Riga Technical University
Institute of Power Engineering
Department of Electric Power Supply

# ELECTRIC SUPPLY

## Methodological guidelines for practical works

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These methodological guidelines for practical works have been developed for students of the course “Electric Supply”. The material includes theoretical and statistical description of medium voltage networks. The lecture notes may be used as an additional material by regular, external, and part-time students of electrical power engineering studies.
This material includes the statistical materials and final examination materials developed and collected by the Department of Electric Power Supply.

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# Contents

# Introduction

One of the basic elements of electric supply system is transformer. Closest to using equipment are distribution transformers that convert electricity from 20 kV or 10 kV, which is usually found in rural territories, to 0.4 kV (0.23 kV), which corresponds to the needs of the majority of households and a large share of industrial electrical utilization equipments.

There are several types of installation (positioning). In rural territories, it is often when special transformer substations are not built but a transformer is mounted on a utility pole. Such substations are called pole-mounted substations. These usually include small power transformers with few numbers of 0.4 kV feeders. Closed transformer substations in which transformers and switchgears are located in a room are built in populated areas. Often, transformers at such substations have greater power and big number of feeders and medium voltage switchgears, that provide the possibility to change the network configuration. The latest trend is that kiosk transformer substations are mounted in populated areas or in regions with large density of using equipment, as they take up less space and can be purchased ready-made straight from the manufacturer. In Latvia, such substations are offered by JSC “Jauda”, which offers standard solutions.

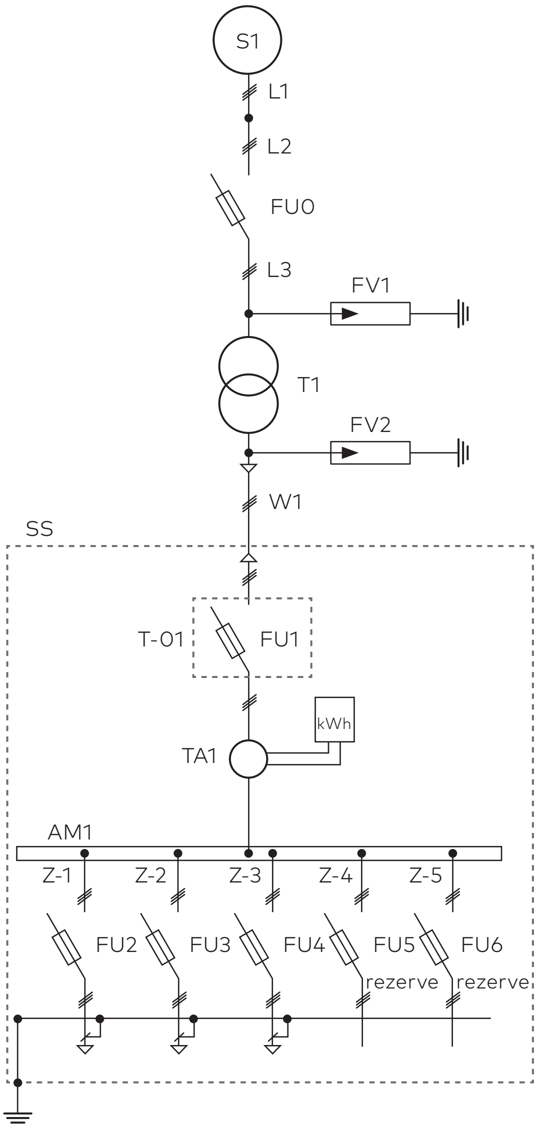
# 1. ELECTRIC SUPPLY RELIABILITY

Electric supply reliability is characterised by the number of disconnections of supply of electricity and duration thereof. Nowadays, electrical utilization equipments are not divided into three groups of electric supply reliability but according to Paragraphs 60, 61, and 93 of the Cabinet Regulation No. 50 "Regulations Regarding the Trade and Use of Electricity".

- Paragraph 60. The user shall take a decision himself or herself regarding the required safety of supply of electricity, i.e. the necessity to prevent disconnections of supply of electricity and damages to his or her electrical installations, which may occur during damages to or repair of separate elements of the supply of electricity system or during planned disconnections.
- Paragraph 61. The user whose electrical installations do not tolerate discontinuations in supply of electricity, voltage dips and overvoltage shall take additional measures in order to achieve the necessary safety of supply of electricity. A reserve connection, an independent power supply and appliances stabilising voltage, as well as automated switching equipment shall be installed and arranged on the account of the user.
- Paragraph 93. In the case of accident or damage of the electrical installations of the system operator, the system operator shall register damages and ensure rectification of the damage as quickly as possible (not longer than within 24 hours).

# 2. CHOOSING THE MAIN CIRCUIT DIAGRAM OF A SUBSTATION

According to the variant of the assignment and technical regulations, the construction of the 20/0.42 kV pole-mounted substation indicated in Fig. 2.1 shall be designed with a possibility to continue the 20 kV branch in the future. The terminal substation under design will be fed from a 20 kV overhead line under design, which will be connected to the existing 20 kV system S1.




S1 — existing 20 kV system
L1 and L2 — 20 kV overhead line under design
FV1 — 20 kV surge arrester
FV2 — 0.4 kV surge arrester
T1 — power transformer
W1–W4 — 0.4 kV cable lines
FU0 — 20 kV fuse
FU1–FU6 — 0.4 kV fuses
TA1 — current transformers
kWh — electricity meter

**Fig. 2.1.** Draft design of the substation's circuit diagram.

If the number of using equipment is little and if a power outage of 24 hours is acceptable, the load may be fed through one transformer. In a rural territory, the transformer under design shall be mounted on a pole together with a fuse disconnector. Considering the number of using equipment (Annex No. 1) and the geographical location, one using equipment will be connected to each of two low-voltage fuse-switch disconnectors, and according to the variant of the assignment set number of using equipments will be connected to one of the chosen fuse-switch disconnectors simultaneously.

## 2.1. Regular conditions

Load feeders are connected to the busbar section AM1 through transformer T1 and are fed from line L1. Fuse FU1, the main transformer switch disconnector T–01, and the fuses FU2, FU3, FU4 that protect each group of using equipment are working under regular conditions.

## 2.2. Emergency conditions

Protection with the corresponding fuse FU2, FU3, FU4, ... FU*n* must be provided for each of the groups of using equipment in case of emergency conditions. If there is short-circuit on 0.4 kV busbars, transformer's protection FU1 must be activated, but if short-circuit occurs on transformer T1, output safety fuse FU0 shall be activate. In case short-circuit occurs on the 20 kV overhead line L1 under design, no separate protection shall be designed at the beginning of the 20 kV overhead line under design in line with the issued technical conditions as this overhead line will be protected with the current protection located at the beginning of the existing line.

# 3. CALCULATION OF THE TOTAL LOAD OF USING EQUIPMENT

According to the size of input protection appliances installed by users and according to the assignment it is possible to determine the maximum power that can be consumed by a user [1, *p.* 53] or to estimate agricultural loads using the table in Annex No. 5.

