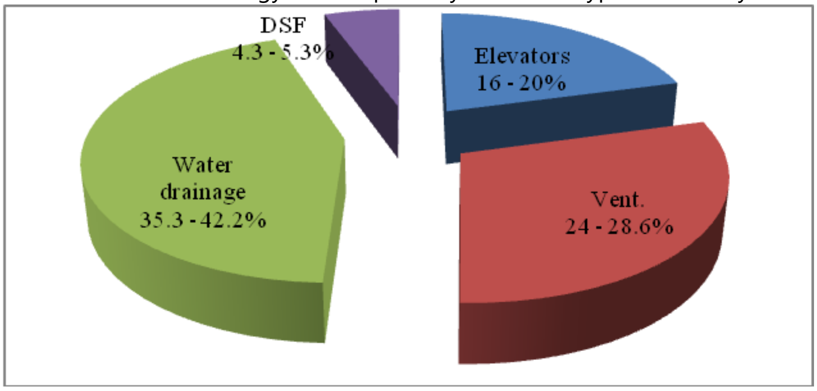


Figure 5. Diagram for levels of electric energy consumption by consumer type of the Rodina-mine (Kryvyi Rih)

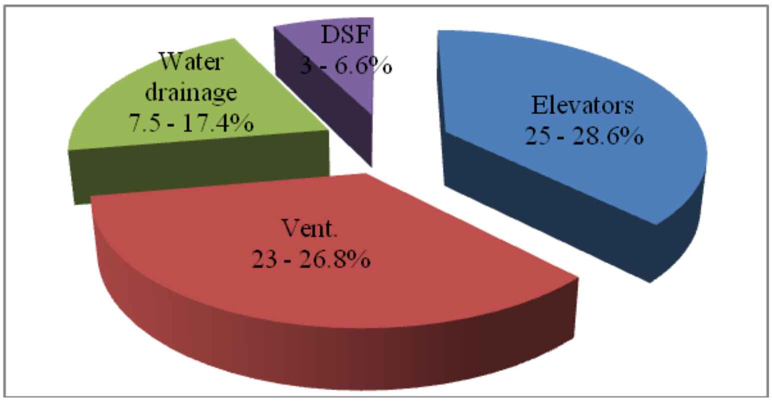


Figure 6 Diagram for levels of electric energy consumption by consumer type of the Hvardiyska-mine (Kryvyi Rih)

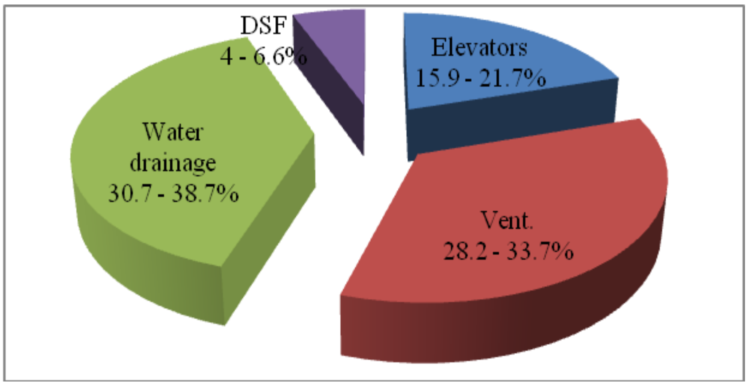
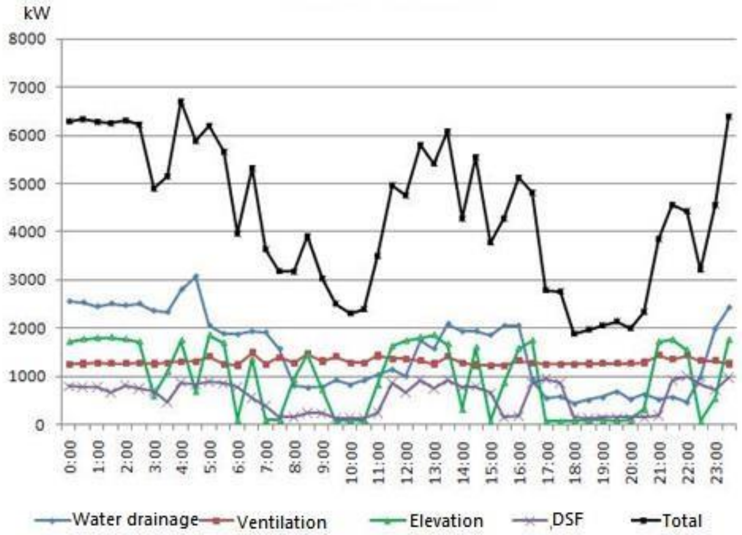


