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ზესტაფონი-ქუთაისი-სამტრედიის მაგისტრალური გზა (E-60)
მონაკვეთი: ზესტაფონის ახალი შემოვლითი გზა კმ 0+000 - კმ 15+172

ZESTAPONI-KUTAISI-SAMTREDIA HIGHWAY (E-60)
SECTION: ZESTAFONI BY-PASS ROAD KP0+000 – KP15+172

გზის გარე ელექტროგანათების სამშენებლო დოკუმენტაციის პროექტი

DESIGN DOCUMENTS FOR ROAD LIGHTING

წიგნი II გზის გარე ელექტროგანათების 10კვ ძაბვის მკვებავი ქსელი
გზის გარე ელექტროგანათების 0,4კვ ძაბვის გამანაწილებელი ქსელი

VOLUME II **10 KV FEEDING NETWORK FOR ROAD LIGHTING**
0.4 KV DISTRIBUTION NETWORK FOR ROAD LIGHTING

ქ. თბილისი - TBILISI

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0.4 KV DISTRIBUTION NETWORK FOR ROAD LIGHTING

დირექტორი დ. კოსტიადი

DIRECTOR D. COSTIADI

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Explanatory Notes

1. General

1.1 Description of road section

New Zestafoni By-pass Road on section between KP0+000 and KP15+172 points is two-way highway. In each direction the road has two lines of 3.75m width each and 3.00m and 1.00m wide roadsides. Total width of each way of the road is 11.50m, and there is the 4.00m wide demarcation strip between the ways. Demarcation strip has 0.75m high concrete borders (protective barriers) and space between barriers is filled with soil.

In areas where highway crosses rivers and ravines, at variable relief sections and passages under the main road the highway runs on bridges. Opposite direction ways of road have separate parallel bridge structures. Width of road on each bridge structure is 11.50m. On bridges roads have 1.12m wide pedestrian walkways on one side and 0.58m wide communication passage (gallery) on other side. Pedestrian walkways and communication galleries are separated from road paving with protective barrier. Distance between parallel structures of bridges is 2.04m.

At road junctions crossing of main highway by other roads on higher level is made via overpass bridge structures with 11.50m wide roads. Roads on overpass bridges are two-way roads without demarcation strip. Overpasses have 1.12m wide pedestrian walkways that are separated from road by protective barriers.

Roads coming out of main highway have 11.50m width in case of two-way roads and 6.75m width in case of one-way roads.

1.2 Components of Road Lighting Network

Designed road lighting network comprises the following main components:

- Extension lines at connection points with existing 10kV overhead power transmission lines and 10kV commercial electricity metering units arranged according to requirements of Technical Conditions of the power utility company “JSC Energo Pro Georgia”;
- 10/0.4kV voltage transformer substations located along the main highway;
- 10kV voltage feeding cable lines from metering units to nearest transformer substations and between groups of transformer substations;
- 0.4kV voltage power distribution cable lines from transformer substations to lighting posts and lighting fixtures.

The following marking of components of road lighting networks is used:

- Metering units are marked by number and name of existing overhead transmission line connected to them:
    - MU#1 – 10kV voltage overhead line “Argveta” coming from substation “Zestafoni 500”;
    - MU#2 – 10kV voltage overhead line “Bardubani” coming from substation “Kurorti 35”;
    - MU#3 – 10kV voltage overhead line “Qvabula” coming from substation “Kurorti 35”.

