Investigation of the Influence of the Electrical Length of the LV Electrical Distribution Network on the Voltage Levels

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***Abstract*— Consumers of electrical energy operate normally when their terminals are supplied with the voltage for which the given electrical motor or device is designed. When electricity is transmitted through wires, part of the voltage is lost by the resistance of the wires and as a result, at the end of the line, that is, at the consumer, the voltage is lower than at the beginning of the line. The report analyzes the main causes of voltage deviation in long low voltage lines.**

***Keywords*— voltage deviation, power quality, electrical distance, voltage asymmetry, electrical parameters**

I. INTRODUCTION

The parameters characterizing the mode of operation of electrical networks are voltage U, frequency f, power factor cos φ and load. The load is set as current I, active power P, total (supplemented) power S or active and inductive power P+jQ. The parameters of the mode change over time during the operation of the electrical network due to changes in the work of consumers. This requires that they be determined both during the design and operation of the electrical network. The most important are the parameters under normal operating conditions with maximum and minimum loads and the loads of post-emergency modes.

The object of the report is the voltage deviation - it is allowed that in 5% of the measured 10-minute intervals the voltage is outside the limits of ±10% of U_n and no measured value of the measured 10-minute voltage intervals is outside the limits of +10/-15 % of U_n[1].

II. CALCULATION OF VOLTAGE AND VOLTAGE LOSSES IN OPEN NETWORKS WITH A SINGLE LOAD

The mode parameters of a single-sided powered transmission line for voltage up to 35 kV can be determined by calculation with graphical and analytical methods. Depending on the configuration of the power line and the distribution of loads along its length, different approaches are applied when calculating the mode parameters [3, 4, 5].

Figure 1 shows a single-line diagram of a power line, and Figure 2 shows its replacement diagram. When calculating the power line, the following symbols are entered:

U, U_f - line and phase voltage;

$\dot{S}_1$, P_1, Q_1 and $\dot{S}_2$, P_2, Q_2 is the total, active and reactive power for the beginning and end of the power line

Figure 1.

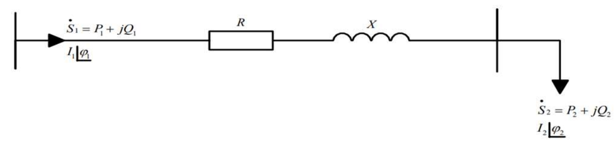

Figure 2.

$\dot{I}_1$, $\dot{I}_2$ - the current at the beginning and at the end of the power line;

φ_1 , φ_2 - the phase difference between voltage and current for the beginning and end of the power line;

θ - the phase difference between the voltage at the beginning and at the end of the power line;

R, X - the active and inductive resistance of the power line.

In Figure 3 and Figure 4 shows the vector diagram of the mode parameters of a power line - at the beginning and at the end of the line. The vector diagram is drawn for one phase of a three-phase power line in a Cartesian coordinate system.

The geometric difference between the voltages $U_{1\phi}$ and $U_{2\phi}$ is called the voltage drop. The voltage drop has a longitudinal component $\overline{ac_3}$. The magnitude of the vector $\overrightarrow{ac}$ projected by rotating it about point "O" on the real axis is the intercept $\overline{O_{c_2}}$.

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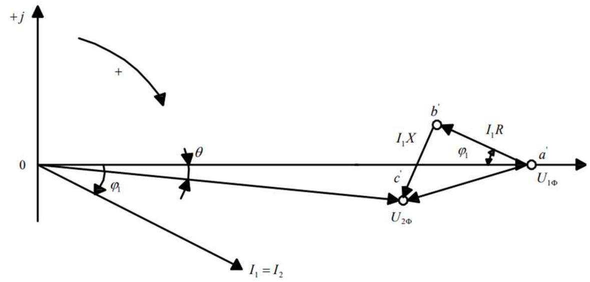

Figure 3.

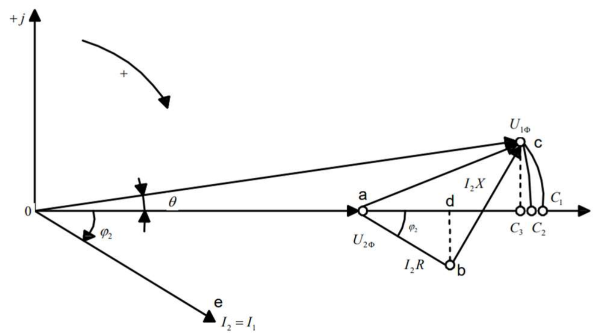

Figure 4.