Figure 7. Diagram for levels of electric energy consumption by consumer type of the Ternivska-mine (Kryvyi Rih)

Virtually all of the main mine drainages of Kryvbas (except drainage horizon 940 m of the Rodina-mine and 1115 m of the Octyabrska-mine), operate from 23:00 - 24:00 to 6:00 - 7:00, the rest time they are off. Pumping water from the underground mine horizons is carried out through difficult structure and mode of operation electromechanical hydroelectric complex (Fig. 8). This complexity arises, firstly, from variability of the water influx and volume of water to pump out. Secondly, from the ongoing so-called "wet conservation" of the worked- out mines and "sboyka", i.e. connection horizons of different mines in a single complex. And finally, deepening of mining operations sets the task for choosing sustainable modes of drainage pumps as electromechanical systems forced to operate in a multicriterion algorithm with an unidentified forecast [8,9,10]

a



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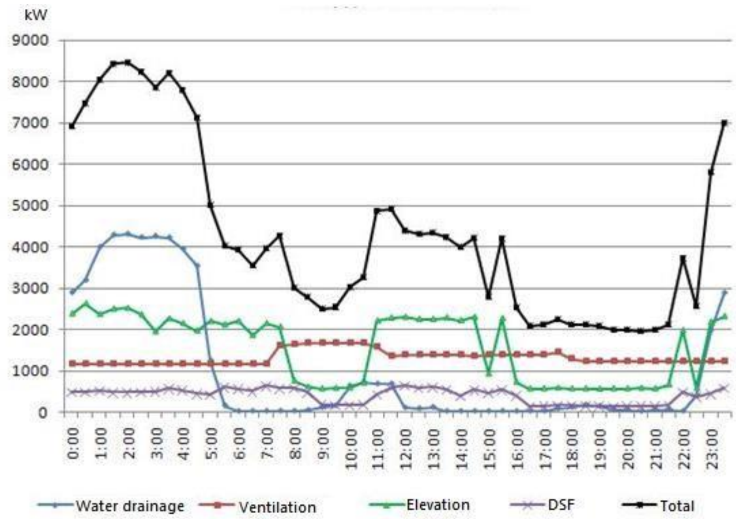

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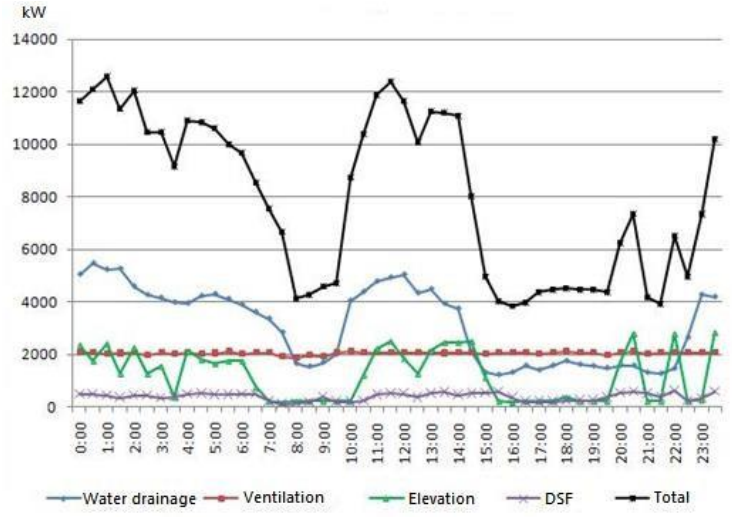

