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CALCULATION OF ELECTRICITY LOSSES IN RURAL POWER TRANSMISSION LINES WITH 6-10 KV VOLTAGE

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ABOUT ARTICLE

Key words: Electricity losses, power transmission lines, rural power supply, SAIDI, SAIFI, reliability parameters, energy loss modeling, step-down transformer, Qibray substation, external factors.

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Abstract: This study presents a detailed analysis of electricity losses in rural power transmission lines operating at 6-10 kV, using SAIDI and SAIFI reliability indices for post-implementation assessments. To proactively evaluate operational efficiency, we model energy losses in the system's components, including substations, overhead lines, cable lines, and step-down transformers. The Qibray 35/6 kV substation is used as a case study for calculating these losses. Our findings highlight that additional losses are notably higher than calculated losses, emphasizing the importance of external factors in loss modeling. This comprehensive approach offers insights into enhancing system reliability and performance for rural power distribution systems.

INTRODUCTION

coefficients requires a time interval of several months or even years after the system has been launched [1,2]. However, to assess the operational efficiency of the power supply system in advance, it is necessary to model the energy losses and evaluate these losses based on the developed model. The higher the energy losses, the more the technical parameters of the equipment used in the power supply system deteriorate, which, in turn, shortens their operational lifespan [3]. Based on this issue, this section of the dissertation examines the problem of modeling electricity losses in the research object's power supply system.

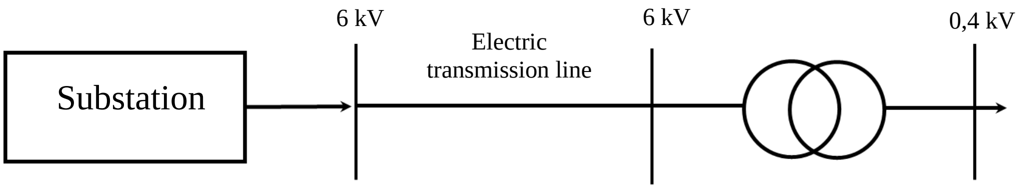

Figure 1. Schematic diagram of the 6 kV rural power supply system

It is known that the object of the study is supplied with electricity based on the scheme shown in Figure 1. Initially, electricity is transmitted to consumers through 6/0.4 kV transformers via substation feeders and through overhead and cable lines. Based on this setup, electricity losses are calculated by dividing the losses into the following parts [4]:

1. Determining the electricity losses at the 35/6 kV substation
2. Calculating electricity losses in the 6/10 kV overhead lines
3. Calculating electricity losses in the 6/10 kV cable lines
4. Calculating electricity losses in the 6/10/0.4 kV step-down transformers
5. Calculating additional electricity losses in the 6/10 kV power supply system

Electricity losses for each stage in the research object are determined in three steps. Initially, the electricity losses at each stage, along with the energy balance, allow for calculating the total electricity losses as follows [5]:

$$\Delta W = W_n - W_{n+1} \tag{1}$$

where: ΔW – Total electricity loss

W_n – n - Meter indicator

W_{n+1} - Meter indicator

In the next stage, calculated electricity losses are determined using specific functional formulas. In the final stage, an energy loss balance is created, and the value of additional electricity losses is determined as follows:

$$\Delta W_{\text{K}} = \Delta W - W_{\text{X}} \tag{1}$$

where, ΔW_{X} – Electricity loss calculated based on the method of computational formulas.

Calculation of electricity losses (EE) is carried out based on the single-line diagram of the 35/6 kV substation, by calculating EE losses in transformers, short transmission lines, switching devices, electricity meters, and protective devices at the substation [6].

METHODS

To calculate electricity losses in rural 6-10 kV power transmission lines, a systematic modeling approach was employed. The study segmented the power system into its primary components: substations, overhead lines, cable lines, and step-down transformers. Losses at each stage were calculated through theoretical formulas and operational data analysis. The methodology incorporated the evaluation of idle and short-circuit power losses, factoring in external influences such as load variation and environmental conditions. For substations, calculations were based on parameters like power consumption in idle and short-circuit modes, using data from the Qibray 35/6 kV substation as a case study. Overhead and cable line losses were computed using resistance, load, and line length data. Transformer losses were assessed with detailed load curves and equipment specifications. Additionally, an energy balance analysis was conducted to determine total and additional losses, enabling the identification of discrepancies due to external factors. This comprehensive approach ensured accurate modeling and evaluation of electricity losses in rural distribution systems.

