Features of a Power Consumption of the Main Electro Receivers of Coal Mine in the Conditions of the South of the Far East of the Russian Federation

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Abstract. In article the data obtained as a result of introduction of the automated system of accounting of electric energy on coal cut in the conditions of Primorsky Krai are analyzed. Schedules of consumption of the fissile and consumption/generation of reactive energy of the main largest power receivers of the cut are provided. On the basis of the obtained experimental datas becomes conclusions about the current state of a power consumption on a coal pit in the conditions of the Far East of the Russian Federation.

1. Introduction
Developed in the last decade of the politician of energy saving, based on directive impact on consumers of the electric power by limitation and rationing of a power consumption, did not bring the expected results. The power consumption of the industrial output grows and several times exceeds power consumption in the developed countries. This problem is especially noticeable for enterprises with continuous technological processes, where the component of energy consumption in product cost is large enough, and the possibilities of maneuvering load are limited. For example, according to the data [1] concerning mining enterprises producing open-pit minerals, it is possible to result that energy consumption in the cost of production in 2000 amounted to 9.4%, in 2010 increased to 18%, and in 2016 reached 24% and continues to grow. At the same time power engineering specialists the main percent of the operating time, are forced to be engaged in tasks unusual for them - development of actions for support of an obsolete inventory (which wear can reach up to 100%) in operating state. Now electric equipment majority (including and SD) developed the considerable proportion of the resource [2]. In view of design features of electric equipment specific costs of its overhauling are higher than in interfacing areas in 1,7 times [2]. Application of zonal accounting at payment for overflows of the reactive electric power also demands padding costs of automatic control of exaltation of SD. For most the enterprises rates of stripping and write-off of the fixed business assets by 3,5–4 times lag behind normative rates of leaving of electric equipment because of a wear [3].

2. The automated accounting system on the basis of ALPHA counters
Approved by the government of the Russian Federation “Rules of functioning of retail markets of electric energy in the transitional period of reforming of electric power industry” according to which consumers are obliged to carry out half-hour planning of electric power consumption in a year, for a
month, for two days ahead and to pay deviations from the declared half-hour mode of electric power consumption, corrected situation of electric power economy in the mining industry to the best. Creation (development) of the automated informational measuring systems of accounting of the electric power on many pits of the Russian Federation, allowed the coal-mining enterprises to gain economic effect of a minimization of increase in a payment for deviations of the planned power consumption modes.

The automated accounting system on the basis of ALPHA counters was introduced as a result of implementation of projects on automation of power economy in the conditions of Primorsky Krai on a cut about management (further CM) “Novoshakhtinsk”.

The Measuring Computer Systems (MCS) of ALPHA CENTR are intended for measurement and accounting of electrical energy and power and also automatic collection, processing and data storage from counters of the electric power and display of the acquired information in a look, convenient for the analysis. ALPHA CENTR's MCS are used for commercial and technical accounting of the electric power on the power stations, substations, the industrial enterprises and the organizations delivering and consuming electrical energy. The MCS important function is formation of specific norms of energy consumption. The system allows to reduce considerably costs of the electric power due to immediate informing the chief power engineer on energy consumption, losses and deviations from norms at all stages of technological process.

The purpose of creation of the automated system of supervisory control and technical accounting of the electric power of substations (further SS) of 110/35/6 kV is support of collection, processing and transmission of information on parameters of operation modes and a status of a switching equipment of SS 110/35/6kB. In CM “Novoshakhtinsk” on SS 110/35/6 of kV “Pavlovka-2” six digital ALPHA counters are set.

From every substation which ALPHA counters were installed several feeder lines depart, which are used as power supply of the equipment involved on the mining and on overburden. Information collection is carried out on the server of operational information processing. The storage is provided with the server of databases. The information display is executed in automated workplaces of the manager and chief power engineer. The radio channel in USW range is used for the information collection.

In consequence of planned and unplanned downtime of the excavator fleet during the observation, individual characteristics of active consumption and consumption/generation of reactive power for all major types of excavators involved in the section were obtained. As a result of experimental studies, a large set of statistics on the consumption of active reactive power for each feeder and separately for all excavators was obtained, which allows an analysis of power consumption.

