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Development of Mathematical Model for Determining The Relative Power Loss of Power Transmission Lines

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ABSTRACT

One of the many problems faced by the power transmission and distribution network in our country is the problem of reducing the power losses during power transmission. This article presents the results of a study on technical losses as a component of intensity losses. In this study, a mathematical model was developed to determine the relative power loss, taking into account both load and conditional-constant losses. For the selected research object, the relative power loss was determined using the mathematical model developed above using MATLAB software, and the results were displayed graphically, and corresponding appropriate conclusions were drawn. It can also be seen from the calculation results that when the cross-section of the line conductor increases or the resistance of the conductor decreases, the loading current increases and the relative power loss can become a smaller value.

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1. INTRODUCTION

Power transmission lines provide communication between electric power stations and consumers of electricity. According to its purpose, all power transmission lines can be divided into distribution, backbone and intersystem. The voltage of the distribution lines does not exceed 220 kV, the backbone lines – 500 kV, and the voltage of the intersystem lines reaches 1000 kV or more, depending on the length of the line.

When transferring electric energy to the consumer, losses of electric power inevitably occur. The main task in designing the electrical connection of an electric generating source with a consumer is to reduce power and energy losses in all sections of the power system. This is due to the fact that losses lead to an increase in the capacity of the power plant, which in turn affects the cost of electricity [1-12].

Technical losses during electric power transmission consist of load and conditional-constant losses according to the standard [13].

Load (variable) loss – this is the loss caused by the heating of the transverse element to the electric power system. These include: transmission line losses (overhead and cable lines), buses, power transformers, and current limiting reactors.

Conditional-constant loss – this is a part of the technical loss that occurs on the elements of the electrical network, which does not depend on the transmitted power. Specifically, it is the loss that occurs in the cross branches elements of the substitution scheme. The three constituents of conditional-constant losses depend on climatic conditions.

In this research work, we studied what measures can be taken to keep conditional-constant losses at a low level, including technical losses, depending on the characteristics of the area where the Overhead

transmission lines (OHTL) is laid, and climatic conditions. The calculation of 110 kV Khotol overhead line was considered as a research object.

2. METHODOLOGY

Overhead transmission lines (OHTL) weather losses include overhead corona losses (ΔW_{cor}), overhead line leakage current losses (ΔW_{ins}), and deicing losses (ΔW_{deic}).

According to [14], the power used for ice melting of overhead lines with a cross-sectional area of 95-330 mm^2 is 24-74 kWh/km, that is, it accounts for approximately 0.2% of the total climate loss. Therefore, the energy consumption factor for deglaciation is not considered in the following calculations.

The power loss due to overhead line load ΔW_{load} is calculated as follows for a line of length L:

$$\Delta W_{load} = 3I_{max}^2 \cdot r_0 \cdot L \cdot \tau, \quad (1)$$

Where: I_{max} – current during the maximum load of the overhead line, A; r_0 –resistivity of the line, Ohm/km; τ – time of maximum loss, h, determined by the following empirical formula:

$$\tau = (0.124 + 10^{-4}T_{max})^2 \cdot 8760, \quad (2)$$

Where: T_{max} – maximum load time, h.

The power loss due to corona on overhead line ΔW_{cor} is determined based on the power loss given in the reference textbook, and depending on the duration of the weather conditions during the calculation, it can be determined by the following formula:

$$\Delta W_{cor} = L \sum_{i=1}^{4} \Delta P_{cor.i} \cdot T_{\rho i} \cdot k_{cor}, \quad (3)$$

Where: $T_{\rho i}$ – duration of i-th type of weather, h; ΔP_{ki} – power loss due to corona during the i-th weather, kW/km; k_{cor} – working voltage correction coefficient, which is determined by the following formula:

$$k_{cor} = 4{,}65U_{rat}^{2*} - 3{,}65U_{rat}^{*}, \quad (4)$$

Where: U_{rat} – the ratio of the working voltage of the line to its normal value.

