Refinement of Calculation Methods for Electrical Load in Industry

O.N. Sinchuk, E.S. Guzov, R.A. Parkhomenko

***Abstract*— An analysis of known and in practice applied methods of electrical load calculation in power supply systems design for iron exploitation and other industry areas is conducted in this paper. Quality and level of discrepancy between the calculated and real values of power supply system parameters are studied. A method of calculation without the shortcomings of methods analyzed is proposed.**

Keywords— **electrical load, calculation methods, power supply**

I. TOPICALITY OF RESEARCH

THE The expected and very much needed improvement regarding economic and technical indicators related to iron exploitation as the raw material for steel industry which is the main participant in Ukraine's GDP formation is directly related with the problem of increasing the effectiveness of power supply systems in mining, including the underground mining facilities [1].

II. MATERIAL AND RESEARCH RESULTS

Many research publications dealing with problem of electrical load calculation for industry and mining have been published [2-5]. These and other works have laid foundations [2] for development in the field of electrical load calculation theory. However, it would not be true to say that this theory of calculation gives a real result that is close enough to actual values, based on the construction schematics of facilities of interest and choice of the parameters for their components.

Exploitation of power supply systems for mining in general, and for iron ore mining in particular is characterized today mainly with significant overestimate in installed power transformers' power in virtually all substations, leading to overestimation regarding the commutator machinery and supply cable cross sections. This situation leads to very big problems, ranging from power losses to supply system protection malfunction. It is result of both objective factors (reduced production and the logically following power consumption) and proactively overestimated values of parameters – electrical loads in the calculation. As we know, all elements of the supply system: transformers, lines, switches etc. are chosen based on the electrical load calculation [2, 3]. A little error in calculation of loads leads to incorrect selection of all components in the supply system, which in turn leads to all sorts of problems. It is not a coincidence that special attention for the calculation of loads has been paid for decades [2-5].

However, the problem of electrical load calculation cannot be considered solved, since significant and non-tolerable discrepancies between calculated and actual loads still exist. Reason for this lies both in imperfection of calculation methods and incorrect use of regulatory factors [4].

III. GOAL OF THIS PAPER

is to analyze methods applied to electrical losses calculation for supply systems in iron mines, measure the quality based on actual and calculated values comparison, as well as to work on suggestions for their improvement.

In mining, as well as other industries, the calculation of electrical loads is usually based on demand factor method and ordered diagrams [2-5]. Let us consider the logic and features of these methods.

Simplest method is one based on demand coefficients, where maximal active power is defined as

$$P_{\max} = \sum_{1}^{n} P_{nom} \cdot c_d \tag{1}$$

where – is the nominal power of a group of power consumers in same work mode;

I– respective demand coefficient for a group of power consumers in same work mode;

II – number of consumers groups.

It means that the calculation of load is conducted for groups of consumers with same work modes, although in reality we have technological groups with different work modes: workshops, sites, enterprises in general. In other words, it can already be seen that logic of this calculation method. It does not correspond to the structure of power supply system, not to mention a real estimate of work modes among the consumers.

For determination of the demand coefficients one needs to artificially divide consumers into groups with the same mode of operation and know the actual maximum load of these groups, which requires special equipment and a large amount of work. It is not surprising to find out that value of demand coefficients which lie in the essence of this method, have not been updated for over 50 years, so of course the results of calculations of electrical loads by this method are far from

O.N. Sinchuk, is with the Kryvoi Rog National University, str. XXII parts'ezda,11. Ukraine. (e-mail: speet@ukr.net).

reality.

Another flaw of the method using demand coefficients is lack of taking into account the number of consumers, although it is well known that more consumers there are, less the probability that they will work at the same time, hence value of electrical load reduces. To eliminate this shortcoming, another coefficient can be introduced – coefficient of the consumers groups maxima, but its value is taken rather arbitrarily [4].

The flaws of demand coefficient method are partially minimized in the ordered diagrams method, which is recommended in the standards for electrical load calculation in industry [3, 4]. In the context of this method load calculation is performed in two stages: first, determining average load, then going from medium (average) to maximum (peak).

Average active load is defined by:

$$P_{av} = \sum_{1}^{n} P_{nom} \cdot c_u \ , \tag{2}$$

where – coefficient of utility for a group of consumers with the same work mode in the most congested shift.

However, same troubles as in demand coefficient method arise – consumers are divided into groups with same work mode, although in actual power supply scheme technology groups consist of consumers with different modes. Therefore, validation and refinement of the estimated coefficients for use in this method in the process of exploitation is also a problem.

Maximum load:

$$P_{\max} = P_{av} \cdot c_{\max} \ , \tag{3}$$

where–maximum coefficient, found using ordered diagrams as a function of the overall utility coefficient and the equivalent number of consumers.