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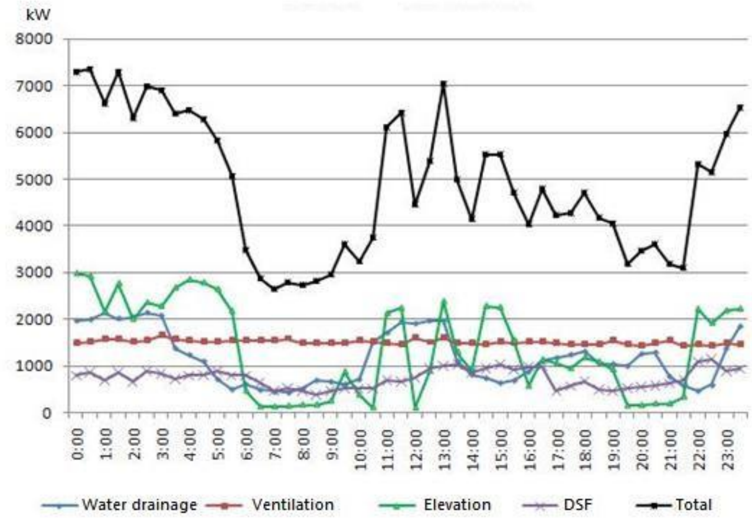

Figure 8. Diagram of daily electricity loads at: *a* - The Ternivska-mine; *b* -The Hvardiyska-mine; *c* - The Rodina-mine; *d* - The Oktyabrska-mine

Fig. 10 shows the daily schedule of power consumption at 30-minute intervals by PJSC "Kryvyi Rih Iron Ore Basin" which confirms the above. As a result of pumping plants working at night-time "zone", electricity consumption makes up 40%, although its duration is 7 hours. Electricity consumption in "half-peak" hours with duration of 11 hours is 38%, and in "peak" hours with a 6hour-duration is 22% (Fig. 11) [11,12,13,14]. Most of the electricity consumption in the hours of "peak" and "half-peak" is going on drainage systems, whose share of individual mines is nearly 90% at night. Drainage installations subdivide to the main (central), auxiliary (local) and temporal. The main installations are intended for interception and pumping all or most of the expected inflow of water to the mines. Long mine fields can be used as several main drainage systems. Usually two or three main drainage installations located on two or three horizons are used in the mines. (Fig. 12).

