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Evaluation of "direct input" effectiveness for industrial enterprises power supply

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Abstract. The cost of energy has increased significantly for the industrial enterprises over the recent years, due to an increase in the electricity tariffs and the changes in the rules of the electricity market. Tariffs for electricity sold to consumers, differentiated according to various parameters, one of which is the voltage range. The higher the voltage range, the lower the tariffs, and thus, the consumer pays less for the supplied energy. Currently only for big consumers made energy supply "direct input" through the construction of an overhead line (OL) with a nominal voltage of 110 kV or 220 kV. However, it is advisable to consider the issue of power supply efficiency of big and medium-sized industrial enterprises based on the "direct input". The questions of voltage level study based on empirical formulas are considered in the article, expressing the dependence of the voltage from the transmission distance and the amount of transmitted power. It was proven that these formulas give a large spread, so intermediate voltage classes 35 kV and 110 kV, which compared with the traditional option of power supply on the basis of the cable line 10 kV, have been selected. Based on the technical and economic calculations it has been proved the value of the transmit power and length of the line at which the power supply of industrial enterprise on the basis of " direct input" with a nominal voltage of 110 kV becomes effective.

1 Introduction

One of the major stages in the planning of production start-up is the selection of the optimal power supply scheme, given that energy costs and industrial power systems constitute from 5 to 60% of the cost, depending on the type of product.

There are centralized and decentralized power supply scheme. In the first scheme, the consumer receives the electrical energy from the power grid, with the second one in the company is expected the construction of its own combined heat and power generation or other means (the local power plant, wind turbines, solar panels, etc.). Centralized electricity supply used in the availability of connection to the grid. This process is characterized by high reliability and efficiency, but requires the construction of lines, substations, and much depends on external conditions (grid). Independent electricity supply is used when it is impossible connection, at a considerable distance the consumer from grid.

Consider a centralized power supply of industrial enterprises. In this case, there is the problem of choosing the optimal voltage class, the number of transformation steps, determining the placement of shop, distributive and main step-down substation. In addition, it is necessary to satisfy the requirements for the quality of electricity. The overall objective of the optimization of industrial power supply (other than those mentioned above) systems includes the task of selection of cross-sections of wires and cable wires, automation and control, accounting and other value indicators.

2 Analytical ways of problem solving

It should be noted that overseas devoted considerable attention to the issue of finding a non-standard voltage rational analytical way. In foreign practice offered the following expressions for the non-standard rational voltage.

In American practice for non-standard voltage is applied Still formula:

$$U = 4,34 \cdot \sqrt{l + 16P}, \quad (1)$$

where P - is the transmitted power, MW; l - the distance, km.

Formula Still was transformed by S.N.Nikogosov and reduced to a more convenient form:

$$U = 16 \cdot \sqrt[4]{Pl} \quad (2)$$

In the directory of Swedish engineers nonstandard voltage is defined as follows:

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$$U = 17 \cdot \sqrt{\frac{l}{16} + P}, \quad (3)$$

where P - is the transmitted power, MW; l - the distance, km.

Formula Still and Nikogosov recommended for enterprises that have a design load of more than 5 thousand kV·A [2].

The above empirical formulas expressing the dependence of the voltage on the transmission distance and the amount of transmitted power, give a large spread. As it is difficult to judge which voltage should be given preference. Moreover, these formulas do not take into account many factors, both economic and technical, so they are not applied in practice.

3 Technical and economic calculations for choosing effective option

Based on all the above we can conclude that a rational power diagram of a specific enterprise is selected on the basis of technical and economic calculations, taking into account the perspective of enterprise development and district, indicators power supply systems and industrial enterprises, and other geographic location.

In recent years, along with the traditional way of power supply using a cable line rated voltage of 10 kV power began to be used the power supply way of an industrial enterprise "direct input" through the construction of overhead lines with a nominal voltage of 110 kV.

High voltage class is characterized by the lowest currents in conductors, and thus the least losses, requires one step of transformation 110/10, as well as the construction of the substation near the place of consumption.

This method is characterized by the largest capital investment in a single chain, the most expensive electrical equipment (switches, circuit breakers), however, the capacity of a circuit is very large. This makes it possible to use the network for the transit of electricity to neighboring businesses, that is, to perform the functions of the electricity supply company and earn extra income.

It is also interesting to consider the option of power supply with the intermediate voltage class 35 kV, accordingly with average values of currents and losses in transmission. The cost of capital in line comparable with the investments in 110 kV lines but less bandwidth. The main disadvantage of this option is the need for an intermediate voltage level and, accordingly, several transformers: 110/35 and 35/10, which leads to the need for the construction of two substations and a significant rise in the cost of this option, the annual increase in the costs of maintenance, repairs and depreciation.