Maximum value of the permitted real power:

- for a single-phase user

$$P_{\text{maks}} = I_{\text{iev.a}} U_{\text{f}} \cos\varphi; \qquad (3.1)$$

- for a three-phase user

$$P_{\text{maks}} = I_{\text{iev.a}} \sqrt{3} U_{1} \cos\varphi \qquad (3.2)$$

where $P_{\text{maks}}$ – estimated permitted maximum real power, kW;
$I_{\text{iev.a}}$ – rated value of input protection appliance, A;
$U_{\text{f}}$ – rated voltage of a phase, kV;
$U_{\text{l}}$ – rated voltage of a line, kV;
$\cos\varphi$ – power factor, detached homes $\cos\varphi = 0.96$.

Considering that there are only three-phase using equipments, only the case involving three phases is discussed further on.

Real power

$$P_{\text{apr}} = K_0 P_{\text{maks}}, \qquad (3.3)$$

where $K_0$ – coincidence factor for using equipments (Annex No. 1).

Reactive power

$$Q_{\text{maks}} = P_{\text{apr}} \operatorname{tg}\varphi, \qquad (3.4)$$

where $Q_{\text{maks}}$ – reactive power, kVAr;
$\operatorname{tg}\varphi$ – power factor, use the numerical value of $\cos\varphi$ for the design.

Apparent power

$$S_{\text{apr}} = \sqrt{P_{\text{apr}}^2 + Q_{\text{apr}}^2}, \qquad (3.5)$$

where $S_{\text{apr}}$ – design apparent power, kVA;
$P_{\text{apr}}$ – design real power, kW;
$Q_{\text{apr}}$ – design reactive power, kVAr.

Estimated powers of all the using equipment must be shown in Table 3.1.

Table 3.1

**Power of using equipment**

| No. of using equipment | Current used by the equipment $I_{maks}$, A | Rated voltage of the equipment $U_{nom}$, kV | Real load of the equipment $P_{maks}$, kW | Coincidence factor $K_0$ | Estimated real load $P_{apr}$, kW | Estimated reactive load $Q_{apr}$, kvar | Estimated total load $S_{apr}$, kVA |
|---|---|---|---|---|---|---|---|
| 1 | 16 | 0.4 | | | | | |
| 2 | 20 | 0.4 | | | | | |
| 3 | 25 | 0.4 | | 0.75 | | | |
| 4 | 32 | 0.4 | | | | | |
| 5 | 40 | 0.4 | | | | | |

# 4. CHOOSING TRANSFORMER

The load connected to the 20/0.42 kV transformer substation under design is composed of typical household loads. One transformer shall be selected for installation that can be replaced within 24 hours in case of damage.

Initially, the design load is calculated as follows:

$$S_{apl} = \sum S_{apr}, \qquad (4.1)$$

where $S_{apl}$ – design load, kVA;

$S_{apr}$ – estimated total load as shown in Table 3.1, kVA.

Power of the previous transformer must be selected according to equation (4.2) [1]:

$$S_{nom} \approx (0.75\text{-}0.85)S_{apl}. \qquad (4.2)$$

One of outdoor transformers with rated power corresponding to the total load (kVA) of the assignment and proportional distribution of load (Annex No. 4) is selected. Permitted maximum load must be checked for the chosen transformer; under emergency conditions, the permitted maximum load may not exceed the rated power of transformer by more than 1.5 times:

$$\frac{S_{maks}}{S_{nom}} < 1.5. \qquad (4.3)$$

## 4.1. Example of transformer test using the table approximation method

To verify the transformer using the table approximation method, the multi-layer load curve (Fig. 4.1) must be found first using the data given in the assignment (Table 4.1).

Table 4.1

**Example of daily load by hours in a winter month**

| Winter (February) | | | |
|---|---|---|---|
| Hour | Electricity load by hours, % | $S_{apl}$, kVA | $S_{apl}$, % |
| 1 | 3.28 | 27.76 | 57.85 |
| 2 | 2.98 | 25.22 | 52.56 |
| 3 | 2.84 | 24.04 | 50.09 |
| 4 | 2.80 | 23.70 | 49.38 |
| 5 | 2.85 | 24.12 | 50.26 |
| 6 | 3.07 | 25.98 | 54.14 |
| 7 | 3.74 | 31.65 | 65.96 |
| 8 | 4.32 | 36.56 | 76.19 |
| 9 | 4.37 | 36.99 | 77.07 |
| 10 | 4.45 | 37.66 | 78.48 |
| 11 | 4.43 | 37.49 | 78.13 |
| 12 | 4.33 | 36.65 | 76.37 |
| 13 | 4.23 | 35.80 | 74.60 |
| 14 | 4.18 | 35.38 | 73.72 |
| 15 | 4.19 | 35.46 | 73.90 |
| 16 | 4.27 | 36.14 | 75.31 |

| Winter (February) | | | |
|---|---|---|---|
| Hour | Electricity load by hours, % | $S_{apl}$, kVA | $S_{apl}$, % |
| 17 | 4.44 | 37.58 | 78.31 |
| 18 | 4.92 | 41.64 | 86.77 |
| 19 | 5.60 | 47.40 | 98.77 |
| 20 | 5.67 | 47.99 | 100.00 |
| 21 | 5.51 | 46.64 | 97.18 |
| 22 | 5.17 | 43.76 | 91.18 |
| 23 | 4.55 | 38.51 | 80.25 |
| 24 | 3.81 | 32.25 | 67.20 |