RESULTS AND DISSCUSSION

Determining electricity losses at the 35/6 kV substation. The "Qibray" 35/6 kV substation in the research object is equipped with a 4000/35 TMN transformer, manufactured in 1982. The main parameters of the installed transformer are provided in Table 2.3.

Table 1.

Parameters of the Main Step-Down Transformer of the Qibray 6/35 kV Substation

Types	S кВА	$U_{\text{н}}$, кВ		Connection diagram	ΔP, кВт		$U_{\text{қ.т}}$, %	$I_{\text{салт}}$
		ЮК	ПК		салт	қ.т.		
ТМН 4000/35	4000	35	6	Y/Δ-11	5,6	33,5	7.5	0.003

It is known that the main electricity losses at the substation occur in the main step-down transformer. Therefore, the annual energy loss is calculated as follows [7]:

$$\Delta W_{\text{пс}} = \sum n_i \cdot P_{\text{салт}} \cdot \mathrm{T}_i + \sum\left(\frac{1}{n} \cdot k^2_{\text{ю.ю}} \cdot P'_{\text{қ.ю}} \cdot T_i + \frac{1}{n} \cdot k^2_{\text{ю.п}} \cdot P'_{\text{қ.п}} \cdot T_i\right) \tag{2}$$

where:

n – Number of elements

$P_{\text{салт}}$ – Power consumption in idle mode

T – Operating time.

$\text{к}_{\text{ю}}$ - Load factor (HL – high voltage, LL – low voltage)

$P'_{\text{қ}}$ – Power consumption in short-circuit mode (SC-HV – high voltage, SC-LV – low voltage)

(1) The coefficients and unknown terms in the formula are determined as follows:

1. **Determining active power losses in idle mode.** It is known that active power loss in idle mode is determined as follows [10]:

$$P_{\text{салт}} = \Delta P_{\text{салт}} + \text{к}_u \cdot Q_{\text{салт}} \tag{3}$$

In that case: $\text{к}_u -$ Power loss variation coefficient, which characterizes the relationship between reactive power consumption and active power consumption in idle mode. Considering that in idle mode $Q_{\text{салт}} = \frac{I_c;\%}{100} S_{\text{ном.т}}$ expression (3) takes the following form:

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$$P_{\text{салт}} = \Delta P_{\text{салт}} + \text{к}_u \cdot \frac{I_c;\%}{100} S_{\text{ном.т}} \quad (4)$$

2. **Determining active power loss in short-circuit mode.** To determine active power loss in short-circuit mode, reactive power variation is also considered, as was done for active power loss in idle mode, and is calculated as follows [86]:

$$P'_{\text{қ}} = P_{\text{қ}} + \text{к}_u \cdot Q_{\text{қ}} \quad (5)$$

Here, considering that the reactive power loss in short-circuit mode $Q_{\text{қ}} = \frac{U_{\text{қ}}\%}{100} \cdot S_{\text{ном.т}}$ expression (5) changes as follows:

$$P'_{\text{қ}} = P_{\text{қ}} + \text{к}_u \cdot \frac{U_{\text{қ}}\%}{100} \cdot S_{\text{ном.т}} \quad (6)$$

Calculation of electricity losses in 6/10 kV overhead and cable transmission lines. The research object consists of overhead and cable lines. The total annual electricity losses in the overhead transmission lines are determined as follows [87,88].

$$\Delta W_{\text{ҳл}} = \frac{P_{\text{ҳл}}^2 + Q_{\text{ҳл}}^2}{10^3 \cdot U_{\text{ҳл}}^2} \cdot r_o \cdot L_{\text{ҳл}} + \Delta P_{\text{салт.ўз}} \cdot L_{\text{ҳл}} \cdot \text{T} \quad (7)$$

where:

$L_{\text{ҳл}}$ - Length of overhead lines

r_o - Specific active resistance of overhead lines.

$P_{\text{ҳл}}$ ва $Q_{\text{ҳл}}$, T – Active and reactive power flowing over a time interval.

$U_{\text{ҳл}}$ – the time interval is assumed to be 0.5 hours.