The voltages in the power lines are 5 – 10 times greater than the voltage drop, therefore the sections $\overline{O_{c_2}}$ and $\overline{O_{c_3}}$ are approximately equal. For power lines with a length of up to 300 km, it is assumed that the longitudinal component of the voltage drop is equal to the voltage losses.

In MV and LV power lines, the phase difference θ between the voltages at the beginning and end is very small. As a result, the transverse component (c_3c) of the voltage drop is small, therefore the combs $\overline{O_{c_2}}$ and $\overline{O_{c_1}}$ are approximately the same, or the voltage drop and loss are almost equal.

In MV and LV power lines, only voltage loss is examined and calculated.

Analytical determination of mode parameters.

From the graphical determination of the voltage drop (Fig. 4) for the resulting right-angled triangle ac_3c, it is found that the side ac_3, equal to the voltage loss, can be calculated with the expression

$$\Delta U_\Phi = \overline{ac_3} = \overline{ad} + \overline{dc_3} = I_2R\cos\varphi_2 + I_2X\sin\varphi_2 \quad (1)$$

With a symmetrical load, the voltage loss in the three phases is the same and is equal to that calculated by (1).

The voltage at the beginning of the line for each phase is

$$U_{\Phi 1} = U_{\Phi 2} + \Delta U_\Phi \quad (2)$$

$$\Delta U = \sqrt{3}\,\Delta U_\Phi = \sqrt{3}(I_2R\cos\varphi_2 + I_2X\sin\varphi_2) \quad (3)$$

For three-phase electrical networks with a symmetrical load, the following expressions are used:

$$P = \sqrt{3}UI\cos\varphi \quad \text{or} \quad I = \frac{P}{\sqrt{3}U\,\text{co}} \quad (4)$$

$$Q = \sqrt{3}\,UI\sin\varphi \quad \text{or} \quad I = \frac{Q}{\sqrt{3}U\sin\varphi} \quad (5)$$

After substituting equations (4) and (5) into equation (3) and assuming in the general case that $I_2 = I$ and $\varphi_2 = \varphi$, we obtain

$$\Delta U = \frac{PR+Q}{U} \quad (6)$$

In electrical networks for voltages up to 35 kV with sufficient practical accuracy, the voltage loss is calculated with the nominal voltage instead of the actual voltage:

$$\Delta U = \frac{PR+Q}{U_n} \quad (7)$$

<u>Voltage loss in two-phase and single-phase branches:</u>

Three-phase networks, built with single-phase and two-phase branches, are called networks with partial phase mode of operation.

The voltage loss in the phase conductors of resistance R in the two-phase branch is

$$\Delta U_{\Phi A} = \Delta U_{\Phi B} = I_AR = I_BR = IR \quad (8)$$

The current in the neutral conductor of a two-phase branch from a three-phase power line is equal to the phase current, therefore the cross-section of the neutral conductor is recommended to be equal to the cross-section of the phase conductors. Hence $R_0 = R$ and the voltage loss is

$$\Delta U = 1{,}5.IR\sqrt{3} \quad (9)$$

In two-phase deviations, the power P_Φ in each phase is distributed equally: $P = 2P_\Phi = 2U_\Phi I$, from where the current in the phase is equal to

$$I = \frac{P}{2U_\Phi} = \frac{P}{2\frac{U_\text{н}}{\sqrt{3}}} = \frac{\sqrt{3}P}{2U_\text{н}} \quad (10)$$

Substituting equation (10) into equation (9) yields an expression for calculating voltage losses through power flow:

$$\Delta U = 2{,}25\frac{P.R}{U_\text{н}} \quad (11)$$

Therefore, the voltage loss is 2.25 times greater than the corresponding one for a three-phase electrical network with the same loads and parameters.

