Improving the accuracy of calculations of electrical loads for industrial enterprises

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Abstract. Nowadays many enterprises of the mineral resource complex install modern and energy-efficient equipment. By the way nobody takes into account that it influences the correctness of the electrical loads calculation. The aim of this study is to determine the necessity of adjustment of the electrical loads of the calculation method in order to avoid an unjustified overestimation of power consumption, which affects the reliability of the whole system. Conducted analysis of the difference between reference and actual values of electrical loads calculation shows a discrepancy of more than 25%. This suggests that reliable determination of power consumption at the initial design stages allows one to create an efficient power supply system.

1. Introduction
The power industry develops with high rates, so it demands raising the efficiency of capital investments and material inputs. Today, about two thirds of electric power consumption is accounted for by industrial enterprises. Therefore, it is essential to apply a comprehensive set of measures to improve technical and economic indexes at the design stage. One of the first priority goals in the design enterprises is to determine electrical loads and the reliability of estimates directly affects the technical and economic indexes of the entire enterprises system. Values obtained in the calculation of electrical loads are used to determine the elements of the power system. Understating or overstating these values leads to heavy losses and an increase of capitalizable costs [3, 5]. The reliability of values depends on the methods used for the calculation of electrical loads. The purpose of this article is to adjust and improve the accuracy of the load calculation method.

2. Load calculation method
Throughout its existence, various methods of calculation underwent significant changes from the 20s of the XX century: an experimental presentation - to modern methods, which use the mathematical apparatus of probabilities and a stochastic process.

Research in the field of electrical loads started in 30s of the previous century. But the lack of theoretical and experimental data did not allow using such methods with adequate accuracy.

The second period in the development of the theory of electrical loads is rightfully considered in the 50s of the twentieth century. Because of the numerous investigation studies conducted at industrial enterprises there was an information base, developed methods of mathematical statistics, which made it possible to create mathematical models on the basis of random variables. As a result, in 1968 the “Guidelines for the Determination of the Electrical Loads of Industrial Plants” were published, which
were based on the method of the ordered diagram (MOD) [6]. In accordance with the MOD, the expected value of the use factor is determined by the expression:

$$K_{u,c} = \bar{K}_{u,av} \left( 1 + \frac{\sqrt{3} \sigma K_u}{\sqrt{n_f}} \right) = \bar{K}_{u,av} \left( 1 + \frac{\sqrt{3} f_{ku}}{\sqrt{n_f}} \right). \quad (1)$$

$$\bar{K}_{u,av}$$ – mathematical expectation $$K_u$$, $$\sigma K_u$$ - mean square deviation $$K_u$$, $$f_{ku}$$ - crest factor arrange map $$K_u$$, $$n_f$$ - effective number of electric load. Because the deficiency of reference data in the values of $$K_{u,av}$$ and $$f_{ku}$$ does not allow one to consider this method as completely reliable, the obtained power consumption figures from a survey of existing enterprises indicate an overestimation of the calculated maximum load over the actual value of 1.5-2.5 times.

The updated instructions for the calculation of electrical loads 36.18.32.4-92 v (since 01/01/1993 to the present day) took place in the instructions of 1968. New guidelines were developed by Tyazhpromelektroproekt and scientist Zhokhov and Godgel who made a great contribution to this work. Nowadays the instructions for the calculation of electrical loads are based on a modified statistical method (MSM). Due to it, the calculated value of the demand factor is determined by the expression:

$$K_d = K_{u,c} + \frac{0.5 - 0.4 K_u}{\sqrt{n_f T/T_0}} = \bar{K}_{u,av} + \frac{K_u - K_{u,av}}{\sqrt{n_f}} + \frac{0.5 - 0.4 K_u}{\sqrt{n_f T/T_0}}. \quad (2)$$

$$T_0$$ - 10 min - heating time constant electric conductor, $$T$$ - fact heating time constant of element systems, $$K_u$$ – weight average reference value. MSM is based on the equation of liner regression, which characterizes the correlation between the values of $$K_u$$ and $$\bar{K}_{u,av}$$ – these dependences are shown in Figure 1.

![Figure 1. Analysis of interrelated value of $K_u$ and $\bar{K}_{u,av}$.](image)

Correlation analysis of the paired values population $$K_u$$ and $$\bar{K}_{u,av}$$ allowed one to establish that an intimate connection between these parameters takes place in splitting the population into two ranges ($K_u < 0.5, K_u \geq 0.5$), with the number of points in each range $$N_f > 50$$ shows a fairly accurate significance of the correspondence. Using the least square method, the equations of the regression lines for the first and second ranges are obtained:
\[ \bar{K}_{u,av} = 0.58K_u - 0.05 \text{ at } K_u < 0.5 \]  \hspace{1cm} (3)
\[ \bar{K}_{u,av} = 0.7K_u - 0.12 \text{ at } K_u \geq 0.5. \]  \hspace{1cm} (4)

The value of \( K_{u,av} \) obtained by equations (3) and (4) are the average values of the use factor groups of receivers, characterizing the mathematical expectation with a known weighted average reference value \( K_u \).