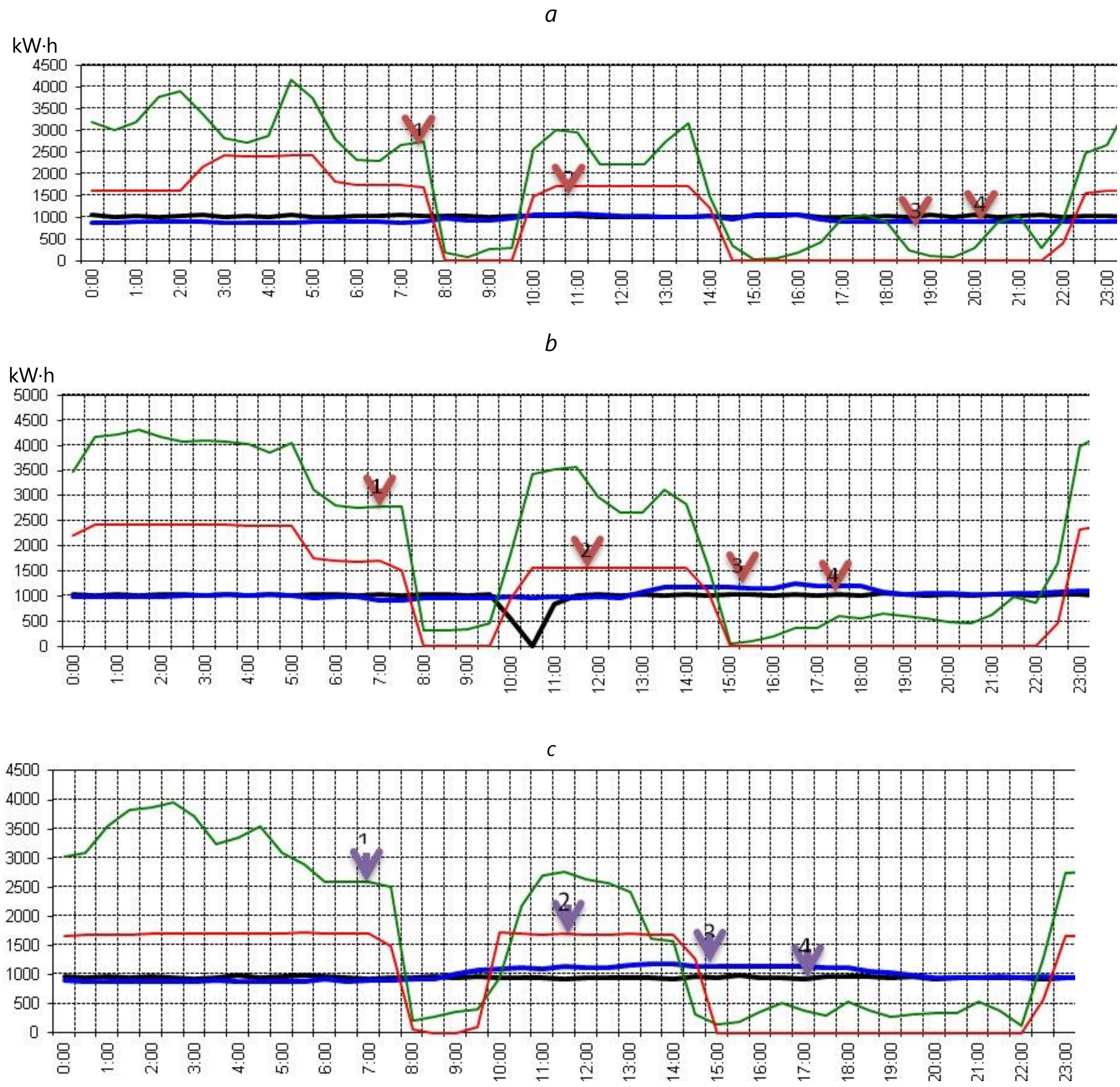

Figure 9. Charts of daily electricity consumption at the Rodina-mine:
a -5.02.2016; *b* -5.02.2015; *c* -5.02.2014 (1 - Water drainage at horizon 940 m; 2 - Water drainage at horizon 500 m; 3 - Northern ventilation; 4 - Southern ventilation)

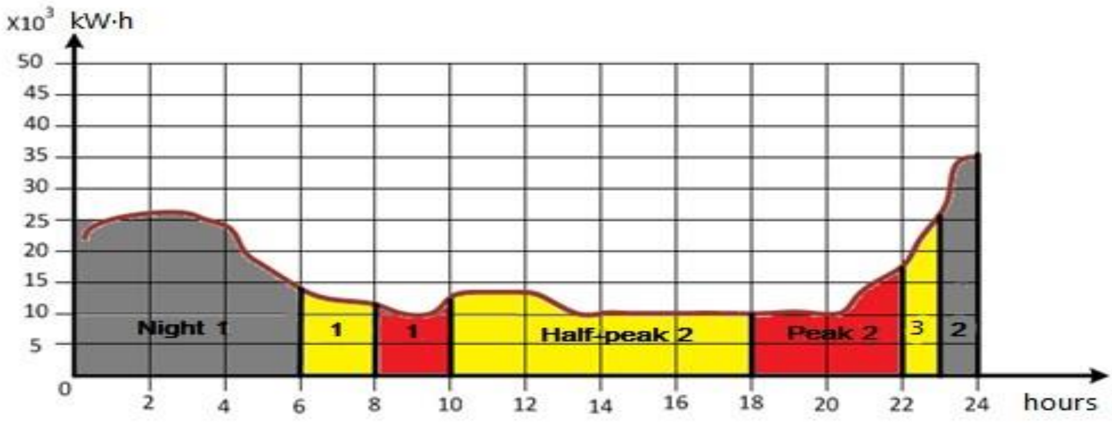

Figure 10. Daily schedule of power consumption at PJSC "Kryvyi Rih Iron Ore Basin"