$P_{\text{сол.из}}$ – Power loss in the insulator is calculated and determined by the following formula [8,9]:

$$\Delta P_{\text{сол.из}} = \frac{1000 \cdot P_o}{365 \cdot 24} \quad (8)$$

where: P_o – taken as 0.011 kW/km for the 6 kV line, it estimates the power loss per unit distance of the insulator.

Electricity losses in cable lines are determined using the following formula [91]:

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$$\Delta W_{\text{А}} = 3\text{К}_{\text{э}} \cdot R_{\Sigma} t (I_{\text{мин}}^2 + (I_{\text{макс}}^2 - I_{\text{мин}}^2)\beta) \cdot 10^{-3} \quad (9)$$

where, R_{Σ} – Active resistance of the transmission line.

$\text{К}_{\text{э}}$ – Equivalence coefficient of the distribution network resistance. This coefficient is determined based on the graph.

t - Calculation period (excluding line outage time), in hours;

$I_{\text{мин}}$ ва $I_{\text{макс}}$- maximum and minimum load values from annual load graphs taken on a daily basis, in amperes (A);

β – form factor.

Calculation of electricity losses in 6/0.4 kV step-down transformers. In calculating electricity losses in 6/0.4 kV power transformers, primary data such as the transformer's type, capacity, rated current, idle and short-circuit losses (from specification data), operating time, and average and maximum current values from the load curves are used. Based on this primary data, electricity losses in the 6/0.4 kV transformer are determined using the following formula [11,12]:

$$\Delta W = \Delta P_{салт.i} t + \Delta P_{\text{қ.т.}i} \tau^2 \text{к}_{\text{ю}}^2 \quad (10)$$

where t - Operating hours of the transformer;

τ - time of maximum losses (the conditional time during which losses in the active resistance of the network element under constant maximum load are equal to the energy losses in the same element calculated over the actual load schedule in the time interval), in hours;

$\Delta P_{салт.i}$, $\Delta P_{\text{қ.т.}i}$ - power losses in idle and short-circuit modes, in kW;

$\text{к}_{\text{ю}}$ - annual maximum load factor of the transformer, which is calculated as follows [13,14]:

$$\text{к}_{\text{ю}} = \frac{I_{cp.\text{макс}}}{I_{\text{н.}i}} \quad (11)$$

where, $I_{cp.\text{макс}}$ – Average maximum current value of the transformer's daily load graph, in amperes (A);

$I_{\text{н.}i}$- Rated current of the transformer, in amperes (A);

Considering the time of maximum load, the time of maximum losses is determined as follows [15,16]:

$$\tau = \left(0{,}124 + \frac{T}{10^4}\right)^2 \cdot 8760 \quad (12)$$

Calculation of additional electricity losses in the 6/10 kV power supply system. Based on the provided data of the research object (see Section 1.2 of the dissertation), the losses outlined in the previous subsections are calculated to identify additional losses in the research object. By determining the difference relative to the total losses, additional electricity losses in the 6/10 kV power supply system are estimated. The calculation results are presented in Table 2.

Table 2. Electricity loss calculation table for the research object

№	Date	Total EE losses (млн. кВт · соат)	Calculated EE losses млн. кВт · соат	Additional EE losses млн. кВт · соат
1	**2021**	**99,2**	**22,4**	**79,8**
2	**2022**	**104,5**		**82,1**
3	**2023**	**93,54**		**71,14**

The results presented in Table 2.2 indicate that additional losses are significantly higher compared to the calculated losses, highlighting the need to consider external factors in modeling electricity losses. Therefore, in the next subsection of the dissertation, electricity loss modeling was carried out, taking into account additional electricity losses.

CONCLUSION

The study reveals that the primary sources of electricity losses in rural 6-10 kV power transmission systems stem from various system components, particularly at substations and transformers. Calculations conducted for the Qibray 35/6 kV substation indicate significant additional losses beyond theoretical estimates, primarily due to external factors such as environmental conditions and equipment wear. These findings underscore the need for comprehensive modeling that integrates both inherent system parameters and external influences. Future research should focus on developing adaptive modeling techniques to predict and mitigate losses effectively, ensuring greater operational efficiency and longevity of rural power supply infrastructure.

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