The purpose of the data analysis is to generalize the information contained in them to identify hidden and confirm existing problems that lead to unreasonably high payments for consumed active and reactive electric power cut.

3. The analysis of the consumption of active and reactive power consumption/generation
The analysis of the consumption of active and reactive power consumption/generation time series of daily and hourly power consumption for each of the six feeders of the coal cut was carried out in the following order:

1) dependences of basic data on the active and reactive energy in function from time are constructed for the purpose of application of the visual valuation method of nature of change of data in time;

2) the cleaning of basic data providing deleting from the considered daily periods of energy consumption of the excessive dips (related to the forced outage of a major power consumers of the mine with repair works) is carried out;

3) the analysis of energy consumption of the main types of excavators:
   ESh-20/90, ESh-15/90, ESh-10/70, the ECG – 8I, EKG-5 - is executed.

We will conduct the research according to a power consumption of CM “Novoshakhtinsk” for 2010-2017. The data were removed from ALPHA counters with an interval length – 10 minutes. Daily
diagrams of a power consumption of feeder lines of a mine for winter months are shown in a figure 1 (changes, when all electrorreceivers of lines were in work state, were selected).

![Diagram of power consumption](image)

**Figure 1.** Graphics of overflows of energy of feeder lines of a mine for winter months (December, January, February) of generalization during 2010-2017.

For summer months the changes of characteristics of maintenance of the equipment connected to changes of mining-and-geological conditions on a mine are characteristic. The coal-mining enterprises of Primorsky Krai producing open-pit minerals are under the influence of specific weather climatic conditions inherent in influence of monsoonal climate with hot wet summer. An annual average amount of precipitation - 600 mm, in case of oscillations from 400 to 800 mm. The main amount of precipitation falls on summer months. During the summer and autumn periods of year downpours are watched (with drop-out of precipitates to 198 mm a day). Relative air humidity in the summer 90-95%. Under the influence of climatic conditions coal-mining sections have a row of the technological and mining-and-geological features influencing changes of overflows of the active and reactive energy on feeder lines of a mine.

During downpours rain water, rolling down surfaces of shoulders and dumps, blurs the breeds composing them and forms in a compound with them a water-carbon pulp which floods most the under sections of framings of a mine. The top 1/3 of the pulp, as its most liquid phase, is pumped out by pumps almost immediately. The following third of a layer of a pulp is pumped out by pumps, after a pulp sediment within several days. The remaining least liquid phase of the pulp after the addition of dry rocks is excavated by draglines, which increases the volume of rock mass preexcavation in the summer and autumn periods of the year.

Daily generalized diagrams of a power consumption of feeder lines of a mine for summer months are shown in a figure 2 as well as for winter months the loaded changes when all electrorreceivers of feeder lines were in work state were selected.

Analyzing the synthesized graphics of consumption of the active power it is possible to draw a conclusion that both for summer, and for winter season for feeder lines from which excavators receive a supply (feeder lines “Dump-3”, “Mine-2,3”, “Mine-4”, “Opencast mine-1”) similar overfalls of consumption of the active power within days are watched. Graphics are characterized by existence of two sheer failures of consumption, falling on time interval from 9 to 10 o’clock and in the evening from 20 to 21 o’clock. This time corresponds to change of operators of excavators. In the same hours some increase in generation of reactive energy on above to the listed feeder lines is watched that is connected to absence of loading on a shaft of synchronous motors of the drive of excavators which idle in these hours.
a) for consumption of the active energy, b) consumption/generation of reactive energy

Figure 2. Graphics of overflows of energy of feeder lines of a mine for summer months (June, July, August) of generalization during 2010-2017.

The persistence of consumption of the active energy within days is characteristic of feeder lines “Pavlovka-2” and “Dump-2” for summer and winter months that is connected to kind of work of the electroreceivers which are powered from these lines (a water low tide, the sorting and loading bunker, auxiliary aggregates and mechanisms).