The main factor for determining the losses caused by the corona of the overhead line is the ratio of the electric field strength of the conductor surface to the initial strength, which is determined depending on the working voltage of the corona, the cross-section and quantity of the phase conductors, the type of support, and the electrical characteristics of the air. In the absence of information on the duration of climatic types, the line corona power loss can be determined by the annual average power loss, which is determined depending on the region in which the overhead line is located.

$$\Delta W_{cor} = 8760 \cdot L \cdot \Delta P_{cor.ave}, \quad (5)$$

Power losses due to leakage currents in overhead line insulation.

The current flowing through the insulator under normal operating conditions is called the background leakage current.

$$\Delta W_{i.s} = \frac{U_{nom}^2}{3 \cdot R_{i.s} \cdot N_{i.s}} \cdot T_{OHTL} \cdot L \cdot N_{i.d} \quad (6)$$

Where: T_{OHTL} - duration of wet weather during the calculation period, h; $N_{i.d}$ – number of insulator disk of insulator string, quant/km; $R_{i.s}$ – insulator's resistance depending on the level of air pollution ($R_{i.s} = 915$ kΩ for the chosen level of pollution); $N_{i.s}$ – the number of insulators per line phase.

In the calculation of determining the number of insulator disk for overhead lines of different voltage levels, their average whole number (per 1 km) is selected according to [14].

Table 1. The number of insulator disk depending on the line voltage

Overhead line voltage, kV	$N_{i.s}$**, quant/km**

500	11,3
220	9,8
150	11,2
110	12,9
35	23,4
6-20	46,8

The annual relative power loss of total energy $\frac{\Delta W_\Sigma}{W}$ for a given overhead line is determined by the following formula:

$$\frac{\Delta W_\Sigma}{W} = \frac{\Delta W_{load} + \Delta W_{cor} + \Delta W_{i.s}}{W}$$

$$\frac{\Delta W_\Sigma}{W} = \frac{(3I_{max}^2 \cdot r_0 \cdot L \cdot \tau) + (8760 \cdot L \cdot \Delta P_{cor.ave})}{\sqrt{3} U_{nom} I_{max} \cdot T_{max} \cdot \cos\varphi} + \frac{\left(\frac{(U_{nom}^2)}{(3R_{i.s} N_{i.s})} (T_{OHTL} \cdot L \cdot N_{i.d})\right)}{\sqrt{3} U_{nom} I_{max} \cdot T_{max} \cdot \cos\varphi}; \quad (7)$$

Therefore:

$$\frac{\Delta W_\Sigma}{W} = f(I_{max}, r_0, L, \tau, \Delta P_{cor\ ave}, R_{i.s}, N_{i.s}, N_{i.d}, T_{OHTL}, \cos\varphi)$$

In this (7) way, the correlation concentrates all the technical parameters of the line and steady state, and can be adjusted using the above ratio to keep the relative power loss to a minimum value.

3. RESULTS AND DISCUSSION

The transmission line named Khutul from 110 kV bus of Darkhan substation was taken as the object of this study. The length of line is L=45.1 km, voltage $U_{nom} = 110$ kV, and the maximum load usage time is $T_{max} = 5868$ hours. We can determine the relative power loss in the overhead line using the mathematical model developed above using MATLAB software.

During the construction of high-voltage lines and distribution facilities, the level of air pollution in the area is determined [15-16]. According to the International Electrotechnical Commission (IEC) recommendation standard, the environment is divided into 4 pollution zones, and the Central Region Branch of the Electric Power System, in which located our object of study, is covered by the 2nd zone according to the standard.

The minimum relative power loss within a conductor with a cross sectional area of AC 95; 120; 150; 180; 205 mm^2 is determined, and its dependence on the load current is shown in figure 1.

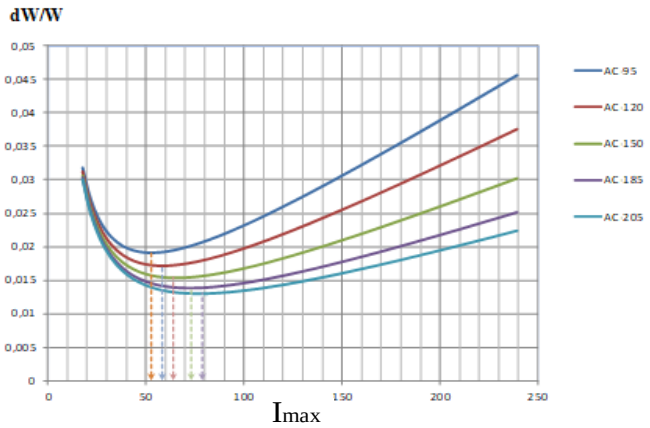


Figure 1. Dependence of the relative power loss of the 110 kV overhead line depending on the load current