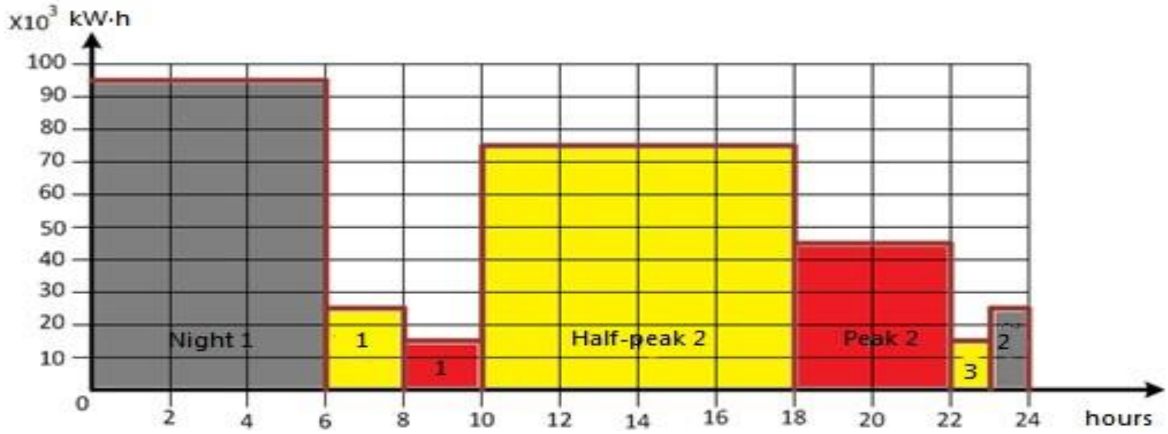

Figure 11. Schedule of electricity consumption by tariff zones of daytime at PJSC "Kryvyi Rih Iron Ore Basin"

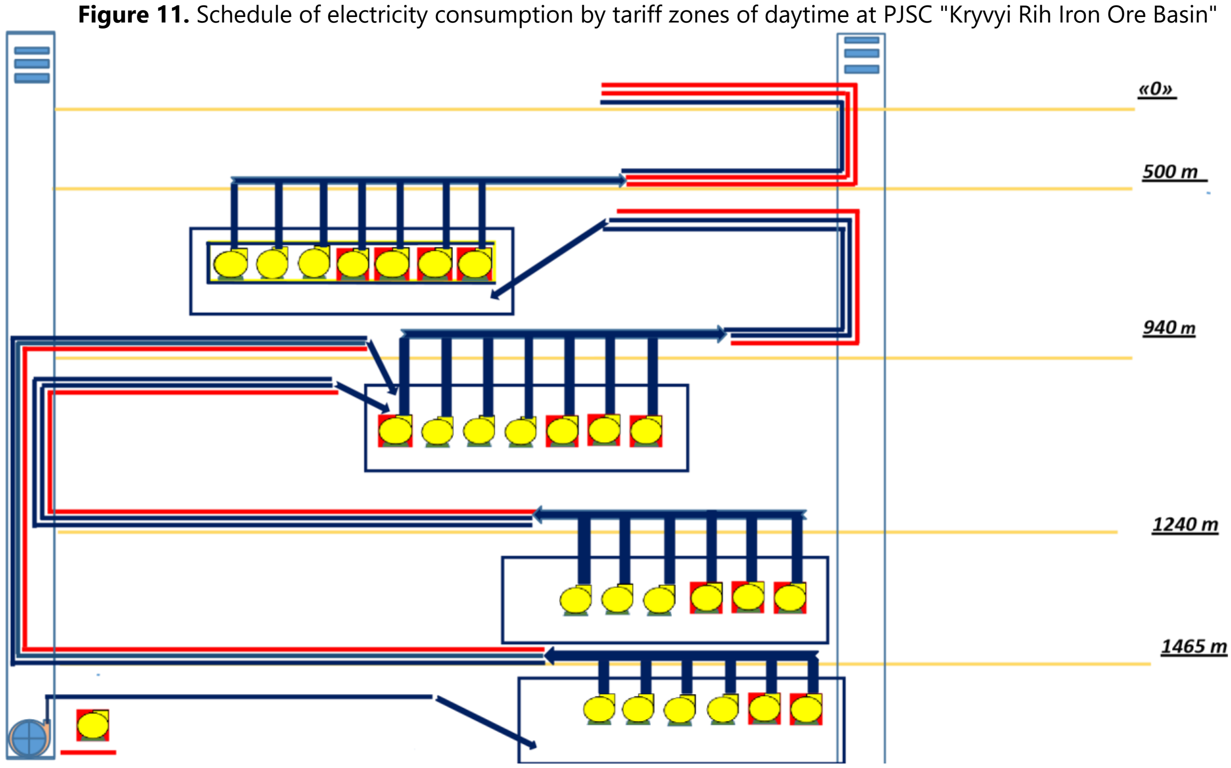

Figure 12. Structure of water pumping units at the Rodina-mine

The main drainage installation per each mine consists of 4 stages, which includes: water collectors, a pumping chamber, a substation chamber. Each chamber is equipped with a stationary pump unit consisting of: a pump CNS300, a motor, a vacuum tank, valves, etc. The number of pump units at each stage in each of the mines is predetermined by the project. In the first half of 2015 the average water inflows in the mines PJSC "Kryvyi Rih Iron Ore Basin" were:
mine "Ternivska" - 183.1 m^3/h mine
"Hvardiyska" - 142.1 m^3/h mine
"Oktyabrska" - 129.7 m^3/h mine
"Rodina" - 476.2 m^3/h