<u>Single-phase branching from a three-phase network.</u>

It is performed with two wires - phase and zero. The current through the phase conductor I_A is equal to the current through the neutral - I_0. The cross-section of the neutral wire must be equal to the phase wire, from which it follows that $R_0 = R$. Loss of voltage is

$$\Delta U = \sqrt{3}IR \quad (12)$$

$$I = \frac{P}{U_\Phi} = \frac{P}{\frac{U_n}{\sqrt{3}}} = \frac{\sqrt{3}P}{U_n} \quad (13)$$

After substituting equation of (13) into (12) is obtained:

$$\Delta U = 6\frac{P.R}{U_\text{н}} \quad (14)$$

The linear voltage loss in a single-phase deviation is 6 times greater than the voltage loss in a three-phase network with the same load and parameters.

<u>Conclusion:</u> The voltage loss in single-phase and two-phase branches can be calculated with equation (7) for a three-phase network and then increased by 2.25 for two-phase sections and by 6 for single-phase sections.

Voltage loss in power line branches depends on the following factors:

• Section of the wire;

• Current load – user load;

• Length of the power line deflection – R.

The voltage loss calculations will be made at branches from the three-phase electrical network with sections of 6, 10, 16, 25 and 35 mm^2, current-limiting automatic devices with I_n 6, 10, 16, 25 and 32 A.

The calculations of the branch lengths at voltage loss of 10% and 7% respectively under the conditions described above are shown in Table 1 and Table 2.

Table 1.

I_n, A	P_n, (1f.), kW	P_n, (3f.), kW	Ном. сечение (S), мм^2	R, W/км, 32/S	ΔU (1f.), %	ΔU (3f.), %	L, км (1f.) при ΔU=10%	L, км (3f.) при ΔU=10%
1	2	3	4	5	6	7	8	9
6	1,380	4,152	4	8,00	16,56%	8,30%	0,604	1,204
10	2,300	6,920	6	5,33	18,40%	9,23%	0,543	1,084
16	3,680	11,072	10	3,20	17,66%	8,86%	0,566	1,129
25	5,750	17,300	16	2,00	17,25%	8,65%	0,580	1,156
32	7,360	22,144	25	1,28	14,13%	7,09%	0,708	1,411

Legend:

Column 1 – rated current of the breaker;

Column 2 – 1 f. Load of consumer;

Column 3 – 3 f. Load of consumer;

Column 4 – cross-section of the electrical branch;

Column 5 – electrical branch resistance. The resistance calculation formula shown in the table - $R = 32/S$ gives good results and can be used for engineering calculations;

Column 6 – voltage loss at 1f. Branch;

Column 7 – voltage loss at 3f. Branch;

Column 8 – limit length of 1f. Branch at ΔU=10%;

Column 9 - limit length of 3f. Branch at ΔU=10%.

Table 2.

I_n, A	P_n, (1f.), kW	P_n, (3f.), kW	Ном. сечение (S), мм^2	R, W/км, 32/S	ΔU (1f.), %	ΔU (3f.), %	L, км (1f.) при ΔU=7%	L, км (3f.) при ΔU=7%
1	2	3	4	5	6	7	8	9
6	1,380	4,152	4	8,00	16,56%	8,30%	0,423	0,843
10	2,300	6,920	6	5,33	18,40%	9,23%	0,380	0,759
16	3,680	11,072	10	3,20	17,66%	8,86%	0,396	0,790
25	5,750	17,300	16	2,00	17,25%	8,65%	0,406	0,809
32	7,360	22,144	25	1,28	14,13%	7,09%	0,495	0,988

Legend:

Column 8 – limit length of 1f. Branch at ΔU=7%;

Column 9 - limit length of 3f. Branch at ΔU=7%.

CONCLUSIONS

1. Derived formulas for calculating voltage loss can be used for engineering calculations.
2. When implementing the electrical network and the current-limiting automation in accordance with the regulatory requirements, the only criterion for compliance with the regulatory requirements for permissible voltage loss remains the electrical length of the power line deviation.
3. Limit values of the conductive deviation for 1f. users is from 400 to 500 m. depending on the section of the deviation and the size of the load.
4. For 3f. consumers, the limit values of the power line deviation is from 750 to 1000 m. depending on the section of the deviation and the size of the load.
5. The calculated values of the limit lengths of power line deviations can be considered as criteria for evaluating the remoteness of consumers.

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