Riga Technical University
Institute of Power Engineering
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DISTRIBUTION NETWORKS

Methodological Guidelines and Summary of Lecture Notes

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This summary of lecture notes and methodological guidelines include the theoretical and statistical description of medium voltage distribution networks as provided in the programme of the course “Distribution networks”. The lecture notes have been developed as an additional study material for 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

Traditionally, 1939 is regarded as the birth-year of energy industry in Latvia; in this year, Ķegums Hydroelectric Power Station was built and connected to the general system of power transmission and distribution networks. Later, the State Electricity Enterprise Ķegums started operation. Over time, the company's name has been changed to AS Latvenergo and it has become a Baltic-wide provider of energy supply services: generation, transmission, and distribution of energy.

In 2007, the daughter company AS Sadales tīkls (hereinafter — distribution network or DN) of the group of companies AS Latvenergo was established. AS Sadales tīkls deals with the maintenance and development of the power distribution network and provides the population with quality power supply. Since development of modern society cannot be imagined without electricity, the main task of the company is to ensure sustainable development of distribution networks by investing in projects and raising the quality and reliability of power supply to consumers.

The existing electrical grid in Latvia is very wide and branched, and covers 99 % of the State's territory. Large part of the network has been retained from the Soviet times and does not have sufficient level of optimisation. More than half of the Latvian electrical grid consists of overhead lines that go through overgrown territories in a total of 21,000 km. Problems often arise in rural territories where long overhead lines with insufficient cable cross-section go to consumer causing low-quality characteristics of voltage [1].

The methodological guidelines summarise information on the description of distribution networks, standards applicable to the network maintenance and improvement solutions.

1. STRUCTURE AND KEY PARAMETERS OF DISTRIBUTION NETWORKS

1.1. Architecture of distribution networks

The Latvian power system consists of high-voltage lines (330–110 kV), medium-voltage lines (6–20 kV), and low-voltage lines (0.23–1.00 kV). For the provision of power supply services, AS Sadales tīkls uses low-voltage and medium-voltage equipment and lines the total length of which exceeded 95,000 km covering 99 % of the territory in 2015. Power supply is ensured by approximately 27,000 transformer substations. More than half of the territory of Latvia is covered in wood, and some 21,000 km of the distribution lines go through woods. Medium-voltage overhead lines account for about 30,000 km while cable lines for 7000 km of the total network. The total length of low-voltage electrical grid reaches nearly 58,000 km, out of these overhead lines account for 37,000 km and cable lines – for 21,000 km [1].

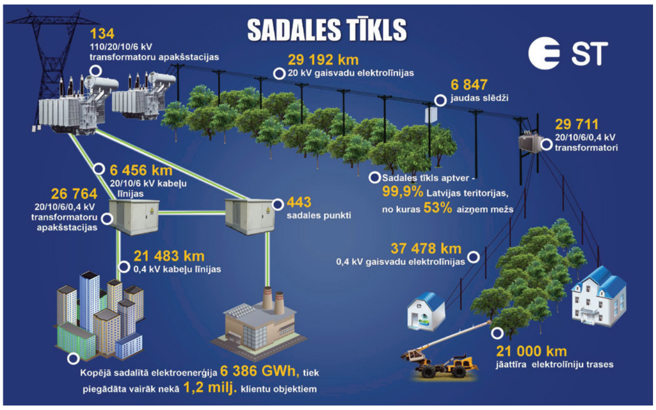
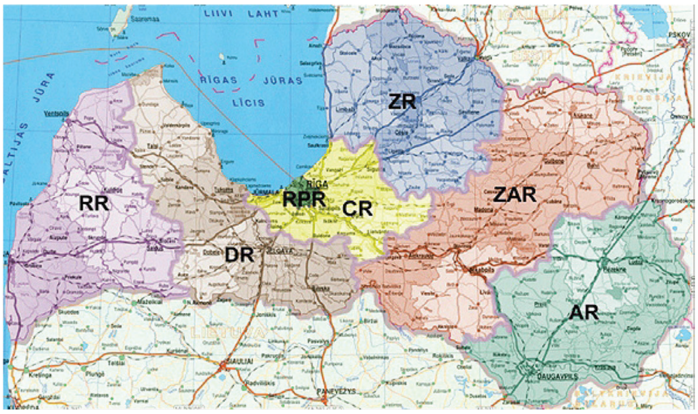


Fig. 1.1. Architecture of distribution networks [1].