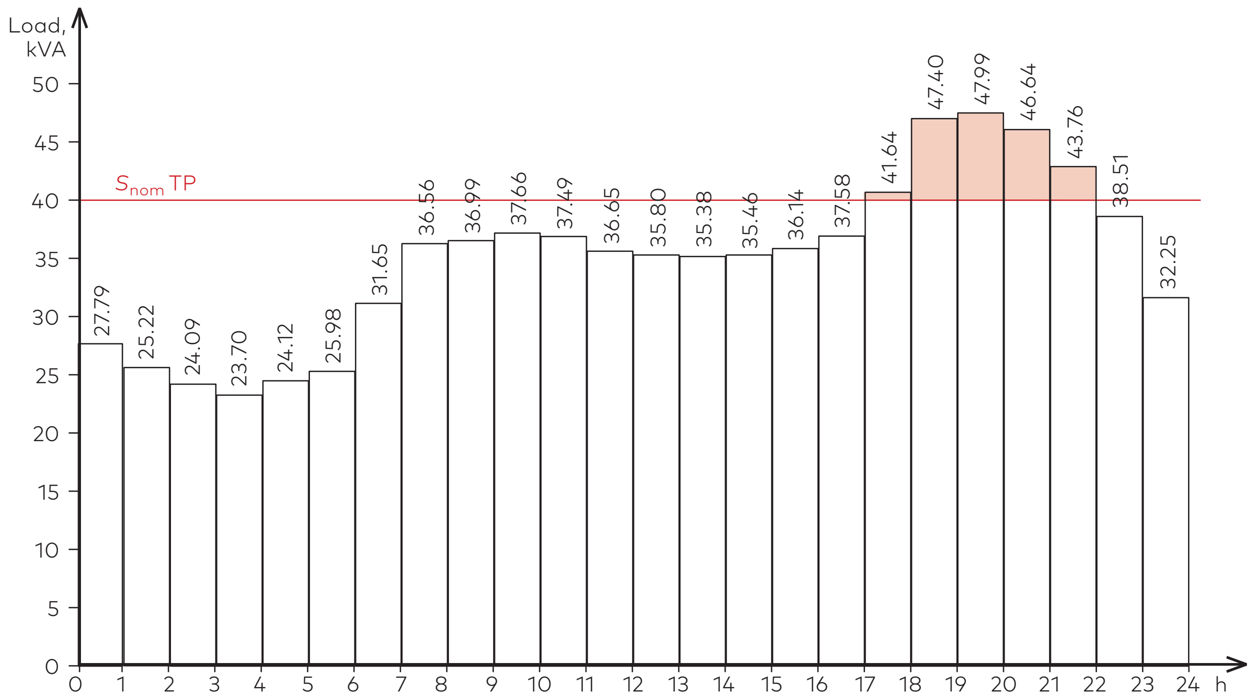



**Fig. 4.1.** Multi-layer load curve in winter.

Overload must be checked for the winter load curve. In the given load curve (Fig. 4.1), a line is drawn, which matches the rated power of the transformer and hours are marked during which there is overload. As shown, one overload zone is marked from 17.00 until 22.00. In the found maximum zone the following must be determined: equivalent maximum $S_{ek.m}$ and equivalent initial load $S_{ek.s}$, which conforms to the average load in the remaining time.

Equivalent maximum $S_{ek.m}$:

$$S_{ek,m} = \sqrt{\frac{S^2{}_{p,1}t_{p,1} + S^2{}_{p,2}t_{p,2} + S^2{}_{p,3}t_{p,3} + S^2{}_{p,4}t_{p,4} + S^2{}_{p,5}t_{p,5}}{t_{p,1} + t_{p,2} + t_{p,3} + t_{p,4} + t_{p,5}}} = \quad (4.4)$$

$$= \sqrt{\frac{41.64^2 \cdot 1 + 47.4^2 \cdot 1 + 47.99^2 \cdot 1 + 46.64^2 \cdot 1 + 43.76^2 \cdot 1}{5}} = 45.55 \text{ kVA}.$$

Actual overload factor $k_{2,apl}$:

$$k_{2,apl} = \frac{S_{ek.m}}{S_{nom}} = \frac{45.55}{40} = 1.13. \quad (4.5)$$

It must be checked if adjustment of the factor $k_{2,\mathrm{apl}}$ is necessary. In the example:

$$k_{2,\mathrm{apl}} = 1.13 > 0.9k_{\max} = 0.9 \cdot 1.19 = 1.07, \qquad (4.6)$$

where

$$k_{\mathrm{maks}} = \frac{S_{\mathrm{maks}}}{S_{\mathrm{nom}}} = \frac{47.99}{40} = 1.19; \qquad (4.7)$$

thus it is established that no adjustment is necessary.

Equivalent initial load:

$$S_{\mathrm{ek,s}} = \sqrt{\frac{S^2{}_{\mathrm{s,1}} t_{\mathrm{s,1}} + S^2{}_{\mathrm{s,2}} t_{\mathrm{s,2}} + \ldots + S^2{}_{\mathrm{s,19}} t_{\mathrm{s,19}}}{t_{\mathrm{s,1}} + t_{\mathrm{s,2}} + \ldots + t_{\mathrm{s,19}}}} =$$

$$= \sqrt{\frac{27.76^2 \cdot 1 + 25.22^2 \cdot 1 + 24.09^2 \cdot 1 + 23.70^2 \cdot 1 + 24.12^2 \cdot 1 + 25.98^2 \cdot 1 + 31.65^2 \cdot 1 + 36.56^2 \cdot 1 +}{20}}$$

$$\sqrt{\frac{36.99^2 \cdot 1 + 37.66^2 \cdot 1 + 37.49^2 \cdot 1 + 36.65^2 \cdot 1 + 35.80^2 \cdot 1 + 35.38^2 \cdot 1 + 35.46^2 \cdot 1 + 36.14^2 \cdot 1 +}{20}}$$

$$\sqrt{\frac{37.58^2 \cdot 1 + 38.51^2 \cdot 1 + 32.25^2}{20}} = 32.18 \text{ kVA}; \qquad (4.8)$$

Initial load factor $k_1$:

$$k_1 = \frac{S_{\mathrm{ek.s}}}{S_{\mathrm{nom}}} = \frac{32.18}{40} = 0.80. \qquad (4.9)$$

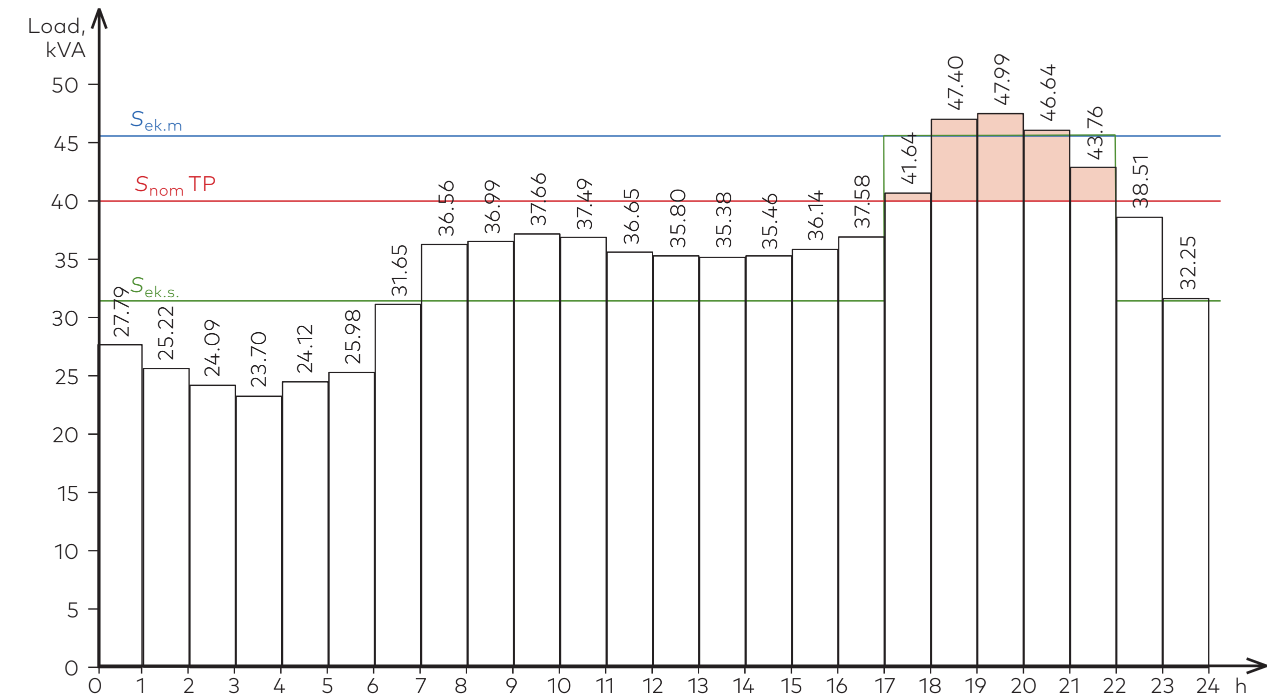



**Fig. 4.2.** Winter load curve at maximum load and transformer rated load.

According to the Latvian Environment, Geology and Meteorology Centre, the equivalent cooling environment temperature in Latvia in winter and summer 2017 [6] — $\vartheta_{\mathrm{ek}}$, °C.