In summer months there is a lowering of consuming of the active energy in general on a section that is connected first of all to change of properties of excavated soil and as a result of reduction of the active load on a shaft of drives of excavators. On difficulty of excavation of breed of carboniferous thickness (except for basalts) on the considered mine changes from the III-IV group during the winter period to the I-II group during the summer period.

Consumption of the active energy on feeder lines during the winter and summer period changes depending on the equipment which receives a supply from lines. Consumption of the active energy on feeder lines from which mining and overburden excavators during the summer period of year receive a supply decreases by 15-20% in comparison with winter months. When reviewing feeder lines from which to be made a supply of water-removing installations it is possible to state increase in consuming of the active energy during the summer period for 10-15% in comparison with the same winter period that is explained by increase in an operating time of water-removing mechanisms.

Among the most energy-intensive consumers of quarries with cyclic and cyclic-flow technology should be attributed to the single-bucket excavators, the share of electricity consumption of which is up to 80% of the total consumption of the opencast mine. Therefore, the main attention is paid to the study of electric loads of single-bucket excavators.

When considering a single-bucket excavator as an electroreceiver in the electric power supply system of a opencast mine, it is important to find out the characteristics of the sharply variable total curve of the power consumed by the networked engine during the operating cycle. At the same time, it is necessary to proceed from the fact that the total load of the mains engine is not deterministic, since its level and dynamics are influenced by a number of random factors (indicator of the difficulty of excavation, the degree of freezing, lumpiness, change in volumetric weight, the degree of filling of the bucket, the degree of preparedness and working height of the face, the type and intensity of load, the quality of combining lifting and pressure or traction efforts, the type of machine, various psychological factors, etc.). Moreover, all of the above factors have an impact on the formation of the load schedule of the network engine is not directly, but acting on the load of each of the drives of the main working mechanisms of the excavator — lifting, turning and pressure or thrust.

In a number of works [4, 5-12] it is established that the change of the total load of 5-6 electroreceivers is subject to the normal law. Besides, in [5] it is established that change of total load on tires of opencast mine substation is also described by the normal law.
With regard to the conduct of this justification, it is appropriate to make the following observation. The normal law of distribution of a random variable occurs when the number of disturbing factors, insignificant in size, tends to infinity. In previous works, a limited number of electric receivers involved in the formation of the total schedule were used for the number of disturbing factors, while the load of a single electroreceiver itself is the object of a large number of random factors. Therefore, it is more natural to assume that it is the change in the load of an individual consumer under the influence of the environment and working conditions, the disturbing factors of which cannot be fully taken into account and their number tends to infinity, is subject to normal law. Then, based on Lyapunov’s theorem, the change in the total load under the normal law not only with a limited number, but also one excavator seems quite logical.

For check of normality of the distribution law of the average capacity of excavators – 20/90, ESh – 15/90, ESh – 10/70, the ECG – 8I, the ECG – 5 Far East state technical university (mining institute) in 1989 [6, 7-18] were carried out the experimental records and processing of parameters of loadings of excavators of the specified types. After processing of 100 cycles of operation the output about normality of distribution of the average capacity of single-bucket excavators from where follows that value of operation of power, average for a cycle, can be read within available accuracy of calculations independent of working conditions was received.

However in these works other, not less important characteristics of diagrams of loading of excavators (the maximum capacities, coefficients of the form and filling of the schedule, and also from distribution, etc.) were not received.

For the purpose of detection of key parameters on consumption of the active and consumption/generation of reactive energy of the largest electroreceivers of a mine (mine excavators) pilot studies with use of the instrument MT-1010 were conducted. Tasks of the pilot study were simultaneous registration of values of the active and reactive energy during time, sufficient for volume of selection, in the modes “operation”, “idling” of the main types of excavators: ESh – 20/90, ESh – 15/90, ESh – 10/70, the ECG – 8I, the ECG – 5. The measured data remained in memory of the instrument MT-1010 then via the RS-232 interface were transferred to the computer. The received database on values of the active and reactive energy of electroreceivers were exposed to computer processing for a set in data array. In result of what diagrams for an operation mode of excavators were received: "operation", "idling", "pacing". Fragments of diagrams are provided in figures 3 - 6.