- Transformer substations of the road lighting network have numbers:
  - SS#z1, SS#z2, SS#z3, … SS#z11
- 10kV voltage cable lines from metering units to transformer substations have the following markings:
  - MU1-z1, MU1-z2, … MU2-z6, … MU3-z10, MU3-z11
- 10kV voltage cable lines between transformer substations have the following markings:
  - z2-z3, z3-z4, z5-z6, z6-z7, z7-z8, z9-z10
- 0.4kV voltage cable lines coming out of transformer substations have the following markings:
  - z1/1, z1/2
  - z2/1, z2/2
  - z3/1. z3/2, z3/3, etc
- Lighting posts with lighting fixtures are divided into the following groups:
  - Type A2 – 10.0m high lighting posts on point foundation, with two-arms and two lighting fixtures 2X153W (These posts are installed in demarcation strip of main highway)
  - Type B – 10.0m high lighting posts installed on bridge structure, with one arm and one lighting fixture 153W (These posts are installed on bridges)
  - Type C – 9.0m high lighting posts installed on overpass structure, with one arm and one lighting fixture 100W (These posts are installed on overpasses)
  - Type D – 9.0m high lighting post installed on drilled pile, with one arm and one lighting fixture 100W (These posts are installed sides of road)
- Lighting posts installed along the main highway are marked by the following numbers:
  - #1A2, #2A2, #3A2, #4A2, … - for posts located in demarcation strip
  - #74B, #75B, #76B, $77B, … - for posts located on bridges
- Lighting posts installed on road junctions are marked by the following numbers:
  - 3-1D, 3-2D, 3-3D, … - posts installed on z3/3 cable line
  - 4-1D, 4-2D, 4-3D, … - posts installed on z6/4 cable line

2. Electric-Technical Part

2.1 Metering Units

Source of electric power for road lighting is the 10kV voltage overhead transmission lines that belong to JSC “Energo Pro Georgia” who issued the Technical Conditions, according which connections to existing lines and meter units should be made. Proposed metering units should be connected to the following overhead lines:

- MU#1 – 10kV voltage overhead line “Argveta” coming from substation “Zestafoni 500”;
- MU#2 – 10kV voltage overhead line “Bardubani” coming from substation “Kurorti 35”;
- MU#3 – 10kV voltage overhead line “Qvabula” coming from substation “Kurorti 35”.

Metering unit MU#1 will be connected to four 10/0.4kV voltage 25kVA power transformer substations with total calculated load 47.2 kW (52.5kVA).
Metering unit MU#2 will be connected to four 10/0.4kV voltage 25kVA power transformer substations with total calculated load 48.8 kW (54.2kVA).
Metering unit MU#3 will be connected to three 10/0.4kV voltage 25kVA power transformer substations with total calculated load 44.1 kW (49.0kVA).

At each place of connection to existing 10kV network line disconnector and three ОПН-10 type overvoltage limiters should be installed. From the line disconnector of connection point the feeding cable should be connected to metering units, where commercial metering of consumed electricity will be carried out on 10kV side.
According to standard requirements of the JSC “Energo Pro Georgia” the metering unit should include the following equipment:
Electronic one-way three-phase active-reactive electricity meter with parameters U_N=57/100V, I_N=5A, precision class – not less than 1.0; counting mechanism – not less than 5+1 digits. Metering unit should comply with the requirements of Articles 11.1, 11.2 and 11.3 of the Technical Condition issued by JSC “Energo Pro Georgia”. Metering unit should have cable input-output option.

10kV cables coming out of the metering unit will feed 10/0.4kV transformer substations, which according to Article 12 of the Technical Condition from JSC “Energo Pro Georgia”, should have back-up metering of electricity. Back-up meter should be installed on 0.4kV voltage incoming line and electronic one-way three-phase meter should be used with parameters: U_N=3X380/220V, I_N=5A, precision class – not less than 1.0, counting mechanism – not less than 5+1 digits.

Schemes of transformer substation connection to feeding network are given in the design drawings. Models of types of equipment shown on schemes are given for indicatory purposes and similar equipment can be used.

Current transformers should be checked on thermal resistance to short circuit currents and approved by JSC “Energo Pro Georgia”.

2.2 Transformer Substations

Number of 10/0.4kV voltage transformer substations and their power capacities were selected on the basis of expected load and location of power source. Structurally substations should be factory-made packaged transformer substations, parameters of which are determined by technical conditions given in the design documents. Design includes installation of substation grounding circuits and fences around the substations. Resistance of grounding circuit should not exceed 4 Ohms and is calculated for ground soil parameters - ρ=50 Ohm/m and ρ=100 Ohm/m.