Following the design all the data necessary for establishing the permitted overload factor $k_{2,\mathrm{piel}}$ are obtained according to tables [2] that are necessary for emergency overload test. If the values of average temperature $\vartheta_{\mathrm{ek}}$ (°C) do not match the standard values in tables, the table closest to the highest temperature is selected. According to the overload duration (duration of the equivalent maximum $t_p = 5$ h) and initial load factor ($k_1 \approx 0.8$), the permitted value of overload factor shall be found in the table and compared with the calculation:

$$k_{2,\text{pieļ,s}} = 1.25 > k_{2,\text{apl}}. \qquad (4.10)$$

## 4.2. Example of transformer test applying the analytical method

To test a transformer using the analytical method, the software *Trafo–1* shall be used; this software is available here: *http://www.eef.rtu.lv/doc/studiju_materiali/031.pdf*

Data for the analytical testing calculation for winter:

- cooling system — *ONAN*;
- load curve — winter;
- design month — February;
- transformer location — outdoors;
- transformer maximum load — 47.99 kVA;
- transformer rated load — 40 kVA;
- transformer load loss — 0.133 kW (from the manufacturer's technical documentation);
- transformer no-load loss — 0.883 kW (from the manufacturer's technical documentation).

Table 4.2

Results of the analytical testing, example (40 kVA power transformer)

| $T_i$ | $\vartheta_0$, °C | $S[I]$ | $S_i/S_{nom}$ | $\vartheta_e$, °C | $\vartheta_{tin}'$, °C | $\vartheta_{tin}''$, °C |
|---|---|---|---|---|---|---|
| 1 | –8.1 | 27.76 | 0.6940 | 50.8 | 60.8 | 59.4 |
| 2 | –8.2 | 25.22 | 0.6305 | 49.8 | 58.4 | 57.8 |
| 3 | –8.5 | 24.09 | 0.6023 | 48.8 | 56.8 | 56.6 |
| 4 | –8.6 | 23.70 | 0.5925 | 48.2 | 56.0 | 56.2 |
| 5 | –8.7 | 24.12 | 0.6030 | 47.7 | 55.7 | 56.7 |
| 6 | –8.8 | 25.98 | 0.6495 | 47.5 | 56.5 | 59.9 |
| 7 | –8.9 | 31.62 | 0.7905 | 47.7 | 6.1 | 63.3 |
| 8 | –8.9 | 36.56 | 0.914 | 48.3 | 63.9 | 64.2 |
| 9 | –9.0 | 36.99 | 0.9248 | 48.7 | 64.6 | 65.0 |
| 10 | –9.0 | 37.66 | 0.9415 | 49.1 | 65.4 | 65.3 |
| 11 | –8.4 | 37.49 | 0.9373 | 50.0 | 66.2 | 65.7 |
| 12 | –7.7 | 36.65 | 0.9163 | 50.8 | 66.5 | 65.9 |
| 13 | –6.9 | 35.80 | 0.8950 | 51.7 | 66.8 | 66.5 |
| 14 | –6.2 | 35.38 | 0.8845 | 52.3 | 67.1 | 67.1 |
| 15 | –5.8 | 35.46 | 0.8865 | 52.7 | 64.5 | 68.0 |
| 16 | –5.8 | 36.14 | 0.9035 | 52.8 | 68.1 | 69.1 |
| 17 | –5.9 | 37.58 | 0.9395 | 52.8 | 69.1 | 72.0 |
| 18 | –6.1 | 41.64 | 1.0410 | 53.2 | 72.4 | 76.8 |
| 19 | –6.4 | 67.40 | 1.1850 | 53.9 | 77.5 | 78.0 |
| 20 | –6.6 | 47.99 | 1.1998 | 54.5 | 78.6 | 77.5 |
| 21 | –6.9 | 46.64 | 1.1660 | 54.6 | 77.6 | 75.4 |
| 22 | –7.3 | 43.76 | 1.0940 | 54.2 | 75.0 | 71.1 |
| 23 | –7.6 | 38.51 | 0.9628 | 53.3 | 70.2 | 66.1 |
| 24 | –7.8 | 32.25 | 0.8063 | 52.1 | 64.9 | 62.1 |
| **MAKS.** | **–5.8** | **47.99** | **1.1998** | **54.6** | **78.6** | **78.0** |

Highest top oil temperature $\vartheta_{e.maks}$ = 54.6 °C < $\vartheta_{e.pieļ}$ = 105 °C does not exceed the permitted value (Annex No. 2). The temperature of the hottest spot of transformer winding $\vartheta_{tin.max}$ = 78.6 °C < $\vartheta_{tin,pieļ}$ = 140 °C also does not exceed the permitted value (Annex No. 2).