ER — Eastern region
NER — North Eastern region
NR — Northern region
SR — Southern region
CR — Central region
WR — Western region
RCR — Riga City region

Fig. 1.2. Regional division of distribution network [2].

To ensure electricity distribution, distribution network maintains all the electrical installations necessary for distribution. Electrical installations include medium-voltage lines and poles, low-voltage lines and poles, transformer substations, distribution transformers, supply stations, and switching devices on the lines. At a closer look, distribution network consists of 1,219,699 power transmission poles, out of these 498 are of metal, 256,048 — of reinforced concrete, and 963,153 — of wood. The total length of medium-voltage lines is 35,469 km, 7,186 km of them are cable lines, 26,357 km — bare wire lines, and 1926 km — lines with insulated wires. Low-voltage lines account in total for 58,345 km, including 23,601 km of cable lines, 22,060 km of bare wire lines, and 12,684 km — aerial cables. Distribution network maintains 26,909 transformer substations, from these 11,776 are outdoor, 2650 — containerised, 6644 — kiosks, 5836 — closed substations.

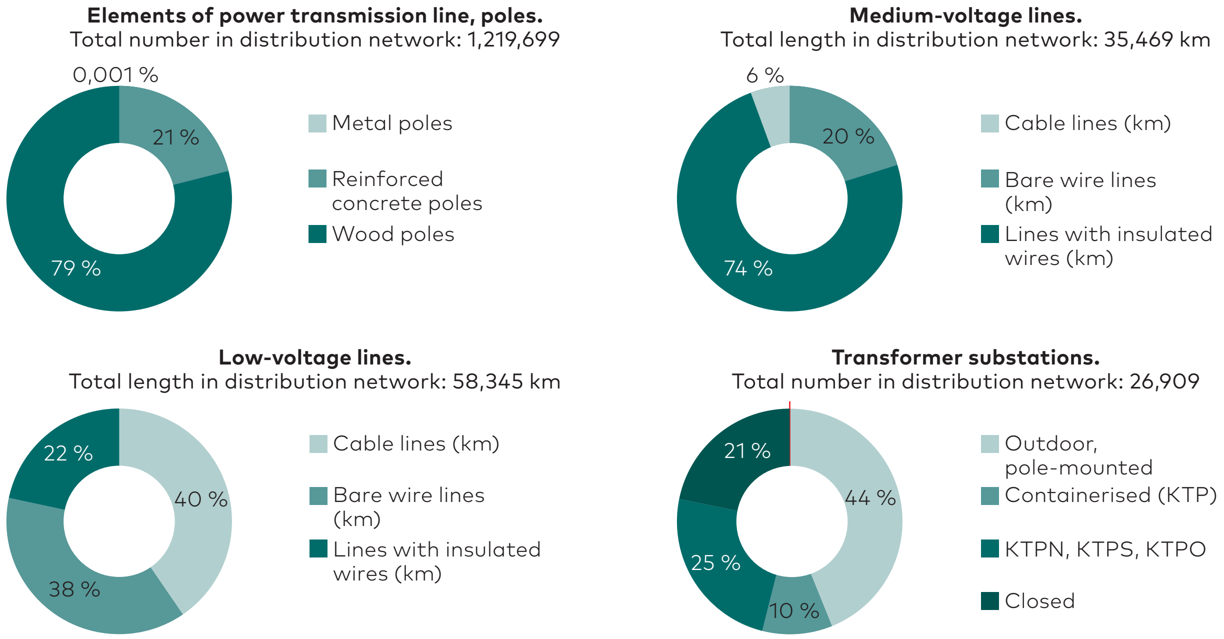


Fig. 1.3. Number of electrical installations of distribution network.