As can be seen from Figure 1, at a certain value of the current, the total relative power loss is at its minimum value, which can be called the minimum current loss. As the cross-sectional area of the conductor increases, the optimum current I_{opt} shifts to the right, but it shifts to the left as the peak operating time increases. From the expression (7) above, the formula for determining the value of the optimal current corresponding to the minimum relative power loss after conversion to zero can be derived as follows:

$$I_{opt} = 10{,}54 \times \sqrt{\frac{26285{,}07 N_{i.s} R_{i.s} \Delta P_{cor.ave} K_{cor} + U_{nom}^2 T_{OHTL} N_{i.d}}{N_{i.s} R_{i.s} r_0 \tau}}; \quad (8)$$

In this way, the line current load corresponding to the I_{opt} value causes the relative power loss of the minimum loss of the given OHTL. This current is called the minimum loss current, depending on the technical parameters of the overhead line and its mode parameters. Based on the calculation made by formula (8) using MATLAB software for 110 kV substation located in the 2nd zones according to the level of pollution,

For overhead lines located in the 2nd zone by the degree of pollution, the optimal current relationship was established based on the calculations made using the MATLAB software. Calculations were made using MATLAB for the overhead line located in the 2nd zone of the degree of pollution, and based on result of calculation the optimal current correlation graph was created. (figure 2)

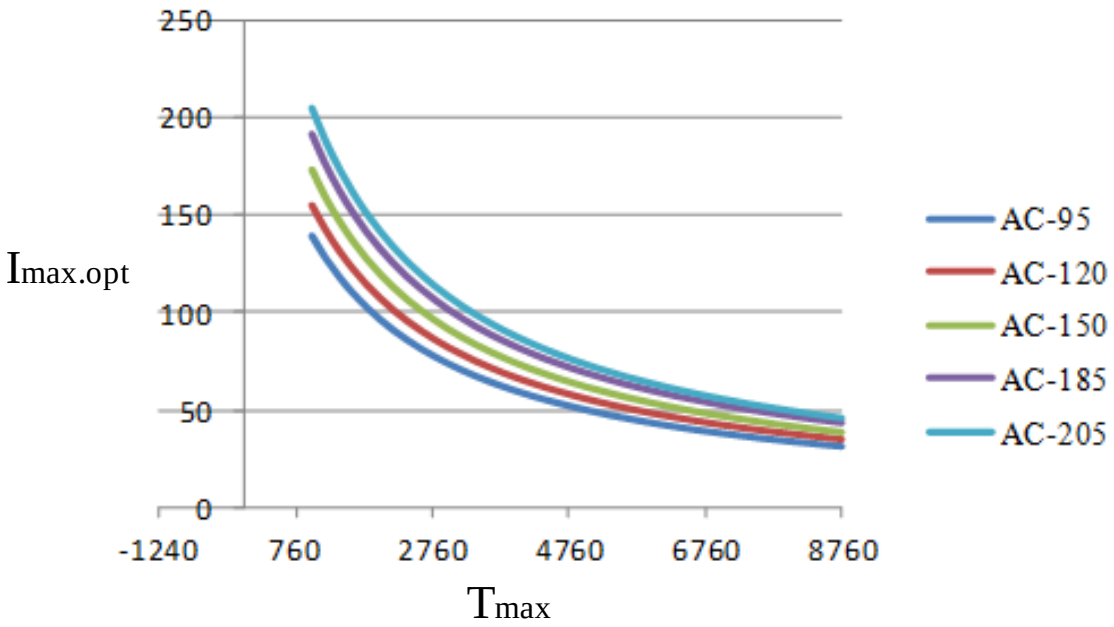


Figure 2. Dependence of the optimal load current on the maximum load usage time of 110 kV overhead line located in Air Pollution Zone 2

As can be seen from the arrangement in figure 2, the optimal overhead line load current decreases as the maximum active power consumption time increases. After that, the result calculated by formula (8) was substituted into (7) and the relation

$\frac{\Delta W_{\Sigma}}{W} = f(I_{\text{оновч}})$ was established, shown in figure 3.