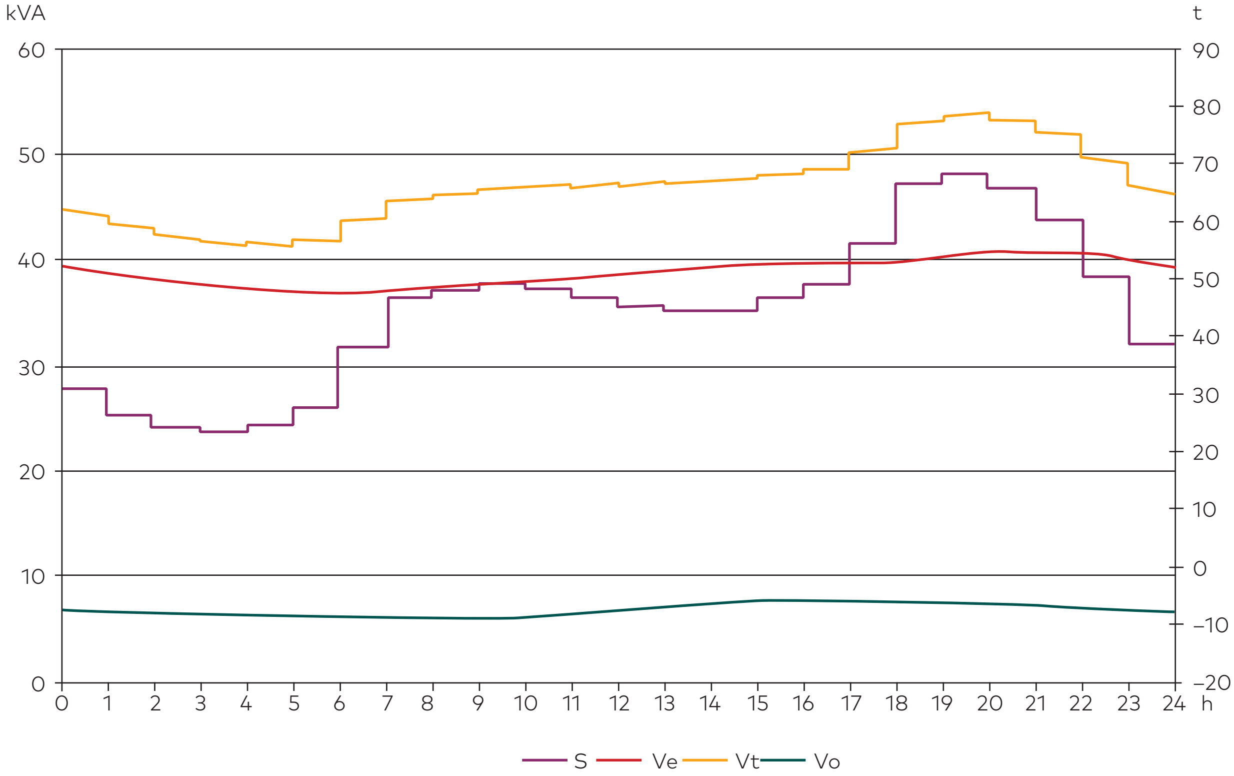



**Fig. 4.3.** Daily temperature curve of a transformer (40 kVA) in winter.

**According to the assignment variant, verify one month in the summer and winter season using the analytical method.** In order to use a pre-selected transformer for covering the load presented in the graph, it must comply with the selection criteria.

# 5. SELECTION OF MEDIUM VOLTAGE DEVICES

## 5.1. Selection of a 20 kV overhead line

Reason for overhead line calculation: to establish the wire cross-section and conductor type [1, *p.135*].

To check if a network complies with economic and power quality criteria, the following calculation method shall be applied [2, *p.167*]. The line is selected according to criteria (5.1)–(5.3).

The rated voltage $U_{nom}$ is compared with the voltage of the particular network $U_t$:

$$U_{nom} \geq U_t. \tag{5.1}$$

Economic cross-section

$$S \approx S_{ek} = \frac{I_{apl}}{J_{ek}}, \tag{5.2}$$

where

$S$ – the wanted cable cross-section, mm$^2$;
$S_{ek}$ – most economic cross-section of a conductor, mm$^2$;
$I_{apl}$ – design current under continuous regular conditions, A;
$J_{ek}$ – economic current density in the conductor, A/mm$^2$ [1, *p.132*].

The calculated economic cross-section of a wire is added to the standard cross-section scale. The standard cross-section shall be larger than the calculated $S_{ek}$ otherwise the voltage loss may exceed the permitted value. According to the Energy Standard LEK 005, conductor must be found and the cross-section thereof.

Permitted current under continuous duty

$$I_{pieļ} = K_1 I_{pieļ.nom} \geq I_{apl}, \tag{5.3}$$

where

$I_{pieļ}$ – actually permitted current, A;
$K_1 = 0,8$ – correction factor, which considers the inhomogeneous distribution of current in single-phase conductors.

It must be checked if the calculated wire cross-section is valid for the operation of the 20 kV overhead line under design. According to the Energy Standard LEK 120 "Wood poles, constructions, and materials of 20 kV overhead lines", wood poles are selected for the 20 kV overhead line under design. In designing the power line, the wind pressure regions and territory division by the icing thickness in the territory of Latvia, as indicated in the Energy Standard LEK 015 "The main technical requirements for /6, 10, 20 kV/ overhead lines", must be taken into consideration. The new 20 kV overhead line is designed along an existing road, and the pole type is shown in Table 5.1.

Table 5.1

**Poles of 20 kV overhead lines and summary of the types thereof according to the assignment variant**

| Pole No. | Type, according to regulations |
|---|---|
| Current pole (from the assignment variant) – connection to the system | N |
| | |
| | |
| | |
| | |
| | TA 20/0.4 kV under design |

The overhead line route must be selected as short as possible and with minimum number of turns and by avoiding bogs, hilly terrains, areas with strong winds, nature reserves, etc. It is useful, from the operational point of view, if the route is close to roads and populated areas. It is not advisable to mount overhead line poles in flooded areas. Serial numbers shall be placed on overhead line poles 2.5–3.0 m above ground. The pole serial number and the specified designation is needed on the terminal poles, the first poles of branches, the restrictive poles of crossings of one-voltage overhead lines, the poles restricting overhead line crossings with railway and roads, as well as all the poles in sections parallel to overhead lines if the distance between overhead line axes is less than 200 m. Additionally, each circuit shall be marked in twin-circuit overhead line poles.

A warning sign shall be placed on all poles in cities, towns, villages, and other densely-populated areas, as well as on poles that are located in the protection zone of communication cables. The sign shall be placed on overhead lines alternately on the left and right side, and on the road side. In the warning sign, distance from the pole to communication cable shall be indicated.

## 5.2. Selection of medium voltage fuses

Fuses are designed to protect network apparatuses from short-circuit and large overloads. In case of overload or emergency, the fusible plug flows away and breaks the power circuit.

Medium voltage fuses in Fig 2.1 are FU0. Detailed selection of these fuses is shown hereafter; the selection is based on specific medium voltage type fuses, according to the assignment variant. Testing and selection of medium voltage fuses is done according to requirements (5.4)–(5.10).

Rated voltage

$$U_{\text{dr.nom}} \geq U_{\text{nt}}. \tag{5.4}$$

Rated voltage of fusible plug (according to design current)

$$I_{\text{el.nom}} \geq K_{\text{dr}} I_{\text{apl.A}}, \tag{5.5}$$

where

$I_{\text{el.nom}}$ – smallest rated current of the fusible element, A;

$K_{\text{dr}} = 2$ – reliability factor, which is used to prevent non-selective activation of fuse in case of technological overloads, for example, for the protection of transformers $K_{\text{dr}}$ value range is [1.5; 3.0] [2, *p. 217*];

$I_{\text{apl.A}}$ – design current in the transformer's medium voltage part, A;

$$I_{\text{apl.A}} = \frac{S_{\text{apl}}}{\sqrt{3} U_{\text{nom}}}, \tag{5.6}$$

where

$S_{\text{apl}}$ – calculated design load, kVA;

$U_{\text{nom}}$ – rated voltage, kV.

Calculate the rated current of fusible plug:

$$I_{\text{el.nom}} > K_{\text{dr}} I_{\text{apl.A}}. \tag{5.7}$$

The next nominal closest to the fusible plug, from the values offered in the catalogue.

Test after breaking capacity:

$$I_{\text{atsl.nom.dr}} \geq I_{\text{K1}}^{(3)}, \tag{5.8}$$

where

$I_{\text{atsl.nom.dr}}$ – maximum short-circuit current that a fuse can interrupt [16, p. 306];

$I_{\text{K1}}^{(3)}$ – value of the periodic component of short-circuit current in point K1.