According to the MSM, when determining the maximum load for the permissible heating, the average component should be calculated not by the mathematical expectation, but by the upper limit of the confidence intervals \( K_{u,av(g)} \) of the normal distribution law of particular values of \( K_{u,av} \) for the first and second ranges can be exceeded with a probability of not more than 0.05:
\[ K_{u,av(g)} = 0.6K_u \text{ at } K_u < 0.5 \]  \hspace{1cm} (5)
\[ K_{u,av(g)} = 0.8K_u \text{ at } K_u \geq 0.5. \]  \hspace{1cm} (6)

The formula for calculating the true power:
\[ P_t = K_f K_u P_{normal} \]  \hspace{1cm} (7)

\( K_f \) – coefficient of wattage rating:
\[ K_f = \frac{K_d}{K_u}. \]  \hspace{1cm} (8)

So, when using MSM, the error in the determination of electrical loads has decreased, using the existing reference and information base of values.

3. Justification for the correction of the approved method

Due to the change of law it became necessary to carry out technical re-equipment of all industrial facilities, including enterprises of the mineral resource complex, as one of the most energy-intensive systems [9]. The main aim of energy saving activities is to reduce electricity consumption. However, present methods for determining design loads don’t take into account occurred changes in power systems in recent years, therefore, it is essential to do research and identify the relationship between change in power consumption and the use of modern equipment and energy saving activities [2, 8]. Thus, in the modern methods of calculation it is essential to pay attention to the individual features of modern technological processes and, if necessary, to make adjustments to the factors used in the calculations [4, 7]. For this purpose, we carried out studies of the electric drive.

![Figure 2](image-url)  

Figure 2. Consumption of true and reactive power of the conveyor with and without the converter.
4. Experimental studies
The conveyor drive consists of the following components: drive 3-phase asynchronous motors 660V, 250 kW; 3-phase frequency converters 660V, 250 kW.

Figure 2 shows the dependence of the change in the active and reactive power consumed by the conveyor drive on the speed of the conveyor belt, both without regulation and with automatic regulation of the belt speed.

Figures 3 and 4 show the characteristics of changes in the active power of a conveyor system with an unregulated electric drive (Fig. 3) and an adjustable electric drive (Fig. 4). According to the results of the research, we revealed a discrepancy between established reference values $K_u$ of individual consumers with the adjustable speed of the conveyor belt and without regulation.

![Figure 3. True power consumption without converter..](image)

![Figure 4. True power consumption with converter..](image)

| Table 1. Propulsion parameters. |
|---------------------------------|
| Parameter of conveyer operation in a period probation | With converter | Without converter |
| Average value of true power consumption $P_{av}$ kW | 174.85 | 138.99 |
| Average value of reactive power consumption $Q_{av}$ kvar | 88.01 | 73.48 |
| Specific value of true power consumption per ton ore kW*h/t | 0.441 | 0.206 |
| Specific value of reactive power consumption per ton ore kvar*h/t | 0.222 | 0.109 |

The data obtained as a result of testing the conveyor is summarized in Table 1. The tests were carried out for two modes: in the mode with a constant speed of 3.15 m/s and in the mode of automatic control of the speed of the conveyor belt.
A comparison of the actual and predicted values of $K_u$ revealed that the reference data did not correspond to the experimental data, the values were given in the table below.

| $K_u$ | Reference value | $K_u$ fact with converter | $K_u$ fact without converter |
|------|-----------------|---------------------------|-----------------------------|
| 0.75 | 0.7             | 0.5                       |

Analyzing the values of table 2, we can conclude that the actual value of the use factor is 5% lower than the reference value, and using the converter it is 25% lower. The obtained data proves the need to adjust the approved method of load calculation.

The research in another technological processes have also shown a high energy effect from the use of converters, in particular, on pumps, fans, cranes, etc., and as a percentage this can reach about 70% in comparison with operation without adjusting the speed of technological rotation [1].

### 5. Conclusion

The article presents the rationale for the adjustment of the approved method for the calculation of electrical loads in order to improve the accuracy of the values that affect the technical and economic indicators of the entire complex of the enterprise. To reduce the error in determining electrical loads to acceptable values in engineering calculations, it is necessary to take into account the effect of energy saving measures taken on each electric receiver separately, in particular from the frequency converter installation. The conducted studies confirm the need to adjust the coefficients involved in the calculations using the existing method.

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