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Optimizing the operation of a high-voltage power line in Turkmenistan considering climatic conditions

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Abstract. This scientific article is devoted to the optimization of a 500 kV high-voltage power line, taking into account the climatic characteristics of Turkmenistan. As a result of the research, it was found that with a nominal line voltage of 500 kV under standard weather conditions, the load losses were 11.45 MW, the corona losses were 0.76 MW and the total power losses were 12.21 MW, in dry snow, corona losses amounted to 2.98 MW, and total power losses amounted to 14.43 MW; in rainy weather, corona losses amounted to 9.76 MW, total power losses amounted to 21.21 MW, and during frosts, corona losses amounted to 26.02 MW, total power losses amounted to 37.47 MW. For this reason, to reduce power losses in the line Mary PPS – Serdar 500 kV for P=0.2P_{nat} value, it is recommended to keep the voltage at 1.05 U_{nom} in standard weather conditions, at U_{nom} value in dry snow, and at $0.95U_{\text{nom}}$ in rain and frost.

1 Introduction

The demand for electric energy is increasing due to the extensive development of manufacturing industries and the expansion of the infrastructure of cities. Thus, along with the consumption of electric energy, the amount of its loss also increases. This inefficiency affects the operation of the power system, highlighting the need for optimization to limit electrical energy losses in power systems and networks [1]. In this regard, on February 21, 2018, within the framework of the "State Energy Saving Program of Turkmenistan for 2018-2024" was launched. The program’s goals remain crucial today, and finding effective strategies to minimize energy waste and enhance the power grid’s reliability is a top priority [2].

In general, optimization problems related to transmission and distribution of electric power are distinguished by their complexity and diversity. Therefore, it is necessary to take into account the optimization problems when designing or upgrading the power grid [3-4].

An increase in the electric field strength beyond a certain threshold value leads to increased ionization of the air around the conductor, resulting in corona discharge, a type of spontaneous gas discharge [5]. As the conductor voltage increases, the electric field

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strength also increases. This leads to further strengthening of the ionization process and an increase in free charges. Depending on the weather conditions, the transition of the ionization process changes, and as a result, the specific active corona loss also changes [6].

1.1 Literature review

In [7], the authors studied the causes of power outages in mining mines, and determined that the most typical accidents were due to overlapping of 6 kV cables, insulator punctures, damage to couplings and cable breaks. In [8], the authors investigated the difference between the calculated and measured conductor temperature and obtained a value of 2.28oC, which obviously leads to errors in the calculation of the line capacitance. For this reason, the authors tested the two known methods (integration and Monte Carlo) to reduce the estimation errors. And in [9] the authors have done a great job in reviewing the work done on the effect of weather conditions on the temperature dependencies of transmission lines and the implications of connecting additional energy sources from renewable energy sources, also discussing the theoretical limitations of traditional power flow and state estimation methods and reviewing the developed approaches to overcome the temperature limitations of traditional methods. And the paper [10] by our colleagues from the State Energy Institute of Turkmenistan focuses on the effect of changing the zero-sequence resistance on the detection of line faults. To determine the short-circuit current from the oscillograms, it is proposed to determine the steady state of the fault, in which the value of the current is approximately the same. The oscillogram of single-phase short-circuit in 110-220 kV networks of the southern part of the power system of Turkmenistan has been analyzed.

This scientific work aims to determine the optimal voltage in electrical network nodes to minimize total power losses, encompassing both load and corona losses.

The object of the study is the Mary PPS–Serdar 500 kV power transmission overhead line with a nominal voltage of 500 kV and a length of 271 km.

2 Materials and methods

2.1 Features of the climate of Turkmenistan

Data on the country's climate were analyzed in [11], and data on the intensity of solar radiation and wind speeds are given in [1-2].

2.2 Formulation of the problem

Let's consider some issues of optimizing the operation of the research object.

The diagram of the studied overhead power line (OHPL) is shown in Figure-1.