The array represents a matrix in which lines correspond to the current parameter values in specific timepoints.

The collected array represents the provided selection providing an admissible deviation of an arithmetic average of value of regime parameter within % ±3.

Determination of quality of the electric power was carried out in the estimated way by the technique developed by authors.

![Figure 3](image.png)

**Figure 3.** Consumption of power for the EKG-8I excavator.
a) Reactive power, kVAr, b) Active power, kW.

**Figure 4.** Consumption of power for the ESh-10/70 excavator by operation on a dump.

As it was mentioned above, the data obtained as a result of carrying out the experimental measurements, represent a big statistical row in different parameters of an electrical network, their processing in manual, would take away a large number of time. Therefore for the purpose of obtaining mean values of the received characteristics of the power supply network the program for processing of statistical data by means of the computer was made. Results of processing are reduced in tab. 1 and tab. 2.

During the experiment, additional measurements for the purpose of clearing up of characteristics of an electrical network depending on different energizing currents of the synchronous motors of the
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principal electric drive of career excavators were also taken, this received in case of change of an energizing current are provided to tab. 3.

**Table 1.** Results of processing of the experimental data (mode “work”).

| Parameters | Values of parameters | ESh-20/90 | ESh-15/90 | ESh-10/70 | EKG-81 | EKG-5 |
|------------|----------------------|-----------|-----------|-----------|--------|--------|
|            |                      | №4       | №6        | №4       | №8     | №6    |
|            |                      | $I_B = 230 A$ | $I_B = 220 A$ | $I_B = 220 A$ | $I_B = 270 A$ | $I_B = 230 A$ | $I_B = 220 A$ |
| S, kV·A   | 2436/2090            | 2188     | 1517      | 728       | 488    | 140    | 198    |
| $I_{av}$ A| 222/191              | 200      | 145       | 69        | 43,2   | 13     | 18,9   |
| U, V      | 6313/6390            | 6314     | 6070      | 6545      | 6506   | 5963   | 6047   |
| f, Hz     | 50,41/50,23          | 50,06    | 50,006    | 50,18     | 49,84  | 50,26  | 50,26  |
| $\sigma_r$, A | 26,05/1          | 48,07    | 61,3      | 13        | 11,5   | 1,686  | 3,88   |
| $\sigma_u$, V | 18,939/1        | 18,972   | 18,226    | 19,662    | 19,542 | 17,888 | 18,142 |
| $\sigma_f$, Hz | 0,41/0,23     | 0,06     | 0,0594    | 0,185     | 0,1627 | 0,267  | 0,2609 |
| V, %      | 5,21/4,38           | 5,227    | 1,169     | 9,09      | 8,436  | -0,62  | 0,788  |
| $\sigma_v$, % | 0,314/0,503  | 5,75     | 3,459     | 6,46      | 0,419  | 0,176  | 0,203  |

**Table 2.** Results of processing of the experimental data (mode “idling”).

| Parameters | Values of parameters | ESh-20/90 | ESh-15/90 | ESh-10/70 | EKG-81 | EKG-5 |
|------------|----------------------|-----------|-----------|-----------|--------|--------|
|            |                      | №4       | №6        | №4       | №8     | №6    |
|            |                      | $I_B = 220 A$ | $I_B = 270 A$ | $I_B = 230 A$ | $I_B = 220 A$ |
| S, kV·A   | 1914                 | 1085     | 267,8     | 555       | 222    | 122    | 94,2   |
| $I_{av}$ A| 174                  | 95       | 25,13     | 48        | 21,2   | 11,7   | 9,01   |
| U, V      | 6316                 | 6569     | 6156      | 6630      | 6021   | 6031   | 6033   |
| f, Hz     | 49,98                | 50,07    | 50,18     | 50,27     | 49,86  | 50,27  | 50,19  |
| $\sigma_r$, A | 2,44/4,458  | 0,961    | 2,43      | 0,63      | 2,3    | 0,925  |
| $\sigma_u$, V | 18,912/19,707 | 18,466   | 18,891    | 18,239    | 18,094 | 18,15  |
| $\sigma_f$, Hz | 0,0247/0,07  | 0,044    | 0,1795    | 0,1389    | 0,269  | 0,195  |
| V, %      | 5,27                 | 9,485    | 2,593     | 10,5      | 0,353  | 0,522  | 0,8    |
| $\sigma_v$, % | 0,1848/0,0587 | 0,1056   | 0,305     | 0,2112    | 0,1188 | 0,2    | 0,106  |
Table 3. Results of processing of the experimental data (in case of different energizing currents).