Packaged transformer substations should comply to following requirements:

- Temperature range -45^{0}C - +45^{0}C, climatic rating – Y1;
- External insulation – grade II-III;
- By operation requirements for included equipment – operation on elevations up to 1000m above sea level;
- Wind and freezing resistance – I-IV region;
- Ambient conditions – explosion-free and fire-safe environment, without electric conducting dust, no chemical admixtures (Type II atmosphere);
- No vibration and shocks.

Packaged transformer substation should have cable incoming and outgoing lines on 10kV side and cable outgoing lines on 0.4kV side.

Schemes of substations are shown on main power supply schemes.

Power capacity of transformers was selected with account of minimal losses of electric energy – load coefficient of transformers equals to 0.7-0.8.

Main parameters of selected transformer substations are the following:

- Capacity of hermetic power transformer – 25kVA, Nominal voltage – 10kV, Nominal current – 1.45A, Maximal operational voltage – 12 kV;
- On 0.4 kV side – Nominal voltage – 0.4kV, Nominal current – 41.7A;
- Level of insulation contamination – II, III;
- Resistance of insulation of substation circuits – 1000 Ohm;
- Noise level – 60 dB;
- Connection scheme of transformer coils and their group - Δ/Y_σ - II;
- Insulation level – Normal;
- Housing protection degree – IP34;
- Relative air humidity – 80% at 25^{0}C temperature.

Structural properties of the packaged transformer substation:

- Type – “Kiosk”- or “City”-type, in metal frame;
- Three compartments – 10kV (high) voltage equipment (HVE), power transformer and 0.4kV (low) voltage equipment (LVE).

10/0.4kV packaged transformer substation should have the following protections:

- Atmospheric and commutation over-voltage;
- Short circuit between phases;
- Overloading and short circuits between phases on 0.4kV lines;
- Short circuits on lighting lines.

The following blocking should be included:

- Blocking between main and grounding blades of load switch;
- Blocking between 0.4kV input disconnector and automatic switch;
- Blocking between HVE compartment door and grounding blades of load switch. In case of open position of grounding blades opening of door should be impossible.
- Other types of blockings depending on the substation structural arrangement.

Packaged transformer substation's 10kV distribution equipment should contain:

- On outgoing cable lines – load switch with main and grounding blades, ОПН-10 type overvoltage limiters;
- In power transformer cubicle – load switches with main and grounding blades, fuse.

Packaged transformer substation's 0.4kV distribution equipment should include:

- On incoming line – disconnector and automatic switch;
- On outgoing lines – automatic switches and lighting control equipment;
- Current metering Amper-meters and back-up meter of consumed electric energy – electronic one-way three-phase electric meter with the following parameters: U_N=220/380V, I_N=5(10)A, precision class – no less than 1.0; counting mechanism – no less than 5+1 digits. Electric meter should be included into the Register of Measuring Devices Accepted in Georgia and should have seals and approval certificate of the Georgian National Agency for Standards, Technical Regulations and Metrology.

Packaged transformer substation should have grounding circuit. Resistance of grounding circuit should correspond to requirements of Article 1.7 of the Rules of Installation of Electric Equipment (ПУЭ) and not exceed 4 Ohms for substations with 0.4kV outgoing line cables. Specific resistance of soil is not exceeding 100 Ohm/m.

2.2.1 Calculation of Grounding Circuit Resistance for 10/0.4kV Packaged Transformer Substation

Calculation of grounding circuit resistance for packaged substation is carried out for two cases – ground specific resistance ρ=50 Ohm/m and ρ=100 Ohm/m. According to requirements of the Article 1.7.62 of the Rules for Installation of Electric Equipment (ПУЭ) resistance of grounding circuit should not exceed 4 Ohms. Dimensions of the grounding circuit are shown on drawing.