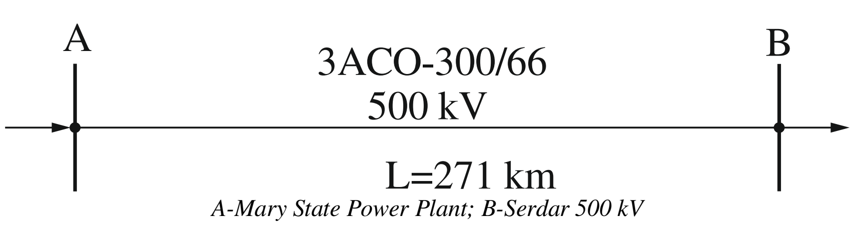

Fig. 1. Line Mary PPS – Serdar 500 kV.

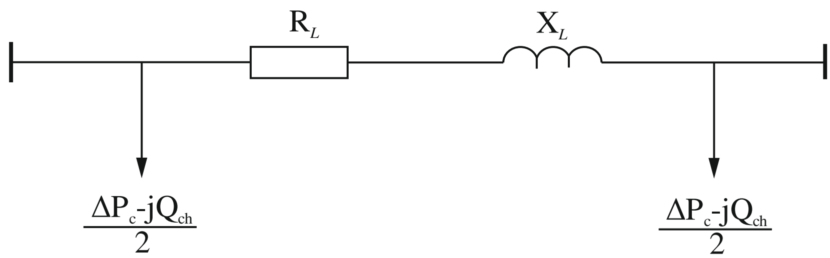

Fig. 2. Substitution diagram of the 500 kV line.

This line is made of 3xACO-300/66 wire, the dimensions of the conductor are shown in Table 1 [13].

Table 1. Wire core sizes.

Nominal area, mm² **(aluminium/steel)**	**Number of wires per phase**	r_0**, Om/km**	x_0**, Om/km**	b_0**, Sm/km**
300/66	3	0.33	0.31	$3.97 \cdot 10^{-6}$

M core 3xACO-300/66 and its value in different weather conditions Table 2 shows [14]

Table 2. M core 3xACO-300/66 and its value in different weather conditions.

Rated mains voltage, U, kV	**Active loss to the crown in various weather conditions,** ΔP_{uk}**, kW/km**			
	in good weather	**dry snow**	**in the rain**	**in the cold**
500	2.8	11.0	36.0	96.0

The minimum active power loss on this line is used as a criterion for optimizing the operation of the 500 kV overhead line.

2.3 Calculation formulas

In this case, the optimal voltage that provides the minimum value of the total active power loss is selected [15]:

$$\Delta P_{\Sigma} = \Delta P_{ý} + \Delta P_{k} \rightarrow \min \tag{1}$$

Where, $\Delta P_{ý}$ - active load losses, MW; ΔP_k - active corona losses, MW.

The active load losses associated with the transmission of active capacity along the line can be determined by the following formula:

$$\Delta P_{\text{los}} = \left(\frac{P}{U}\right)^2 \cdot R_L \tag{2}$$

Where R_{L} is the active resistance of the line, which is determined by the following formula:

$$R_L = r_o \cdot L \tag{3}$$

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Where, r_0 - specific active resistance, Ohm/km; L - line length, km.

Then we calculate the active resistance of the line according to the formula (3):

$$R_L=0.33\cdot 271=89.43 \text{ Ohm}$$

Active corona loss is determined by the following formula:

$$\Delta P_{cor}=\Delta P_{den}\cdot L\cdot k_U \tag{4}$$

Where ΔP_{den} – specific active corona loss, MW.

The k_U coefficient is a coefficient that makes it possible to determine the active power loss when the active U voltage differs from the nominal U_{nom} voltage. This coefficient is defined by the following formula:

$$k_U=6.88\cdot\left(\frac{U}{U_{nom}}\right)^2-5.88\cdot\frac{U}{U_{nom}} \tag{5}$$

In electrical networks with a voltage of 500 kV, the maximum permissible voltage value is determined by the normal operation of the protective devices of electrical loads and is equal to 525 kV.