| Excavator   | Parameters                  | Work          |
|-------------|-----------------------------|---------------|
|             | Idling                      | S. kVA | cosφ | Idling                      | S. kVA | cosφ |
|             | I, A | U, kV | P, kW | Q, kVar | cosφ | I, A | U, kV | P, kW | Q, kVar |
| ESh-20/90   | I₀₀ = 270 A                | 208     | 6.41 | 833 | 1050 | 1340,3 | 0.62 | 265 | 6.41 | 2510 | 930 | 2676 | 0.937 |
|             | I₀₀ = 230 A                | 90.1    | 6.377 | 398 | 706 | 810 | 0.49 | 123 | 6.114 | 1250 | 371 | 1304 | 0.9586 |
|             | I₀₀ = 230 A                | 97.2    | 6.431 | 394 | 965 | 1083 | 0.378 | 119 | 6.367 | 1260 | 376 | 1315 | 0.958 |
|             | I₀₀ = 230 A                | 93.7    | 6.336 | 482 | 845 | 973 | 0.496 | 120 | 6.28 | 1255 | 377 | 1308 | 0.958 |
|             | I₀₀ = 230 A                | 64.8    | 6.48 | 453 | 507 | 680 | 0.666 | 125 | 6.39 | 1250 | 374 | 1304 | 0.958 |
|             | I₀₀ = 220 A                | 34.5    | 6.62 | 250 | 307 | 396 | 0.631 | 73.3 | 6.37 | 803 | 81 | 808 | 0.99 |
|             | I₀₀ = 220 A                | 29      | 6.15 | 43,4 | 300,6 | 303,7 | 0.143 | 120 | 6.31 | 980 | 100 | 985 | 0.31 |
|             | I₀₀ = 214 A                | 23      | 6.1 | 38 | 280 | 282 | 0.13 | 114 | 6.27 | 890 | 48 | 891 | 0.99 |
| ESh-15/90   | 176                      | 6.26 | 498 | 860 | 993,8 | 0.5 | 202 | 6.27 | 1680 | 813 | 1866 | 0.9 |
|             | I₀₀ = 271 A                | 21      | 6.25 | 180 | 310 | 401,1 | 0.44 | 78 | 6.21 | 448 | 679 | 813 | 0.55 |
|             | I₀₀ = 220 A                | 10.8    | 6.18 | 63 | 95 | 116 | 0.55 | 78,3 | 6.21 | 690 | 482 | 842 | 0.82 |
|             | I₀₀ = 180 A                |         |     |     |     |     |     |     |     |     |     |     |     |
| ESh-10/70   | 78.6                      | 6.45 | 325 | 609 | 690 | 0.47 | 145 | 6.33 | 1647 | 720 | 1797,5 | 0.91 |
|             | I₀₀ = 300 A                | 63      | 6.27 | 198 | 615 | 646 | 0.3 | 140 | 6.35 | 1250 | 605 | 1388 | 0.9 |
|             | I₀₀ = 270 A                | 50      | 6.36 | 91 | 580 | 587 | 0.155 | 92.5 | 6.3 | 845 | 530 | 997,5 | 0.847 |
|             | I₀₀ = 250 A                | 45      | 6.25 | 78 | 489 | 495 | 0.157 | 81.5 | 6.28 | 751 | 430 | 865,4 | 0.86 |
|             | I₀₀ = 230 A                | 24      | 6.3 | 71 | 459 | 464,5 | 0.152 | 54 | 6.24 | 690 | 174 | 711,6 | 0.96 |
|             | I₀₀ = 200 A                | 4.8     | 6.27 | 63.4 | 87 | 107.6 | 0.58 | 35 | 6.18 | 530 | 128 | 545,2 | 0.97 |
|             | I₀₀ = 160 A                |         |     |     |     |     |     |     |     |     |     |     |     |
| EKG-81      | 49                        | 6.18 | 175 | 298 | 345,6 | 0.5 | 60 | 6.27 | 525 | 269 | 590 | 0.90 |
|             | I₀₀ = 280 A                | 28      | 6.25 | 148,1 | 256 | 295,7 | 0.5 | 44 | 6.29 | 446 | 100 | 457 | 0.975 |
|             | I₀₀ = 220 A                | 16      | 6.36 | 6.2 | 169 | 169,1 | 0.03 | 43 | 6.25 | 418 | 65 | 423 | 0.988 |
|             | I₀₀ = 200 A                |         |     |     |     |     |     |     |     |     |     |     |     |