Statistical data on the electrical installations maintained by distribution network by regions and comparison of the ratio thereof to the total number of electrical installations of distribution network in 2016 is presented in (Figs. 1.4–1.10).

1. Eastern region

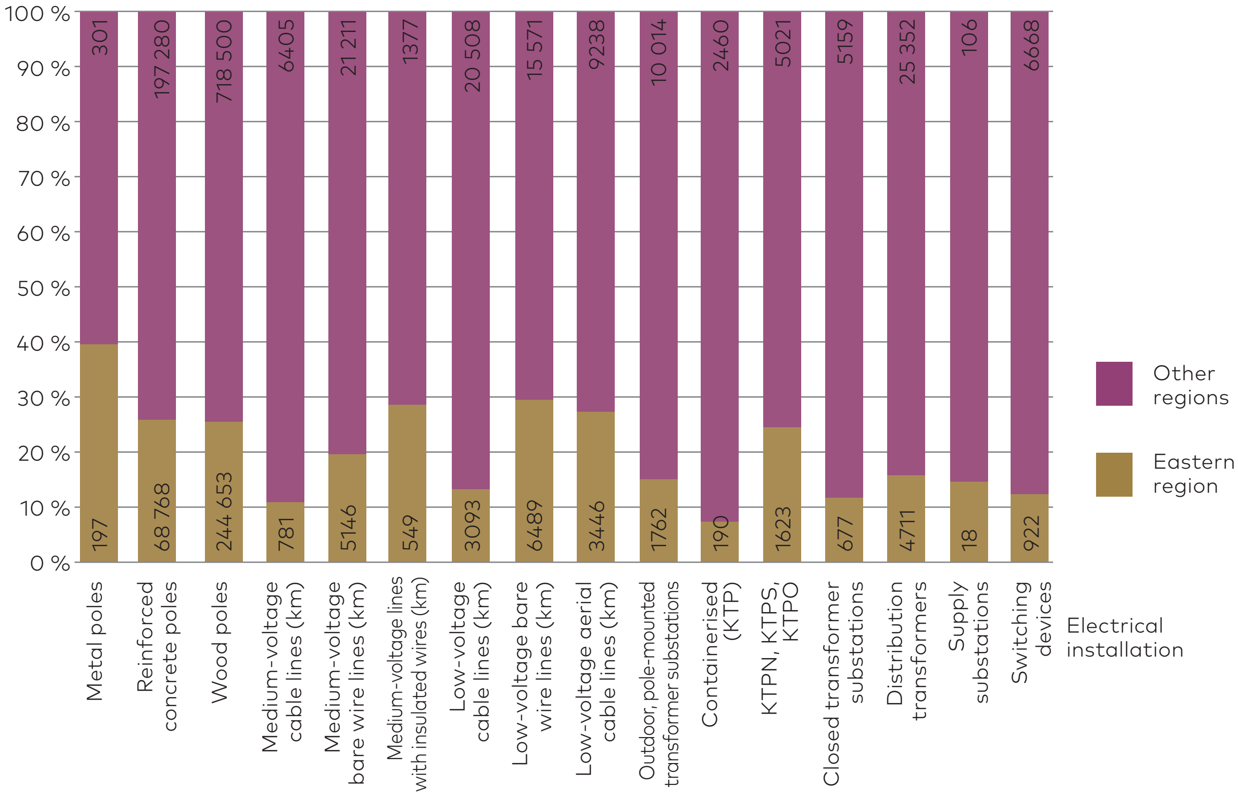


Fig. 1.4. Statistics of electrical installations used in the Eastern region of distribution network.

According to the statistics, there is a large proportion of overhead line poles in the Eastern region (Fig. 1.4). The total number of metal poles in distribution network is 498, and as shown in Fig. 1.4, 197 or 39.5 % of all are located in the Eastern region. In comparison with other regions, also the number of reinforced concrete and wood poles is higher here, consequently resulting in more length of overhead lines and aerial cables. This is explained by the fact that mainly bare wire lines were built in the Eastern region by 1998. As shown by the graph, low-voltage overhead lines in the Eastern region account for 29.4 % of the total length of low-voltage overhead lines maintained by distribution network.