Determine the optimal voltage that provides the minimum value of active power loss for different values of active power ($P=(0.2–1.1)P_{nat}$) and different weather conditions transmitted along the Mary PPS -Serdar 500 kV overhead transmission line . For this, the operating voltage of the line is $U=(0.95–1.05)U_{nom}$ Determine the active power losses corresponding to each power transmitted over the distance ($P=(0.2–1.1)P_{nat}$) by varying the distance . The results obtained are shown in Table-3.

P_{nat} - that's it the natural capacity of the line is determined by the following formula:

$$P_{nat}=\frac{U^2}{Z_t} \tag{6}$$

Where, Z_t is the wave resistance of the line, Ohm

The total resistance of the line is:

$$Z_t=\sqrt{\frac{L_0}{C_0}}=\sqrt{\frac{x_0}{b_0}} \tag{7}$$

Then natural power:

$$P_{nat}=\frac{U^2}{\sqrt{\frac{x_o}{b_o}}} \tag{8}$$

Where: x_0 - the inductive resistance of the line per unit length, Ohm/km; b_0 - voltage per unit length of the line, Sm/km.

(6) calculate the natural capacity of the 3xACO-300/66 wire using the values in Table 1 according to the formula:

$$P_{nat} = \frac{500^2}{\sqrt{\frac{0.31}{3.97 \cdot 10^{-6}}}} = 894.65\,MW$$

3 Results and Discussion

$P = 0.2\ P_{nat}$ value of the power transmitted from the line, by keeping the voltage at $1.05U_{nom}$ in good weather, keeping U_{nom} in dry snow, and keeping it at $0.95U_{nom}$ in rain and frost, Mary PPS –Serdar 500 kV transmission air active power losses in the line can be greatly limited. The power transmitted along this line is P=(0.2–1.1)P_{nat} For other values in the range, it is possible to obtain the correlations in Figures 3 and 4 by performing the same calculations as above for different weather conditions.

Table 3. Data.

Power loss		Operating voltage				
		0.95U_{nom}	**0.97U_{nom}**	**U_{nom}**	**1.03U_{nom}**	**1.05U_{nom}**
Load losses ΔP_L, MW		12.69	12.17	11.45	10.80	10.39
Crown losses, ΔP_c, MW	Standart climate	0.47	0.58	0.76	0.94	1.07
	Dry snow	1.86	2.30	2.98	3.70	4.21
	In the rain	6.08	7.51	9.76	12.12	13.77
	In the frost	16.21	20.03	26.02	32.33	36.71
Total losses ΔP, MW	Standart climate	13.16	12.75	12.21	11.74	11.46
	Dry snow	14.55	14.47	14.43	14.50	14.60
	In the rain	18.77	19.68	21.21	22.92	24.16
	In the frost	28.90	32.20	37.47	43.13	47.10

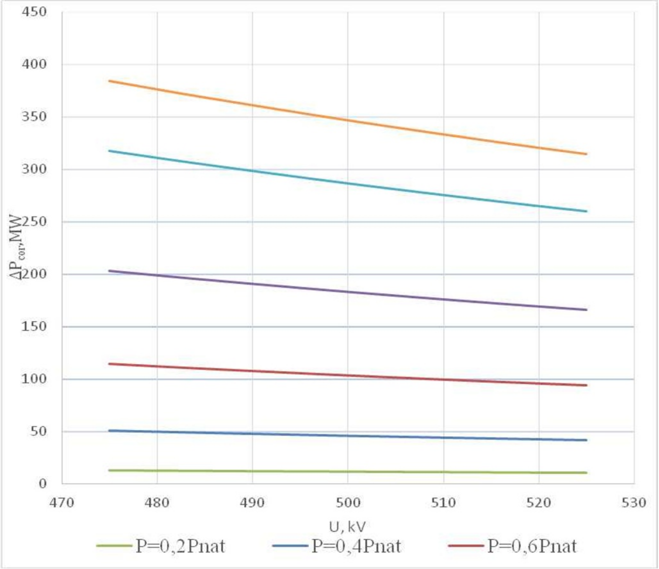

Fig. 3. Active power losses for different values of transmitted power along the line.