Consider the problem of selecting the optimal variant of the centralized power of the industrial enterprise installed electric capacity of 19 MW, located 4 km from the main network. To do this, we define the optimal voltage class by empirical formulas for transmission of electricity, given above recommended for companies with an electrical load of more than 5 thousand kV·A:

1) Still Formula:

$$U = 4{,}34 \cdot \sqrt{l + 16P} = 4{,}34 \cdot \sqrt{4 + 16 \cdot 19} = 76{,}167\,kV; \quad (4)$$

2) Formula of S.N.Nikogosov:

$$U = 16 \cdot \sqrt[4]{Pl} = 16 \cdot \sqrt[4]{19 \cdot 4} = 47{,}241\,kV; \quad (5)$$

3) "Swedish" formula:

$$U = 17 \cdot \sqrt{\frac{l}{16} + P} = 17 \cdot \sqrt{\frac{4}{16} + 19} = 74{,}59\,kV. \quad (6)$$

The results confirm the conclusions previously made, a considerable spread and uncertainty of results. The average value of the voltage is 66 kV, which is intermediate between the voltage of 35 kV and 110 kV classes, so these voltage classes should be considered in the justification option energy industrial plant. As a result, three cases were considered (see Fig. 1):

1) electricity supply by constructing the cable line (CL) of rated voltage 10 kV;

2) "direct input" of electricity supply that is, through the construction of an overhead line (HVL) with a rated voltage of 110 kV;

3) electricity supply with the use of overhead line (HVL) an intermediate voltage class 35 kV.

Initial data for calculations under option are shown in Table 1.

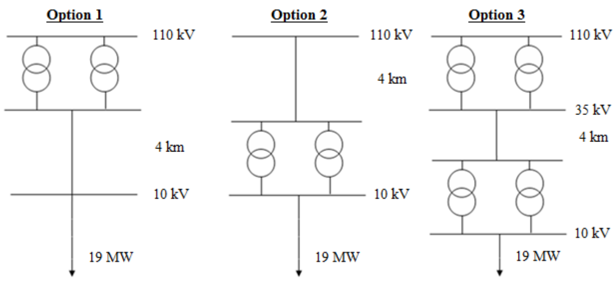

Fig. 1. Scheme of power supply of industrial enterprises.

Table 1. Baseline data on energy supply options.

Index	Option 1	Option 2	Option 3
Rated voltage	***10 kV***	***110 kV***	***35 kV***
The length of the line	4 km		
Using the maximum load	5500 hour		
load factor	cosφ=0,85		
Viewed operation period	15 years		
Location	Leningrad region		

The following assumptions have been made when performing calculations that introduce some uncertainty in the end result:

1) for all considered lifetime electric power consumption is assumed constant;

2) only active losses in the wires were taken into account in the calculation of losses;

3) the construction of substations and overhead lines and putting them into operation is carried out for 1 year;

4) all calculations were carried out based on the integrated value indicators (IVI), given in [3];

5) recalculation of the basic price 2000 year in to price of 2015 year was carried out on the basis of the conversion factors set out in the inter-regional information-analytical bulletin "Price indices in construction", published by KO-INVEST. The conversion factor prices 2000 year in to prices of 2015 year for capital investments in the branch "Electric power industry" is 8.33 [4];

6) zonal multipliers are taken to the European part of Russia;

7) all rates are assumed equal the unit to account complicating conditions.

For more accurate results, it was necessary to specifically consider the situation taking into account the logistics and production capabilities.

Capital expenditures for all of the options under consideration are composed of capital investment in the substation and line (aerial or cable depends on options):

$$I=I_{sub}+I_{line}\,, \tag{7}$$

where I_{sub} - capital investment in the substation (include the cost of the transformer cell, the cost of electric vehicles, for an accomplishment costs, temporary facilities, design and survey works, supervision, other works and the value of the land);

I_{line} - capital investment in the construction of air / cable line (include the material cost of the work on laying, landscaping, temporary structures, design and survey works, supervision, other works and costs, the cost of land).

To calculate the cost of capital used aggregated cost parameters without VAT according to [3], given the prices of 2000, which were recalculated in the prices of 2015 with using conversion factors [4].

The annual costs were calculated for comparative analysis, which include the cost of the substation and cable line, as well as losses in transmission C_{los} and mathematical expectation of damages from unreliable energy supplies M(d):

$$C=C_{sub}+C_{line}+C_{los}+M(d) \tag{8}$$

The value of M(d) is determined by multiplying the specific damage to the undersupply of electricity, ie $M(d) = d\cdot\Delta W$.