Calculation of grounding resistance

Specific resistance of ground for wetland soils and dark soils is ρ=50 Ohm/m. Resistance of one vertical electrode (steel angle bar 40x40x4 mm, length 2m) is equal to:

$$R_{ver} = \frac{0.366\rho}{l}\left(lg\frac{2l}{0.9b} + \frac{1}{2}\ lg\frac{4t+l}{4t-l}\right) = 19\ ohm$$

Resistance on n electrodes is the following

$$R_{n.ver} = \frac{R_{ver}}{n\,\eta_{ver}} = \frac{19}{12{\cdot}0.5} = 3.2\ ohm$$

where n=12 is number of electrodes and for $l_1/l_2=1$, $\eta_{ver}=0.5$ (Table 6-9).

Resistance of horizontal electrode (steel strip 40x4 mm, length 24m) is equal to:

$$R_{hor} = \frac{0.366\rho}{l} lg\frac{2l^2}{b{\cdot}t} = \frac{0.366\rho}{24} lg\frac{2{\cdot}24^2}{0.04{\cdot}0.7} = 3.13\ ohm$$

Resistance of steel strip with account of screening by other electrodes is:

$$R_{n.hor} = \frac{R_{hor}}{\eta_{hor}} = \frac{3.13}{0.6} = 5.21\ ohm$$

where $\eta_{hor} = 0.6$ (for n=12; $l_1/l_2=1$) (Table 6-10).

Total resistance of grounding circuit is the following:

$$R_{gr.} = \frac{R_{ver.}{\cdot}R_{hor}}{R_{ver} + R_{hor}} = \frac{3.2{\cdot}5.21}{3.2 + 5.21} = \frac{16.67}{8.41} = 1.95 ohm < 4 ohm$$

that corresponds to requirements of norms.

Now consider case of specific resistance of soil ρ=100 Ohm/m.
Resistance of one vertical electrode (steel angle bar 40x40x4 mm, length 2m) is equal to:

$$R_{ver} = \frac{0.366\rho}{l}\left(lg\frac{2l}{0.9b} + \frac{1}{2}\ lg\frac{4t+l}{4t-l}\right) = 38\ ohm$$

Resistance on n electrodes is the following:

$$R_{n.ver} = \frac{R_{ver}}{n\,\eta_{ver}} = \frac{38}{12{\cdot}0.5} = 6.4\ ohm$$

where n=12 is number of electrodes and for $l_1/l_2=1$, $\eta_{ver}=0.5$ (Table 6-9).

Resistance of horizontal electrode (steel strip 40x4 mm, length 24m) is equal to:

$$R_{hor} = \frac{0.366\rho}{l} lg \frac{2l^2}{b \cdot t} = \frac{0.366 \cdot 100}{24} lg \frac{2 \cdot 24^2}{0.04 \cdot 0.7} = 6.3\ ohm$$

Resistance of steel strip with account of screening by other electrodes is:

$$R_{n.hor} = \frac{R_{hor}}{\eta_{hor}} = \frac{6.3}{0.6} = 10.5\ ohm$$

where η_{hor} = 0.6 (for n=12; l_1/l_2=1) (Table 6-10).

Total resistance of grounding circuit is the following:

$$R_{gr.} = \frac{R_{ver.} \cdot R_{hor}}{R_{ver} + R_{hor}} = \frac{6.4 \cdot 10.5}{6.4 + 10.5} = \frac{67.2}{16.9} = 3.9 ohm < 4 ohm$$

that corresponds to requirements of norms.

In 10/0.4kV voltage 25 kVA power capacity packaged transformer substation the neutral of transformer is insulated on 10kV voltage side and grounded on 0.4kV voltage side. Due to varying electric resistance of soil the length of vertical electrodes is selected equal to $l_{v.gr.}$=2m, and distance between them is also equal to 2m. Recommended ratio between these values (l_1/l_2=1) is also kept as in calculation. Required resistance of grounding circuit $R_{gr.}$<4 Ohm is observed (Articles 1.7.57-1.7.59 and 1.7.62, 17.36, Rules of Installation of Electric Equipment).