2. North Eastern region

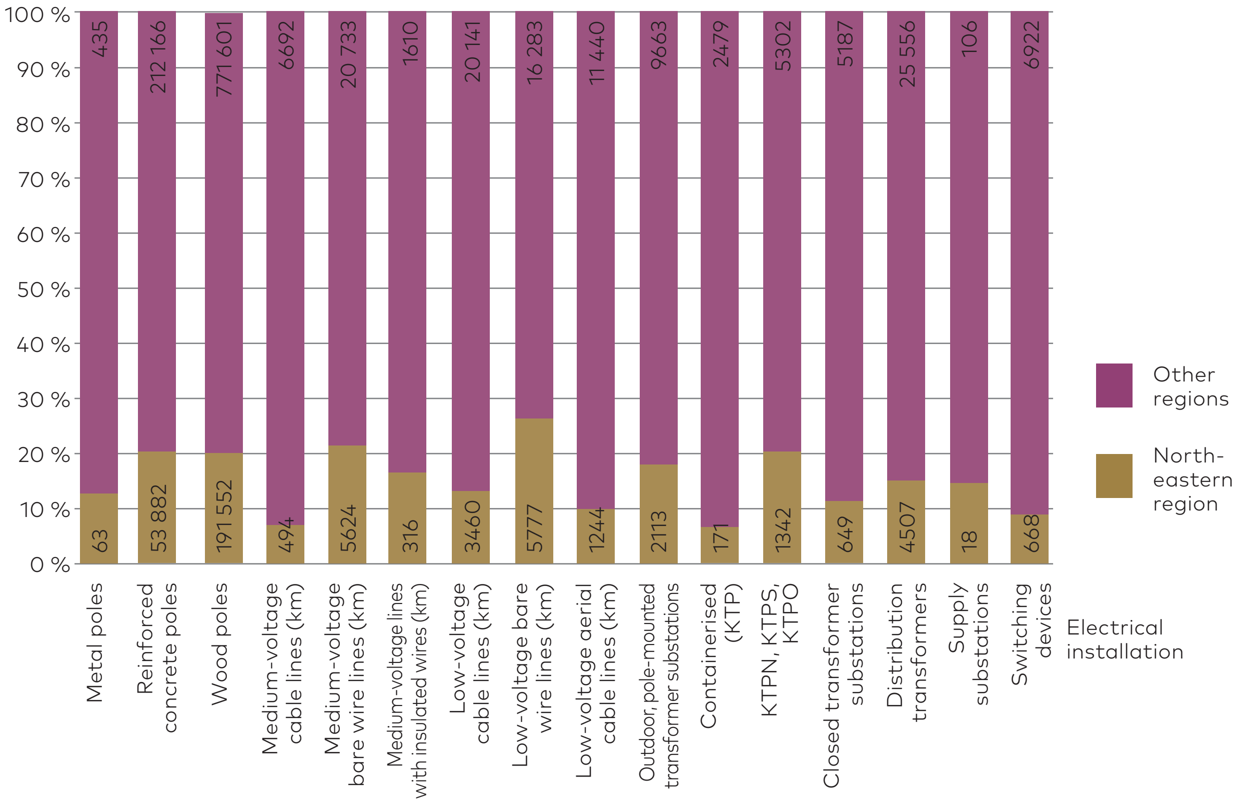


Fig. 1.5. Statistics of electrical installations used in the North Eastern region of distribution network.

Also the North Eastern region (Fig. 1.5) is known for large proportion of overhead lines. Medium-voltage bare wire lines account for 21.3 % and low-voltage bare wire lines for 26.2 % of the total length of bare wires. Since 2000, use of outdoor transformer and pole-mounted transformer substations has increased rapidly. It can be explained by the need to connect new users, and this is realised by building outdoor transformer substations of the necessary power under the existing medium-voltage bare wire lines. In the North Eastern region, there are 17.9 % of outdoor and pole-mounted transformer substations and only 6.5 % of containerised substations of all the substations are maintained by the distribution network.