Sensitivity

$$I_{k.min} \geq \sqrt{3} I_{iel.nom.dr}, \quad (5.9)$$

where

$I_{k.min}$ – minimum short-circuit current in the protected zone of the fuse, which includes transformer's 0.4 kV leads and conductors to the input protection appliance of 0.4 kV switchgear; therefore, the value that was calculated for a two-phase short-circuit on 0.4 kV bussbar section and reduced for 20 kV voltage shall be used:

$$I_{K2}^{(2)20kV} = I_{K2}^{(3)0,4kV} \cdot \frac{\sqrt{3}}{2} \cdot \frac{U_{vid.A}}{U_{vid.Z}}, \quad (5.10)$$

$3I_{el.nom.dr}$ – rated current of a triple fusible plug, A.

Table 5.2

**Selection of high voltage fuse**

| Fuse No. | Selection criterion | | | |
|---|---|---|---|---|
| | $U_{nom} \geq U_t$ | $I_{iel.nom} \geq K_{dr} I_{apl}$ | $I_{atsl.nom} \geq I_{p0}$ | $I_{k.min} \geq 3I_{iel.nom}$ |
| FU0 | | | | |

Summary of compliance test of the fuse selected for the transformer's protection.

# 6. CALCULATION OF THREE-PHASE SHORT-CIRCUIT CURRENT IN 20 kV AND 0.4 kV SWITCHGEAR IN THE NAMED UNITS

When short-circuit occurs in a system, the current intensity may increase rapidly; therefore, the apparatuses installed in a substation must be resistant to such changes in current intensity. There are various reasons for short-circuit, for example, damaged insulation, weather conditions, human activity, etc. Short-circuit caused by these or other conditions causes interruptions in power supply; thus, appropriate measures must be taken to prevent short-circuits or to reduce their duration.

## 6.1. Calculation of three-phase short-circuit in the end of 20 kV line under design

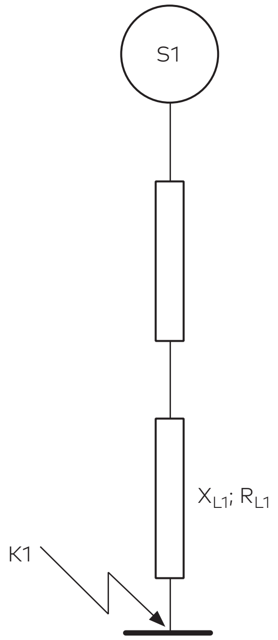



**Fig. 6.1.** Substitution circuit for 20 kV switchgear.

To calculate three-phase short-circuit current in the end of 20 kV overhead line under design, the resistance thereof must be calculated. For calculation, the value of three-phase short-circuit in the beginning of the line under design ($I_{ks}^{(3)}$ = 9 kA) as provided by AS Sadales tīkls is used.

First, according to the equation (5.1), three-phase short-circuit in point K1 is calculated:

$$I_{K1}^{(3)} = \frac{U_{vid}}{\sqrt{3} Z_{\Sigma_1}^{(20kV)}}, \tag{6.1}$$

where

$U_{vid}$ – average voltage value, $U_{vid.20kV}$ = 21 kV;
$Z_{\Sigma}$ – impedance up to the short-circuit point K1, Ω.

To calculate impedance to three-phase short-circuit K1, inductive reactance of the system and feeder link is necessary, as well as the resistance of the feeder link. Resistance of system S1 is determined:

$$X_{S1} = \frac{U_{vid.20kV}}{\sqrt{3} I_k^{(3)}}, \tag{6.2}$$

where

$I_k^{(3)}$ – three-phase short-circuit current at the beginning of the specific line, kA.

Resistance of the feeder link:

$$R_L = r_0 l; \quad (6.3)$$

$$X_L = x_0 l; \quad (6.4)$$

where

$X_L$ – resistance of feeder link, Ω;

$R_L$ – inductive reactance of feeder link, Ω;

$r_0$ – specific resistance of line wires, Ω/km;

$x_0$ – specific inductive reactance of line wires, Ω/km;

$l$ – length of the line, km.

Calculation of resistances $X_L$ and $R_L$ of the line L1 according to the assignment variant must be summarised in Table 6.1.

Table 6.1

**Line parameters**

| Wire brand | $R_0$, Ω/km | $X_0$, Ω/km | Length of the line $l$, km | $R_{L1}$, Ω | $X_{L1}$, Ω |
|---|---|---|---|---|---|
| | | | | | |

Calculation of total resistance up to the short-circuit K1:

$$R_{\Sigma 1}^{(20kV)} = R_{L1} = \quad (6.5)$$

$$X_{\Sigma 1}^{(20kV)} = X_{S1} + X_{L1} = \quad (6.6)$$

$$Z_{\Sigma 1}^{(20kV)} = \sqrt{\left(R_{\Sigma 1}^{(20kV)}\right)^2 + \left(X_{\Sigma 1}^{(20kV)}\right)^2} = \quad (6.7)$$

Three-phase short-circuit current on the side of 20 kV transformer:

$$I_{K1}^{(3)} = \frac{U_{vid}}{\sqrt{3} Z_{\Sigma_1}^{(20kV)}} = \frac{21}{\sqrt{3} \cdot 1{,}67} \quad (6.8)$$

## 6.2. Calculation of three-phase short-circuit in 0.4 kV switchgear

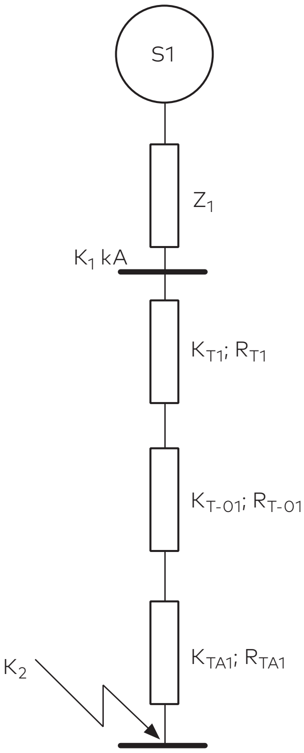



**Fig. 6.2.** Substitution circuit for 0.4 kV switchgear.

Average low-voltage value:

$U_{vid.0.4kV} =$ kV.

The passport data of the selected transformer according to the type of the selected transformer:

$U_{nom} =$ kV;

$\Delta P_K =$ kW;

$U_K =$ kV.

Calculation of resistances $X_{S1}$, $R_{L1}$, $X_{L1}$ for 0.4 kV voltage:

$$X_{S1}^{(0,4kV)} = X_{S1}\left(\frac{U_{Z.vid}}{U_{A.vid}}\right)^2; \quad (6.9)$$

$$X_{L1}^{(0,4kV)} = X_{L1}\left(\frac{U_{Z.vid}}{U_{A.vid}}\right)^2; \quad (6.10)$$

$$R_{L1}^{(0,4kV)} = R_{L1}\left(\frac{U_{Z.vid}}{U_{A.vid}}\right)^2. \quad (6.11)$$

Calculation of transformer resistance:

$$R_{T1} = \frac{\Delta P_K U_{nom}^2}{S_{nom}^2} = \quad (6.12)$$

$$Z_{T1} = \frac{U_K \% U_{nom}^2}{100 S_{nom}} = \quad (6.13)$$

$$X_{T1} = \sqrt{Z_{T1}^2 - R_{T1}^2} = \quad (6.14)$$

Resistance and inductive reactance of current transformers $TA_1$ according to the technical information provided by the manufacturer:

$R_{TA1} =$ Ω;
$X_{TA1} =$ Ω.