2.3 Installation of 10kV cables

10kV cables from 10/0.4kV substations should be placed in trench made in demarcation strip at 0.8m depth according to requirements of Article 2.3 of the Rules of Installation of Electric Equipment. In order to protect 10kV cables from damage warning tape ЛС-150 should be placed over the cable along whole route of the cable lines. On bridges and overpasses 10kV cables should be placed in polyethylene pipes and fixed to bridge and overpass structures by special brackets.

Installation of 10kV cable lines instead of 10kV overhead lines is determined by the following conditions:

- Purpose of 10kV lines is feeding of road lighting network;
- 0.4kV road lighting cable network will be installed in trench dug in ground or on bridge structures and 10kV cables can be installed at required distance from 0.4kV cables in the same trench;
- New by-pass road has many bridges and overheads crossing of which with 10kV overhead lines will be complicated;
- Territory along the road is become available for installation of other overhead lines in future.

Road lighting network design envisages use of copper core ВВГ-10 or BPF-10 or NYY-10 type cables.
External diameter of ВВГ-10 type cable with 3x50mm^2 cross section is 47,62 mm.
External diameter of ВВГ-10 type cable with 3x35mm^2 cross section is 44,82 mm.

2.4 Selection of 10kV Cables

Transformer substations will be loaded by electric power load of lighting fixtures**.** Power rating of selected lighting fixture lamps is 153W. According to catalogs design power load is equal to 165W.

For example, for #3 substation maximum three groups of lighting fixtures will be fed:

- Group #1 – 12 fixtures: design load equals to 3.96 kW.
- Group #2 – 15 fixtures: design load equals to 4.94 kW.
- Group #3 - 38 fixtures: design load equals to 3.99 kW.

Total load of transformer substation is equal to:

$$P_{des.} = 3.96 + 4.95 + 3.99 = 12.9 \text{ kW}$$

that corresponds to value of total load (with $\cos\varphi=0.9$)

$$S_{des.} = P_{des.}/\cos\varphi = 12.9/0.95 = 13.6 \text{ kVA}$$

Selected 10/0.4kV power transformers have power rating 25kVA and their load coefficient is equal to:

$$K_{load} = S_{load}/\ S_{des.} = 13.6 / 25 = 0.544$$

1.Selection of cross section of transformer substation feeding cable is based on cable overheating condition. According to transformer capacity design current at 10kV voltage is equal to:

$$I_{10kV\ nom.} = \frac{S}{\sqrt{3}\ U} = \frac{25}{1.73 \cdot 10} = 1.45 \text{ A}$$

In case of overloading

$$I_{10kV\ nom.} = 1.3\ I_{10kV\ nom.} = 1.3 \cdot 1.45 = 1.88 \text{ A.}$$

Calculated design current of transformer at 0.4kV voltage is equal to:

$$I_{0.4kV\ nom.} = \frac{S}{\sqrt{3}\ U} = \frac{25}{1.73 \cdot 0.4} = 36.2 \text{ A}$$

In case of overloading

$$I_{0.4kV\ nom.} = 1.3\ I_{0.4kV\ nom.} = 1.3 \cdot 36.2 = 46.96 \text{ A.}$$

Based on cable overheating condition for 10kV cables the selected minimal cross section is $3x16mm^2$, for which long period permissible current is 60A (for installation in air) and 75A (for installation in ground).