The costs of the substation include the following components:

$$C_{sub}=C_{a\_tr}+C_{m\_tr}+C_{r\_tr}+C_{a\_eq}+C_{m\_eq}+C_{r\_eq} \tag{9}$$

Conventions and formulas for the calculation of the substation costs are shown in Table 2.

Table 2. Annual costs for substation.

Index	Annual costs	The formula for calculating *)
C_{a_tr}	Annual depreciation expense on transformers	$C_{a\_tr}= n_a\cdot FA_{tr}/100$
C_{m_tr}	Costs for maintenance of transformers	$C_{m\_tr}= n_m\cdot FA_{tr}/100$
C_{r_tr}	The cost of repairs of transformers	$C_{r\_tr}= n_r\cdot FA_{tr}/100$
C_{a_eq}	Annual depreciation expense on electrical equipment	$C_{a\_eq}= n_a\cdot FA_{eq}/100$
C_{m_eq}	Costs for maintenance of electrical equipment	$C_{m\_eq}= n_m\cdot FA_{eq}/100$
C_{r_eq}	The cost of repairs of electrical equipment	$C_{r\_eq}= n_r\cdot FA_{eq}/100$

*) FA – fixed assets; n_a , n_m , n_r - norms of depreciations, maintenance and repair according to the data [3].

For the air (cable) line the costs were determined by the formula:

$$C_{line}=C_{a\_line}+C_{m\_line}+C_{r\_line}. \tag{10}$$

Symbols and formulas for the calculation of the substation costs are shown in Table 3.

Table 3. Annual costs of air / cable lines.

Index	Annual costs	The formula for calculating **)
C_{a_line}	Annual depreciation expense on air / cable lines	$C_{a\_line}= n_a\cdot FA_{line}/100$
C_{m_line}	Costs for maintenance of air / cable lines	$C_{m\_line}= n_m\cdot FA_{line}/100$
C_{r_line}	The cost of repairs of air / cable lines	$C_{r\_line}= n_r\cdot FA_{line}/100$

**) n_a , n_m , n_r – norms of depreciations, maintenance and repair according to the data [3].

The costs associated with payment of electricity losses, defined as:

$$C_{los}=p_e\cdot\Delta W_{los}\,, \tag{11}$$

where p_e – the average price of electricity for 2015 for the tariff group "network organizations that buy electricity for compensation of losses of electric power";

ΔW_{los} – value of transmission loss, kW.

According to the LLC "RKS-Energo" - guaranteeing electricity supplier in the territory of the Leningrad region - unregulated electricity prices to compensate for losses by months in 2015 ranged 1.47-1,93 rub. / kW·h .

On the basis of these data, the average price value was taken into account, which amounted to $p_e = 1.7101$ rub. / kW·h.

The value of the losses in the transmission is determined according to the formula:

$$\Delta W_{los}=3\cdot I_{max}^2\cdot R_{line}\cdot\tau\cdot n_{line} \tag{12}$$

where I_{max} - maximum normal current of the line;

R_{line} - the line resistance;

n_{line} - the number of lines (lines);

τ - equivalent time of loss, which is determined from the graph according to the data load factor and peak load time using [5].

The main criterion for choosing the best option energy efficiency of industrial enterprise is the criterion of maximum net present value, which is the difference between the discounted results of R and discounted cost C:

$$NPV = R - C \rightarrow max . \quad (13)$$

Income and costs are the same for all three options, so instead of the criterion of a maximum net present value, we can use the criterion of the minimum discounted costs.

$$C = \sum C_t (1+E_{nr})^{-t}, \quad (14)$$

where C_t - the costs for the year t,

E_{nr} - the discount rate (the interest rate of the bank).

Given that the calculation of the efficiency variant carried in basis (constant) prices, we can use the real interest rate. There are nominal and the real rate. According to Fisher's equation:

$$E_{nr}=E_r+r_i+E_r\cdot r_i, \quad (15)$$

where E_{nr}, E_r - nominal and real rates of bank, r_i - the percentage of inflation.

For small values of interest rate E_r and inflation r_i product $E_r\cdot r_i$ can be neglected. Then, instead of the nominal bank rates in the calculations we can use the real rate, which can be taken as equal to 2-3% [6].

The results obtained by the choice of power options of industrial enterprise in the transmission power equal to 19 MW at a length of 4 km line are shown in Figure 2.