It's worth noting that ordered diagrams are made for the situation in which demand is random and consumers work independently of each other.

Application in industry is not consistent with reality – energy consumption is a function of the production program and consumers are almost always constrained with a certain production process.

Due to the low accuracy of the ordered diagram method, several authors introduced updates to the method. In [4,5] it is proposed to take the maximum coefficient=1 for consumers with constant load and assume maximum load equal to average in that case, and for the other consumers with variable load maximum coefficient is found using ordered diagrams; in such a manner, an additional division of consumers based on work mode is conducted.

In [4] there is a proposal to use a complex method of electrical load calculation which uses multiple calculation methods at the same time and a data base of analogues as well. Note that the use of the data base of analogues is useful in the application of any of the methods of calculation load, while the use of multiple methods at the same time is not new and does not simplify the task.

The conclusion is that the method of electrical loads calculation and the corresponding estimated coefficients should be focused not on the account of individual consumers and their modes of operation, but on the overall assessment process electricity consumer groups, modes, which are interrelated and being a function of the process.

This corresponds to the structure of real power systems, makes it possible to check the accuracy of calculations and adjust the estimated coefficients using standard instrumentation.

In this regard, statistical calculation methods are of our interest, option from [2] in particular, defining the maximum load as

$$P_{\max} = \left(c_u + \frac{\beta \sigma_*}{\sqrt{n_e}} \right) \cdot \sum_{1}^{n} P_{nom} \ , \tag{4}$$

Where σ_* – relative standard deviation of an effective consumer;

β–probability of maximum (peak) load occurrence (confidence interval), usually in interval 1.5–2.5;

n_e – effective number of consumers.

In the above formula (4), the expression in brackets is nothing but the coefficient of demand:

$$c_d = c_u + \frac{\beta \sigma_*}{\sqrt{n_e}} . \tag{5}$$

Still, in practice it is a problem to use the demand coefficient in this form, since there is no data on the standard deviations and defining them in production conditions is a complex process.

Let us try to simplify the problem. If a known claim [3] that for a single consumer C_d=1 can be taken, then it holds for $\beta\sigma_*=1-C_u$, so we can write:

$$c_d = c_u + \frac{1 - c_u}{\sqrt{n_e}} . \tag{6}$$

This seemingly simple formula well enough expresses the quite complex logic of parameter dependencies in power consumption:

– the main problem of demand coefficient method is solved – effect of the consumers' number is taken into account;

– for a large number of consumers $n_e \rightarrow \infty$, demand coefficient $C_d \rightarrow C_u$, and the maximum power $P_{max} \rightarrow P_{av}$;

– for a small number of consumers $n_{e \rightarrow 1}$, demand coefficient $C_d \rightarrow 1$, and the maximum power $P_{max} \rightarrow P_{nom}$

In this case, calculations of electrical loads by the proposed generalized method requires neither ordered diagrams or standard deviation, or coefficient of utilization for each type of facility. It requires only minimal input information: general utilization rates for technology user groups, and the number of groups, as well as the modes of operation. Then the effective number of consumers is calculated by the known formula [2-5]:

$$n_e = \frac{\left(\sum_1^n P_{nom}\right)^2}{\sum_1^n P_{nom}^2}. \quad (7)$$

For more than 20 consumers, the simplified expression may be used:

$$n_e \approx \frac{2\sum_1^n P_{nom}}{P_{n.\max}}, \quad (8)$$

where $P_{n.\max}$ – nominal power of the consumer with highest power.

In any case while calculating the number of consumers, it has to be remembered that a group of engines working in the same time in a facility is taken into consideration as one motor with the total power given as a sum. On the other hand, consumers in low-power and stand-by modes are not taken into consideration.

For more than 100 consumers, can be taken $C_d = C_u$ [4]. Therefore, for the calculation of electrical loads in 6-10 kV networks average maximal load can be taken as

$$P_{\max} = \sum_1^n P_{av} = \sum_1^n P_{nom} \cdot c_u. \quad (9)$$

Reactive power is determined in a similar fashion as in the ordered diagrams method [2]:

$$Q = \sum_1^n P_{av} \cdot tg\varphi, \quad (10)$$

Where tgφ - power coefficient for respective consumer groups. In order to refine the proposed generalized method and define specific values of coefficients in calculation for design purposes, authors have conducted a series of experimental studies of electrical loads at mining sites of the PJSC "Krivoy Rog's Iron-ore Combine".

During the research, data was collected through electricity meters and daily load graphs were analyzed for three local transformer substations. For the record, meters of active and reactive energy were used, and the power is determined by the number of pulses per unit time

$$P = \frac{N \cdot a}{t}, \quad (11)$$

where N – number of pulses in the considered interval t;
a – measured energy for one pulse.