Total calculated power capacity of four 10/0.4kV transformer substations connected to each other is:

$$\Sigma P = P_1 + P_2 + P_3 + P_4 = 12.54 + 11.55 + 12.6 + 9.57 = 46.26 \text{ kW}$$

Total load is equal to:

$$\Sigma S = \Sigma P / 0.93 \approx 46.26/0.93 = 49.8 \text{ kVA}$$

Calculated current is equal to:

$$I = \frac{\Sigma S}{\sqrt{3}\, U} = \frac{43}{1.73 \cdot 10} = 2.5 \text{ A}$$

Total power capacity of transformers is equal to:

$$\Sigma S_{tr.} = 4 \text{ x } 25 = 100 \text{ kVA}$$

With account of overloading possibility the total power capacity is:

$$\Sigma S_{max.} = 1.3 \cdot \Sigma S_{tr.} = 1.3 \text{ x } 100 = 130 \text{ kVA}$$

Maximal current in line is:

$$I_{max.} = \frac{\Sigma S}{\sqrt{3}\, U} = \frac{130}{1.73 \cdot 10} = 7.5 \text{ A}$$

2.Selection of cable cross section on basis of current density gives small cross section that is unacceptable for 10kV voltage. Selected minimal cross section for 10kV voltage cables is 3x16 mm^2.

3. Selection of 10kV cable cross sections on basis of voltage losses is determined by equation:

$$\Delta U\% = \frac{R\cos\varphi + X\sin\varphi}{Unom \cdot \cos\varphi} Pm \cdot lm$$

when network has same cosφ, the same material cables are used and they have same cross section.

For copper cables results of calculations are given in Table below for different cross sections for #z1 - #z4 transformer substations:

##	Cross section, mm^2	Rcosφ+ Xsinφ	moment $\Sigma P_m l_m$ kW.km	Voltage lost, %	Selected cross section	Transf. power moment $\Sigma P_{tm} l_m$	Voltage loss, %	Selected cross section	
1	3X16	1.085	45.23	5.97%	-	92.2	11.1%	-	
2	3X25	0.71	45.23	3.9%	-	92.2	7.24%	-	
3	3X35	0.51	45.23	2.8%	distribution network 3X35	92.2	5.2%	distribution network 3X35	
4	3X50	0.373	45.23	2.05%	feeding network 3X50	92.2	3.8%	feeding network 3X50	

For transformer substations #z5- #z8:

##	Cross section, mm^2	$R\cos\varphi + X\sin\varphi$	moment $\Sigma P_m l_m$ kW.km	Voltage lost, %	Selected cross section	Transf. power moment $\Sigma P_{tm} l_m$	Voltage loss, %	Selected cross section	
1	3X16	1.085	30.54	4.6%	-	93.1	11.1%	-	
2	3X25	0.71	30.54	2.98%	distribution network 3X25	93.1	7.34%	-	
3	3X35	0.51	30.54	2.14%	feeding network 3X35	93.1	5.27%	distribution network 3X35	
4	3X50	0.373	30.54	1.57%	-	93.1	3.86%	feeding network 3X50	

For transformer substations #z9- #z11:

##	Cross section, mm^2	$R\cos\varphi + X\sin\varphi$	moment $\Sigma P_m l_m$ kW.km	Voltage lost, %	Selected cross section	Transf. power moment $\Sigma P_{tm} l_m$	Voltage loss, %	Selected cross section	
1	3X16	1.085	55.68	6.7%	-	92.9	11.2%	-	
2	3X25	0.71	55.68	4.4%	-	92.9	7.25%	-	
3	3X35	0.51	55.68	3.2%	distribution network 3X35	92.9	5.2%	distribution network 3X35	
4	3X50	0.373	55.68	2.3%	feeding network 3X50	92.9	3.8%	feeding network 3X50	

On busses of 10kV overhead line “#1 Argveta” of the substation “Zestafoni-500” the short circuit power capacity is ____ kVA, short circuit current - ___ kA.
On busses of 10kV overhead line “Bardubani” of the substation “Kurorti” the short circuit power capacity is 7200 kVA, short circuit current – 1.8 kA.
On busses of 10kV overhead line “Qvebila” of the substation “Kurorti” the short circuit power capacity is 6500 kVA, short circuit current – 1.63 kA.

Based on these data the minimal cross section of copper cables with account of thermal strength again short circuit currents was selected:

- for substation “Kurorti” – $3x35mm^2$;
- for substation “Zestafoni-500” – $3x35\ mm^2$.