Centrifugal pumps with drives with a capacity of 800 kW are used for the drainage systems. Up to 6 pumps can operate at each of the horizons of the mines. The graphs of active power consumption by pumps per day at the mines PJSC "Kryvyi Rih Iron Ore Basin" are shown in fig. 13. The graphs show that the pumps do not work constantly, but are switched on once or several times a day to pump out water. If the water collectors provide sufficient volume, the water is pumped out completely at night (mine

"Hvardiyska"). When this volume is not enough to accumulate all the water, the staff have to turn on drainage installation at the daytime (mines "Rodina" and "Oktyabrska").

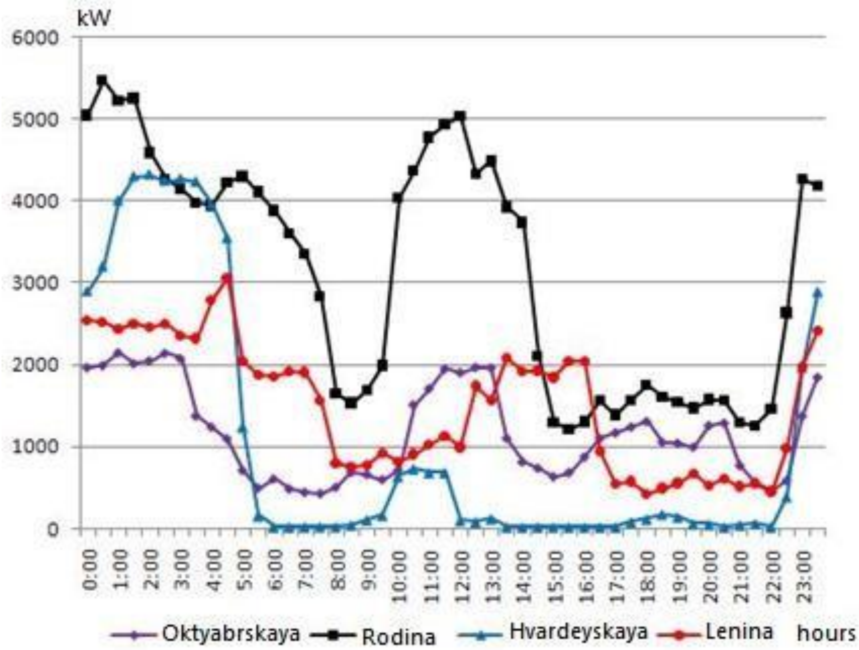

Figure 13. Diagram for active power consumption by pumps per day in the mines PJSC"Kryvyi Rih Iron Ore Basin"

Fig. 14 shows the annual load schedule of drainage installations of PJSC " Kryvyi Rih Iron Ore Basin." As can be seen from the graphs, the fluctuations in the load of the drainage installations are insignificant, due to the change in the inflow of water. Diagram analysis for drainage installations of the same mines showed, respectively:
K_{zap}=0.49...0.57 (K_m=2.04...1.75).
These values of the coefficients are due to the mode of operation mainly in the hours of the minimum tariff (night) to reduce the payment for electricity. However, approximately double the reserve of electric power and capacity of pumping units are required for the implementation of this mode, as well as an increased capacity of water collectors. A better regulation is carried out in the mines "Hvardiyska", Ternivska, while less deep - in the mines "Oktyabrska" and "Rodina". When calculating the electricity tariff for the zones of a day, it is more profitable to reduce consumption in "peak" hours and increase power consumption at night, when energy is less expensive (in 4.8 times) [14,15].