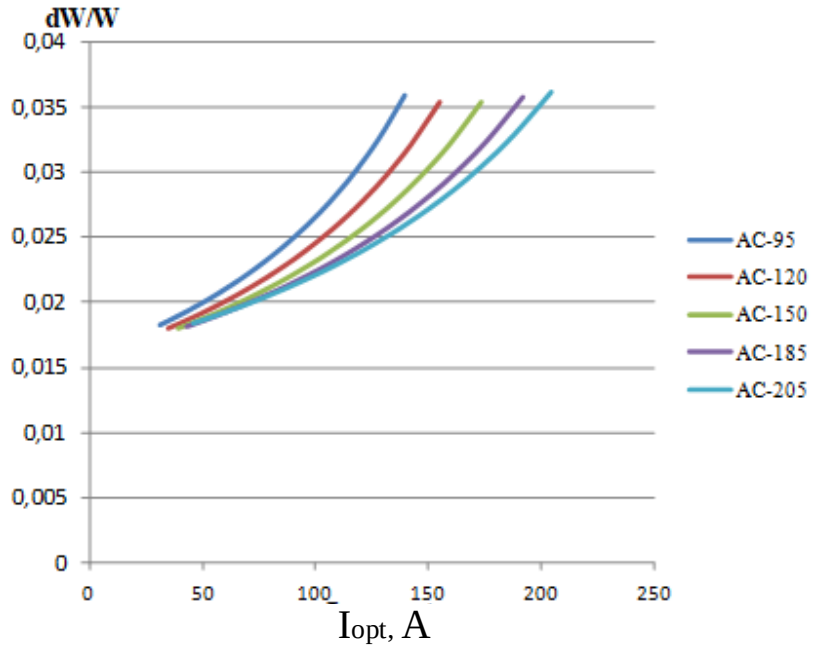


Figure 3. Normalized relative power loss as a function of optimal load current

This non-linear relationship of the minimum relative power loss with the optimal current indicates that the minimum relative power loss increases as the optimal current increases.

The relationship between the load current and the minimum value of the relative power loss of the 110 kV Khutul overhead line of the power network under study was calculated for the following cross-sectional areas of conductors. As can be seen from table 2 and the graph shown in figure 1, the load current of the overhead line is 31 A, which is still not the optimal current for the minimum relative power loss.

Table 2. Dependence of relative power loss on-line load current

Type of conductor	**Load current I_{load}, A**	**Relative power loss dW/W**	**Optimal current I_{opt}, A**
AC-95	37,9÷67,0	0,0191÷0,0201	52,4
AC-120	43,7÷72,8	0,0172÷0,0179	58,3
AC-150	49,5÷81,6	0,0154÷0,0159	64,1
AC-180	55,4÷87,4	0,0139÷0,0142	69,9
AC-205	61,2÷93,3	0,0131÷0,0133	75,8

Therefore, the value of $\frac{\Delta W_{\Sigma}}{W} = 0{,}0204$ is greater than the minimum value of the calculated relative power loss. If the load current is close to its value of 58.3 A, then the relative power loss will be the minimum value of 0.0172.

According to the last five years of load research, the load of the Khutul substation fluctuated between 22-43 A on average. This indicates that the line, once constructed, does not operate in a mode that may have low power loss.

4. CONCLUSION

In this study, the cross-sectional area of the AC conductor of the 45.1 km long line leading to Khutul substation was recalculated, and the relative power loss was determined depending on the load current. As can be seen from the graph, the relative power loss reaches its minimum value in a certain interval of the load current of the line conductor, and the value of the relative power loss increases as it increases and decreases from that base interval. Therefore, it is possible to reduce the technical losses in the network by loading the line conductors with such a current that they are in the interval where the relative power loss is low. When the cross-section of the line conductor increases or the resistance of the conductor decreases, the load current increases and the relative loss can become a smaller value.

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