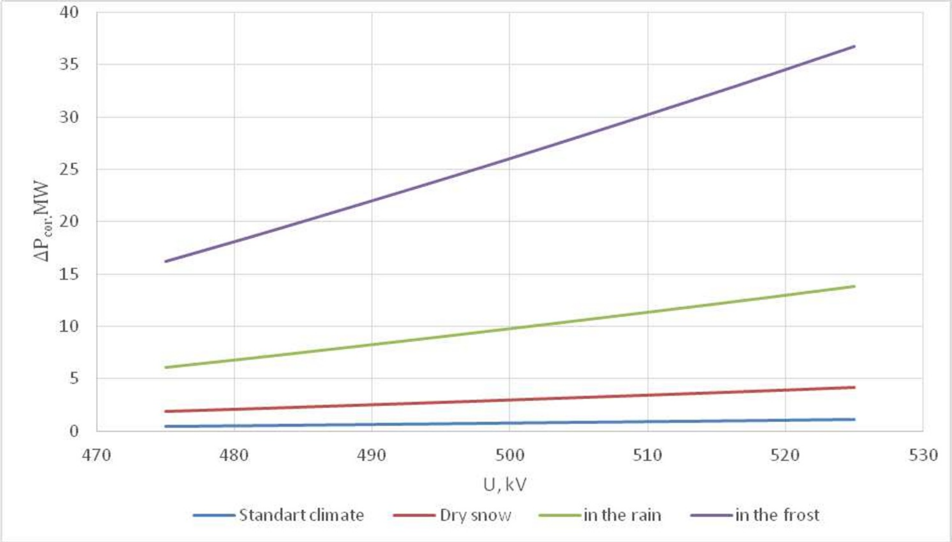

Fig. 4. Active corona losses in 500 kV line for different weather conditions.

As can be seen from Figure 3, the load losses at different values of the transmitted capacity on the line decrease with increasing voltage.

As shown in Figure 4, active power losses to the corona increase with increasing voltage. The resulting corona losses vary depending on weather conditions. Of course, under normal conditions (+20 ºC) insulation losses are kept to a minimum depending on the voltage. But corona losses also increase as the voltage increases in the frosted circuit.

4 Conclusion

This study investigates the impact of weather conditions on power losses in overhead transmission lines. The analysis, informed by the data from Figure 5, suggests that strategically selecting and installing overhead lines based on regional weather patterns can significantly reduce power losses. This approach is particularly beneficial in areas prone to high winds and fog.

The research also examined power losses under various weather conditions on a 500 kV line (Mary PPS-Serdar) operating at nominal voltage. Under standard weather conditions, total power losses were 12.21 MW, with 11.45 MW attributed to load losses and 0.76 MW to corona losses. In dry snow conditions, total losses increased to 14.43 MW, primarily due to a rise in corona losses (2.98 MW). Rainy weather resulted in a significant increase in total losses (21.21 MW), with corona losses reaching 9.76 MW. The most significant losses (37.47 MW) occurred during frost events, with corona losses reaching a peak of 26.02 MW.

To minimize power losses on the Mary PPS–Serdar line, the study recommends implementing voltage regulation strategies based on weather conditions. Maintaining voltage at 1.05 times the nominal voltage (1.05 U_{nom}) during standard weather is recommended. Under dry snow conditions, nominal voltage (U_{nom}) should be maintained. Finally, during rain and frost events, reducing the voltage to 0.95 times the nominal voltage (0.95U_{nom}) is suggested.

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