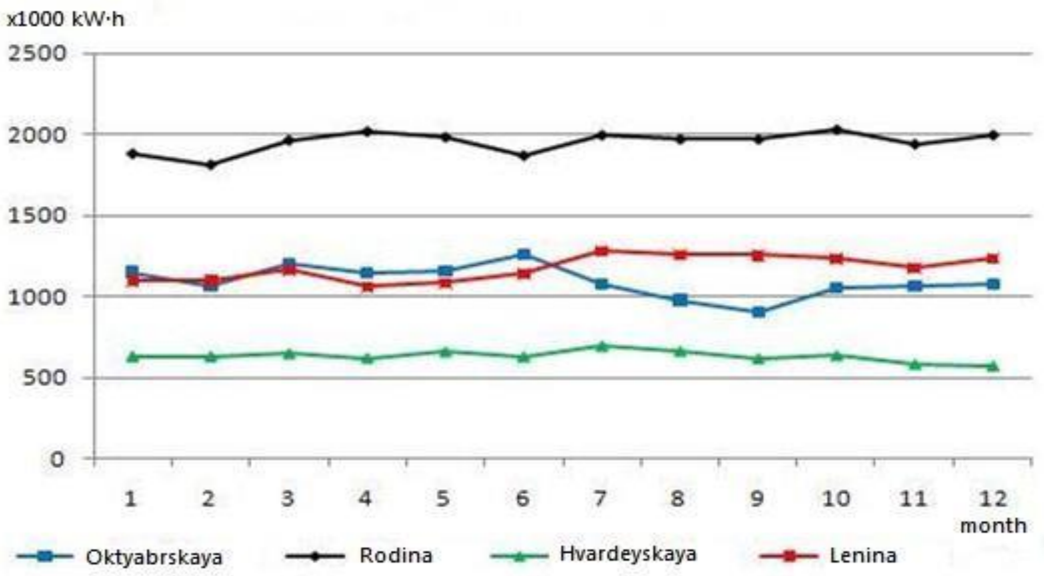

Figure 14. Annual load schedule of drainage installations for PJSC "Kryvyi Rih Iron Ore Basin"

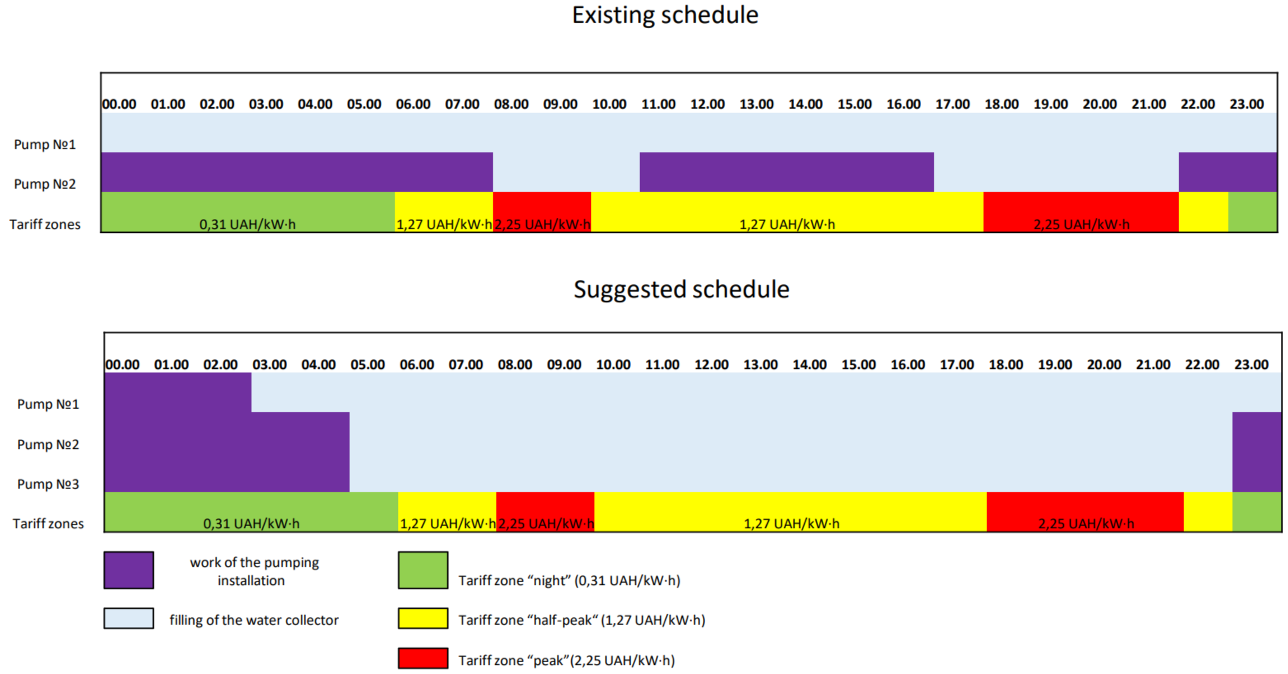

Figure 15. Work of the main drainage installations at horizon 527 m (mine "Ternivska")