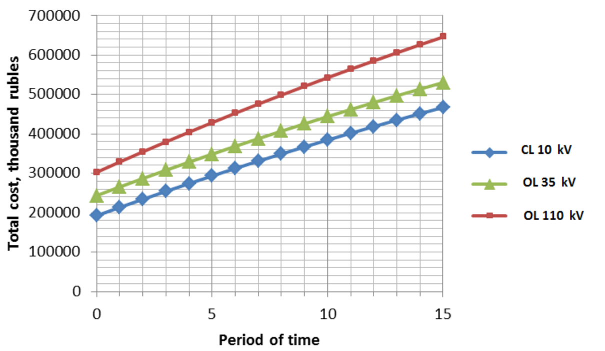

Fig. 2. Comparative characteristics of the three power supply options, depending on the time of operation.

The calculation results show that the option of power supply "direct input" is not effective.

Compare options of energy supply company also carried out when changing the transmitted power from 10 MW to 29 MW with using the minimum of resulted expenses taking into account the security of energy supply:

$$RE = E_{nr}\cdot I+C+M(d) \rightarrow min, \quad (16)$$

where I - capital investment, thousand rubles / year;

C - the annual operating cost, assumed constant during the entire period of operation, rubles / year;

E_{nr} – normative coefficient of comparative effectiveness of capital investments, which in a market economy is accepted at the refinancing rate of the Central Bank;

M(d) – the mathematical expectation of damages from unreliable energy supplies the mathematical expectation of of loss from energy insecurity, thou. / year.

The results are shown in Figure 3.

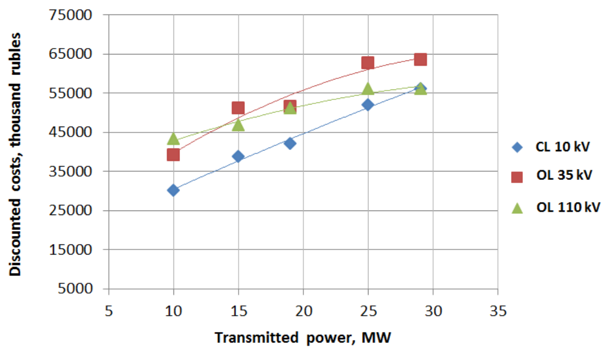

Fig. 3. Comparison of energy options depending on the transmitted power.

On the basis of the calculations we can conclude that the most effective option at the lowest cost given transmission capacity to 29 MW is a variant of the cable line 10 kV. In the transmission more than 29 MW of power supply option overhead line 110 kV becomes preferable the option of the cable line 10 kV. Option 35 kV overhead line is the least effective.

There was also a comparative analysis of options for the industrial supply company, depending on the length of the line (from 1 km to 8 km) using a minimum criterion of reduced costs, taking into account reliability of energy supply (see. Fig. 4).

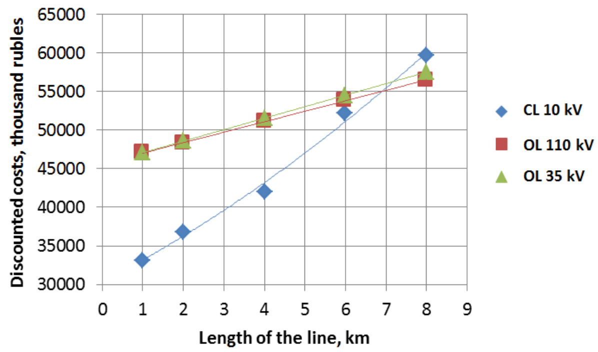

Fig. 4. Dependence of the discounted costs of the line length.

As can be seen from Figure 4 for line lengths of up to 7 km of the highest priority option when transferring 19 MW power is a cable line 10 kV, with a length of more than 7 km of line the best option is the option of using the overhead line 110 kV.

3 Conclusions

1. Existing analytical approaches to find rational voltage for electric power supply of industrial enterprises give a considerable variation in voltage level depending

on the parameters of transmit power and line length. It is expedient to consideration of voltage 35 kV and 110 according to the resulting medium voltage 66 kV.

2. Three energy supply options have been considered In justifying of energy supply of industrial enterprises: energy supply is carried out on the cable line 10 kV overhead line at 110 kV and 35 kV overhead line. On the basis of the calculations It can be concluded that the optimal variant of the power supply of industrial enterprise with capacity of 19 MW, and the 4 km long for connection to the network is the option of using a cable line 10 kV. Other power supply options have as an advantage - a large energy capacity. In this case, the company can act as a supplying company for closely located energy consumers, and thus can extract additional profit.

3. Choosing the best option depends on the installed power capacity of the enterprise and line length. On the basis of calculations, it was determined that the option 110 kV overhead line become preferred over the other options, from the transmit power 29 MW and the line length of 4 km ("direct input" option). Influence of the line length on the choose the optimal variant showed the following. The most effective option is a power option using a cable line 10 kV transmission power 19 MW with a cable length of up to 7 km, with a cable length of more than 7 km the most profitable option is the option of using the overhead line 110 kV.

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