4. Conclusion

Based on data retrieved it is possible to draw the following conclusions:

1. Operation of the synchronous motors of one-bucket excavators is characterized by the considerable changes of the generated reactive power from mean value to maximum that in case of absence of sufficient power of customers of reactive power on the line and a deficit of reactive power in a node of loading leads to its overflows in the system of electrical power supply of the enterprise and increases losses of the active power and energy. In case of an identical energizing current for the synchronous motors of excavators of the operations (overburden, production, loading) occupied on different types, framing of reactive power practically does not change. So for the ESH 20/90 excavator using overburden in case of current excitation equal 230 A framing of reactive power makes 371 kVAr, for the same model of the excavator with the same energizing current of the synchronous motor but occupied on production, framing of reactive power makes 376 kVAr.

2. For determination of characteristics of accidental process of change of power consumption of one-bucket excavators it is enough to research excavator loading during 12-15 cycles, complexes of machines of the continuous action – during change by operation in any conditions with a complete productivity. Parameters of the loading of ball drilling machines depend generally on working conditions therefore duration of researches is defined by conditions of a specific opencast mine.

3. The majority of mine excavators have no automatic regulators of excitation of synchronous motors, and values of energizing currents in case of seasonal adjustments are set for the nominal mode. On many excavators restriction of an energizing current of the synchronous motors in the mode “idle” by serial input of added resistance with the drive winding of the synchronous motor is reached. Installation of the recommended values of energizing currents in an mode “work” is made by the
4. The existing modes of excitation of the synchronous motors of excavators should be read economically inexpedient as they do not allow to provide the rational mode of a reactive power compensation in nodes of system of electrical power supply of the enterprise. Lowering of an energizing current of the synchronous motor of the ESh-20/90 excavator with 230 A to 220 A more than by 3 times reduces value of the generated reactive power that in the absence of its deficit in the feeding line and a node of loading (on condition of support of steady operation of the synchronous motor) allows to raise technical and economic indices of operation of the synchronous motor due to cutting of costs of energy for generation of reactive power.

5. Change of an energizing current of the synchronous motor of excavators from maximum to minimum admissible taking into account a deficit of reactive power in nodes of loading, the principles of creation of electrical power supply system and the new system of calculations for a reactive power compensation will allow to use the synchronous motor as regulators of reactive power for maintenance of the rational modes of a reactive power compensation in nodes of loading and to gain on this basis the appropriate effect due to reduction in cost of framing of reactive power the synchronous motor, losses of energy in electrical networks, reactive power and energy of the enterprise that as a result will lead to reduction of a board for the electric power. However, because there are no accurate recommendations about determination of the necessary mode of excitation today, the synchronous motors of excavators from the point of view of a reactive power compensation work in the nonoptimal modes.

6. Parameters of electrical power supply system are tightly interconnected among themselves and generally are defined by mining-and-geological, technical and geometrical parameters of a opencast mine. Therefore in the power supply network of the mining enterprises it is necessary to carry constant control over flows of the active and reactive energy on power supply networks.

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