Resistance data of connections shall be taken from Table 6.2.

Table 6.2

### Contact resistances

| Type of connection | Resistance, Ω | Number of connections | Total resistance, Ω |
|---|---|---|---|
| $R_{kont.kabelis}$ | 0.00010 | | |
| $R_{kont.kopnes}$ | 0.00001 | | |
| $R_{kont.\Sigma} =$ | | | |

Calculation of summary resistance:

$$R_{\Sigma 1}^{(0,4kV)} = R_{L1}^{(0,4kV)} + R_{T1} + R_{TA1} + R_{kont.\Sigma} = \quad (6.15)$$

$$X_{\Sigma 1}^{(0,4kV)} = X_{S1}^{(0,4kV)} + X_{L1}^{(0,4kV)} + X_{T1} + X_{TA1} = \quad (6.16)$$

$$Z_{\Sigma 1}^{(0,4kV)} = \sqrt{\left(R_{\Sigma 1}^{(0,4kV)}\right)^2 + \left(X_{\Sigma 1}^{(0,4kV)}\right)^2} = \quad (6.17)$$

Three-phase short-circuit currents in 0.4 kV switchgear:

$$I_{K2}^{(3)} = \frac{U_{Z.vid}}{\sqrt{3} Z_{\Sigma_1}^{(0,4kV)}}. \quad (6.18)$$

# SOURCES


1. Timmermanis, K., Rozenkrons, J. *Elektrisko staciju un apakšstaciju elektriskā daļa*. R. Zvaigzne, 1987.
2. “SLO” Vidsprieguma tehnikas katalogs. [Online]. Available: https://www.slo.lv/upload/catalog/slo_katalogi/slo_vidsprieguma_katalogs_2016_web.pdf;
3. AS „Sadales tīkls” Ikstundas patēriņa sadalījuma grafiki . [Online]. Available: http://www.sadalestikls.lv/lat/tirgus/informacija_tirgotajiem/ikstundas_paterina_sadalijuma_grafiks/
4. Latvijas vides ģeoloģijas un meteoroloģijas centrs.*Laika apstākļi 2017. gadam Latvijā* . [Online]. Available: https://meteo.lv/jaunumi/laika–apstakli/laika–apstakli–2017–gada–vasara?id=1107&cid=100;
5. Vanags, A. *Elektriskie tīkli un sistēmas*.Rīga, RTU, 2007.
6. Неклепаев Б. Н., Крючков И. П. Электрическая часть электростанций и подстанций: Справочные матереалы для кусового и дипломного проектирование. Москва, Эенергоатомиздат 1989. – 608 с.
7. Pfiffner zemsprieguma strāvmaiņu katalogs.
8. Draka kabeļu katalogs.
9. EFEN augstsprieguma drošinātāju katalogs.
10. *Elektroietaišu zemēšana un elektrodrošības pasākumi. Galvenās tehniskās prasības*. LEK 048
11. *Pārspriegumu aizsardzība vidsprieguma elektrotīklos*. LEK 042-1., LEK 042-2.
12. POLIM-D. *ABB izlādņu katalogs.*
13. ETI *0,4 kV izlādņu katalogs.*
14. *Elektrotehniskie produkti Katalogs*. 2012/2013.
15. LR MK noteikumi Nr. 359. *Darba aizsardzības prasības darba vietās*
16. LVS EN 62305-3. *Zibensaizsardzība. 3. daļa. Aizsardzība pret būvju bojājumiem un dzīvības briesmām.*
17. OBO BETTERMAN *zibensaizsardzības sastāvdaļu katalogs.* [Online]. Available:http://catalog4.obo-bettermann.com/catalogue/catalogue.do?favOid=tbs_261394&action=start&act=showIO&lang=lv&forward=showSolutionView&catId=KTS
18. LR MK noteikumi Nr. 333. *Noteikumi par Latvijas būvnormatīvu*
19. Vides aizsardzības un reģionālās attīstības ministrija. *Ieteikumi videi draudzīgas būvniecības veicināšanai*. 2008. – 96 lpp.
20. *Energoietaišu tehniskā ekspluatācija*. LEK 002.
21. Darba aizsardzības likums.
22. *Drošības prasības, veicot darbus elektroietaisēs.* LEK 025.

# Annex No. 1
# Coincidence Factor

As the number of using equipment increases, there is an increasing possibility that the transformer is underloaded. Each individual uses power according to the individual needs, which does not always match the activity of their neighbours from other houses or flats. To avoid selection of an overly large transformer, Table A1 shall be used; this Table indicates the coincidence factor of agricultural region depending on the number of using equipment.

Table A1

**Coincidence factor $K_0$ according to the number of using equipment**

| Number of using equipment | 2 | 3 | 4, 5 | 6, 7 | 8–10 | 11–15 | 16–20 | 21–40 | 71–150 | ≥ 151 |
|---|---|---|---|---|---|---|---|---|---|---|
| $K_0$ | 0.93 | 0.87 | 0.75 | 0.63 | 0.45 | 0.41 | 0.38 | 0.33 | 0.30 | 0.28 |

# Annex No. 2
# Permitted overload of transformers

Overload may occur in every transformer. Table A2 provides a summary of transformers of various powers and types.

Table A2

**Permitted overload of transformers under various regulated conditions.**

| Load conditions and parameters | Transformer's power | | |
|---|---|---|---|
| | Distribution transformers with power $S \leq 2500$ kVA | Medium power transformers with power $S \leq 100$ MVA | High-power transformers with power $S > 100$ MVA |
| **Systemic load conditions** | | | |
| Current, rel. unit | 1.5 | 1.5 | 1.3 |
| Temperature of the hottest spot of windings and other metal parts contacting insulation, °C | 140 | 140 | 120 |
| Top oil temperature, °C | 105 | 105 | 105 |
| **Continuous emergency overload conditions** | | | |
| Current, rel. unit | 1.8 | 1.5 | 1.3 |
| Temperature of the hottest spot of windings and other metal parts contacting insulation, °C | 150 | 140 | 130 |
| Top oil temperature, °C | 115 | 115 | 115 |
| **Short-time (30 min) emergency overload conditions** | | | |
| Current, rel. unit | 2.0 | 1.8 | 1.5 |
| Temperature of the hottest spot of windings and other metal parts contacting insulation, °C | Not regulated | 160 | 160 |
| Top oil temperature, °C | Not regulated | 115 | 115 |