Moreover, in terms of assessing power consumption of drainage installatoins in the structure of production technology of iron ore, it has the least impact on the process, and thus, reformatting its functions to another more economical power consumption tariff zone will not cause a change in the technology of production of iron ore (fig.15) For this purpose drainage installations are often used as well-known consumer-regulators in the mines. The maximum effect is achieved if at night the water is completely pumped out, and in other hours of day pumps are not turned on. But this required to provide the sufficient water collector capacity and pumping capacity. Apart from, hydro-accumulators with pumps would have the advantage for both opencast and underground mining. In the "peak" hours (morning and evening), the generator creates electricity through the energy of water released from the surface of the mine or quarry, filling the water collectors. Enterprises consumption in the "peak" hours for a maximum price is reduced resulting to declining payment for the electricity, respectively. Also, the power supply system mode can be improved: decreased voltage and energy loss, improved power factor and others. At night time, when the price of electricity is minimal, drainage pumps are turned on and pump out the water from catchment basins accumulated both from the natural inflow and from the work of hydro generator.

Let us consider the energy component of the process. The potential energy of water located on the surface of the mine or quarry is, kW·h

$$W_{vod} = mqH, J$$

$$W_{vod} = \frac{mqH}{3{,}6 \cdot 10^6},$$

$$W_{vod} = \frac{VH}{360}$$

where m - mass of water, kg; g - acceleration due to gravity, 9.81 m/s^2; H - static pressure or difference of geodetic marks, m.

In hydrogenerator installations, energy of water is converted into electrical energy, kW·h

$$W_{el}=W_{vod} \cdot \eta_{gen},$$

where η_{gen} - total efficiency of hydrogenerator units; $\eta_{gen}, \eta_{turb}, \cdot \eta_{SG}, \cdot \eta_p$ - according efficiency of turbine, synchronous generator, pipes.

Power is sent to the network in hours of maximum, t_{max} (equal to 6 hours), kW·h

$$P_{qen} = \frac{W_{el}}{t_{max}} = \frac{W_{el}}{6}$$

The same amount of water will need to be pumped out by the pumps, which requires to expend energy, kW·h

$$W_{nas} = \frac{W_{nas}}{\eta_{pump}}$$

where η_{pump} - total efficiency of pumping stations: $\eta_{pump}=\eta_m \cdot \eta_{pmp} \cdot \eta_p$ - accordingly efficiency of motor, pump and pipes. The power consumed from the power grid at night t_{noch} (equal to 7 hours), kW·h

$$P_{potr} = \frac{W_{has}}{t_{noch}} = \frac{W_{has}}{7}$$

Saving in cost of electricity will be, uah

$$E= W_{el} \cdot C_{max} - W_{nas} \cdot C_{noch}$$

where C_{max} - cost of 1 kW·h in "maximum" hours of power grid; C_{noch} - cost of 1 kW·h at night. In view of the components of the equation can be represented

$$E = \frac{mqH}{3{,}6 \cdot 10^6} [(C)]_{max} \cdot \eta_{qen} - \frac{C_{noch}}{\eta_{pump}}$$

Results. In general, savings are proportional to the mass of water and drop height. For the realization of the offered systems can be used high-pressure hydro generators intended for small hydropower plants in mountainous areas. And for places with a small height difference can be used reversible installation, operating both in a generator, and in a pumping mode. In addition, analysis of the possibility of changing regimes for pumping installations showed that energy-saving potential is significant.

Conclusions and directions for further research. Increasement of the efficiency of iron ore industries is possible by encouraging enterprises through economic incentives: to move consumers beyond the peak power consumption by introducing tariffs differentiated by zones of a day. This will improve the operation of pumping units of drainage installations in the underground workings for increasing efficiency of electricity consumption. Thus, consumption of enterprises in the "peak" hours of maximum payment for energy is decreased and, fee for electricity reduces, respectively. Also, hydro accumulators may be used as additional alternative sources of energy converting their energy into electricity. Application of the integrated approach to solving the problem

of energy efficiency through the use of technical and organizational methods will achieve the desired result on this issue, namely, reduction of energy consumption.

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