Fig. 1 shows one of the typical daily graphs of local transformer substation load feeding the mining and preparatory site with a total capacity of consumers being

$$\sum_1^n P_{nom} = 215 \text{ kW}. \quad (12)$$

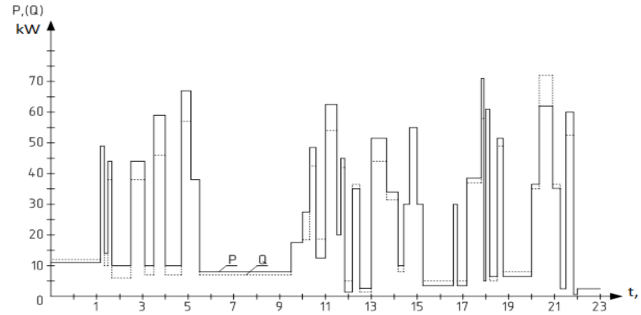

Figure 1 – Daily graph of load for the local transformers substation

In the chart (Fig. 1), one of the typical ones, a three shift working schedule of consumers with sharply varying load can be seen. In some intervals, reactive power (dashed line) is greater than active, indicating short-term overload of the equipment. The average power factor tgφ=0,9.

During the experiment, based on results obtained processing the data (around 20 load charts) following characteristics were determined: peak loads and their duration, mean and standard deviation, coefficients of form, duty fill, demand, utility and power.

Analysis has shown that the transformers' load at the local substations of the state iron ore mines is less than 30% of the installed power. It shows clearly once again the inaccuracy of methods for computation of electrical loads and corresponding coefficients applied.

Experimental data processing and statistical characteristics determination of the daily charts were done using known methods in mathematical statistics, ensuring the required accuracy and reliability of calculations with confidence 0.98 [2].

According to the experimental data, group utility coefficient in different conditions varies between 0.1 and 0.2. For calculation, the maximum value is taken, C_u=0,2.

In calculations, note that the load factor of a single customer is always less than 1 and is usually 0.7-0.9. This allows adjustment of the expression for demand coefficient (6) and presenting it in the form of:

$$c_d = c_u + \frac{0{,}8 - c_u}{\sqrt{n_e}}. \quad (13)$$

If the actual maximum value of utility coefficient C_u=0,2 is used, then the demand coefficient for electrical load calculation in case of iron ore mines can be taken as

$$c_d = 0{,}2 + 0{,}6\frac{1}{\sqrt{n_e}} \quad (14)$$

During the experiment, the power factor tgφ was also determined, which changed in bounds 0.8-0.9 for various sites. For calculations, the maximum value tgφ=0,9 is taken.

To evaluate different electrical load calculation methods comparative calculations were made using ordered diagrams method and the proposed generalized method. Calculation results show that the maximum power calculated with generalized method is 30-40% lower than the one found with ordered diagrams method and significantly closer to the actual value.

Another detail has to be noted, related to design: the design values of total installed power for the equipment are much higher than actual – in the observed sites, going up to 1.6 times. Given the inaccuracy of calculations it turns out that the transformer capacity is approximately doubled, as seen in reality.

The proposed generalized calculation method for the electrical losses appears to be universal and applicable for all industries and supply systems.

To use the method, it is necessary to know the values of group utility coefficients in the shift with the highest load. This value can be calculated, but it is much more precise if measured in the existing facilities. With a limited number of experiments, in order to account for possible deviations, it is recommended to increase the maximal measurement of the utility coefficient $C_{u.meas}$ by 0.05, meaning that the value of the utility coefficient is

$$c_u = c_{u.meas} + 0{,}05. \quad (15)$$

By the means of modern energy accounting in power supply networks, necessary measurements of the greatest mean loads to determine the actual utilization rates for various technology user groups, departments and companies in general. This will significantly improve the accuracy of calculations and reduce the cost of electricity.

IV. CONCLUSION

1. A new approach to electrical load calculation for technological consumer groups has been made, differing from the known methods by not requiring artificial division in means of working mode, relating to the real structure of power supply systems in mining and other industries.

2. The power values calculated by this generalized method are 30-40% smaller in comparison with other methods applied and significantly closer to their actual values, with the load of power transformers being just around 30%. Judging on this, the power of transformers under the ground can be reduced 1.5-2 times. It is concluded that best choice for transformers' power in district iron ore mines is 250 kVA.

3. A new generalized method of electrical load calculation is based on general efficiency for technological consumers groups, which can be determined with a high degree of precision based on existing energy accounting methods. The method proposed appears to be universal and applicable to all industries and power systems.

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