# Annex No. 3

Table A3

## Technical parameters of *AXPK* 0.4 kV cable

| Kabeļu pamatdati | | | 4G16 | 4G25 | 4G35 | 4G50 | 4G70 | 4G95 |
|---|---|---|---|---|---|---|---|---|
| EAN kods | | 64 100+ | 06 210 07-7 | 06210 08-4 | 06 210 09-1 | 06 210 10-7 | 06 210 11-4 | 06 210 12-1 |
| **Konstrukcijas dati** | | | | | | | | |
| Kabeļa ārējais diametrs (1) | | mm | 20 | 21 | 23 | 27 | 30 | 34 |
| Svars (1) | alumīnijs | kg/km | 165 | 265 | 365 | 495 | 720 | 995 |
| | kabelis | kg/km | 380 | 500 | 670 | 830 | 1170 | 1500 |
| **Piegādes dati** | | | | | | | | |
| Standarta piegādes garums | | m | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Standarta piegādes saiva | | | K12 | K14 | K16 | K16 | K18 | K20 |
| Kopējais svars (1) | kabelis + saiva | kg | 470 | 615 | 865 | 1025 | 1400 | 1840 |
| **Mehāniskie dati (2)** | | | | | | | | |
| Minimālais pieļaujamais izliekuma rādiuss montāžas laikā | | m | 0.24 | 0.26 | 0.28 | 0.33 | 0.36 | 0.41 |
| Minimālais pieļaujamais izliekuma rādiuss montāžas beigās (3) | | m | 0.17 | 0.19 | 0.20 | 0.23 | 0.26 | 0.29 |
| Maksimāli pieļaujamais stiepes spriegums ar kabeļu satvērēju | | kN | 0.9 | 1.5 | 2.1 | 3.0 | 4.2 | 5.7 |
| Maksimāli pieļaujamais stiepes spriegums ar vilkšanas ierīci | | kN | 3.2 | 5.0 | 7.0 | 10.0 | 14.0 | 19.0 |
| **Elektriskie dati (2)** | | | | | | | | |
| Dzīslas maksimālā aktīvā pretestība | vads +20 °C | Ω/km | 1.91 | 1.20 | 0.868 | 0.641 | 0.443 | 0.320 |
| Dzīslas maksimālā pilnā pretestība | vads +70 °C | Ω/km | 2.3 | 1.5 | 1.0 | 0.77 | 0.53 | 0.39 |
| **Nominālā strāva (2)** | | | | | | | | |
| Zemē | vads +70 °C | A | 78 | 100 | 125 | 150 | 185 | 220 |
| Gaisā | vads +70 °C | A | 64 | 83 | 105 | 125 | 155 | 190 |
| | vads +90 °C | A | 75 | 105 | 130 | 165 | 205 | 245 |
| **Īsslēguma strāva (2)** | | | | | | | | |
| Maksimāli pieļaujamā īsslēguma strāva 1 s (4) | | kA | 1.5 | 2.3 | 3.3 | 4.7 | 6.6 | 8.9 |

| Kabeļu pamatdati | | | 4G120 | 4G150 | 4G185 | 4G240 | 4G300 |
|---|---|---|---|---|---|---|---|
| EAN kods | | 64 100+ | 06 210 13-8 | 06 210 14-5 | 06 210 15-2 | 06 210 16-9 | |
| **Konstrukcijas dati** | | | | | | | |
| Kabeļa ārējais diametrs (1) | | mm | 38 | 42 | 47 | 53 | 58 |
| Svars (1) | alumīnijs | kg/km | 1260 | 1550 | 1950 | 2550 | 3190 |
| | kabelis | kg/km | 1900 | 2300 | 2800 | 3700 | 4600 |
| **Piegādes dati** | | | | | | | |
| Standarta piegādes garums | | m | 1000 | 500 | 500 | 500 | 500 |
| Standarta piegādes saiva | | | K22 | K20 | K20 | K22 | K24 |
| Kopējais svars (1) | kabelis + saiva | kg | 2310 | 1490 | 1740 | 2260 | 2750 |
| **Mehāniskie dati (2)** | | | | | | | |
| Minimālais pieļaujamais izliekuma rādiuss montāžas laikā | | m | 0.46 | 0.51 | 0.57 | 0.64 | 0.70 |
| Minimālais pieļaujamais izliekuma rādiuss montāžas beigās (3) | | m | 0.33 | 0.36 | 0.40 | 0.45 | 0.49 |
| Maksimāli pieļaujamais stiepes spriegums ar kabeļu satvērēju | | kN | 7.2 | 8.5 | 8.5 | 8.5 | 8.5 |
| Maksimāli pieļaujamais stiepes spriegums ar vilkšanas ierīci | | kN | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| **Elektriskie dati (2)** | | | | | | | |
| Dzīslas maksimālā aktīvā pretestība | vads +20 °C | Ω/km | 0.253 | 0.206 | 0.164 | 0.125 | 0.100 |
| Dzīslas maksimālā pilnā pretestība | vads +70 °C | Ω/km | 0.31 | 0.25 | 0.20 | 0.16 | 0.13 |
| **Nominālā strāva (2)** | | | | | | | |
| Zemē | vads +70 °C | A | 225 | 290 | 330 | 375 | 430 |
| Gaisā | vads +70 °C | A | 220 | 250 | 285 | 330 | 380 |
| | vads +90 °C | A | 280 | 320 | 365 | 430 | 480 |
| **Īslēguma strāva (2)** | | | | | | | |
| Maksimāli pieļaujamā īslēguma strāva 1 s (4) | | kA | 11.3 | 14.1 | 17.4 | 22.6 | 28.3 |

# Annex No. 4

Table A4

## Variants of stylised graphs of standard daily loads of agricultural consumers

| Time of day | Agricultural load 1 | | Agricultural load 2 | | Agricultural load 3 | | Agricultural load 4 | |
|---|---|---|---|---|---|---|---|---|
| | Winter, % | Summer, % | Winter, % | Summer, % | Winter, % | Summer, % | Winter, % | Summer, % |
| 0.00–5.00 | 20 | 15 | 20 | 10 | 20 | 15 | 20 | 15 |
| 5.00–6.00 | 40 | 30 | 40 | 30 | 40 | 30 | 40 | 30 |
| 6.00–8.00 | 70 | 40 | 70 | 40 | 70 | 40 | 70 | 40 |
| 8.00–10.00 | 70 | 40 | 50 | 20 | 70 | 20 | 70 | 40 |
| 10.00–12.00 | 40 | 40 | 50 | 40 | 40 | 40 | 40 | 40 |
| 12.00–13.00 | 40 | 40 | 40 | 30 | 70 | 40 | 40 | 40 |
| 13.00–17.00 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 17.00–19.00 | 100 | 40 | 100 | 40 | 80 | 60 | 90 | 50 |
| 19.00–21.00 | 85 | 40 | 85 | 40 | 85 | 40 | 85 | 40 |
| 21.00–24.00 | 50 | 70 | 50 | 70 | 30 | 50 | 50 | 70 |

# Annex No. 5

Table A5

## Summary of agricultural consumer loads: table for determining design power of connected electrical equipment groups

| Group | Using equipment | Real installed power of one element, $P_{el}$, kW | Number | Real power of element group, $P_{el}$, kW | $\cos\varphi$ | Reactive power of element group, $Q_{el}$, kvar | Apparent power of element group, $S$, kVA | $K_O$ | $k_v$ | $K_p$ | Apparent design power, $S_{apl}$, kVA | Real design power, $P_{apl}$, kW | Reactive design power, $Q_{apl}$, kvar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |
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