3. Northern region

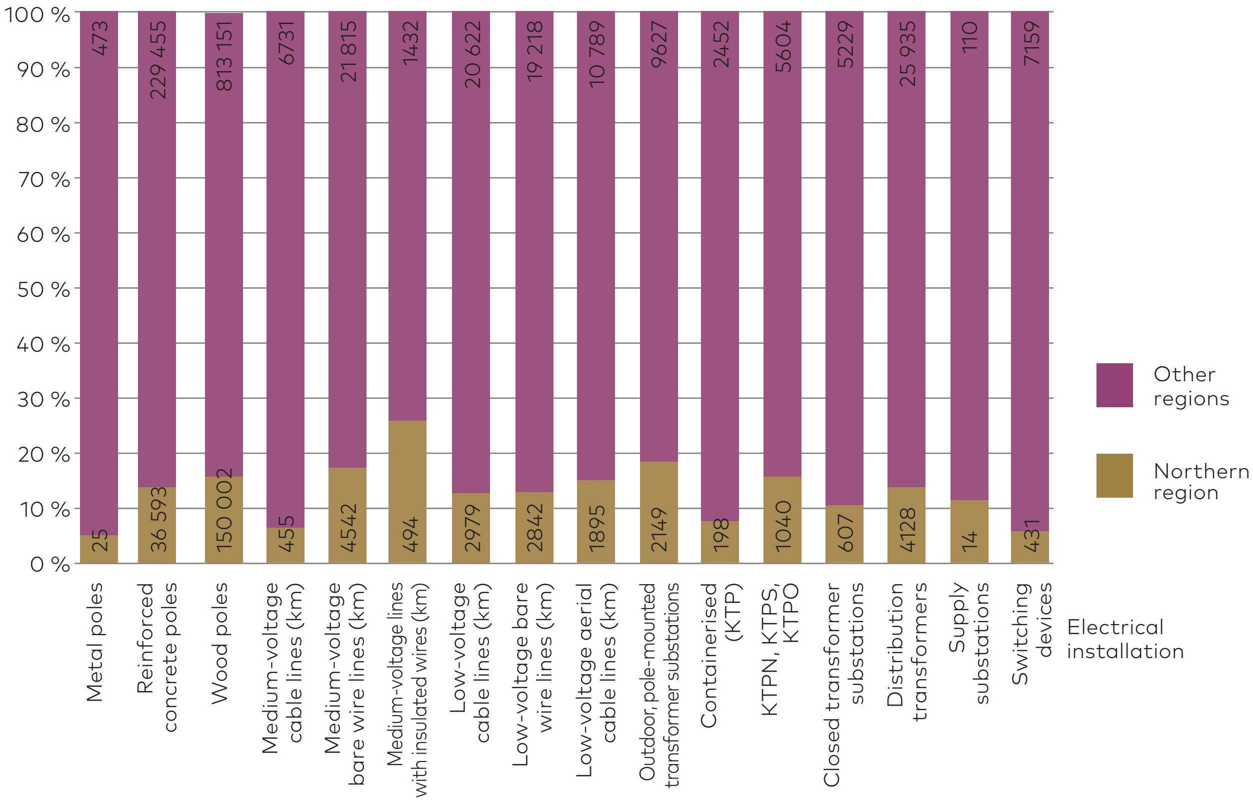


Fig. 1.6. Statistics of electrical installations used in the Northern region of distribution network.

Medium-voltage insulated wire lines in the distribution network account for just 1926 km, and 27.7 % or 494 km of them are located in the Northern region. This trend is explained by the fact that approximately half of the territory of the Northern region is covered in wood and insulated wires are used to prevent supply interruptions caused by weather conditions as much as possible. Low-voltage bare wire lines account for 12.8 % of the total length, and low-voltage cable lines — for 12.6 %. It can be concluded from the above that the Northern region network consists mainly of medium-voltage lines that are located close to users, and there is no necessity to build long low-voltage lines straight to consumers.

4. Southern region

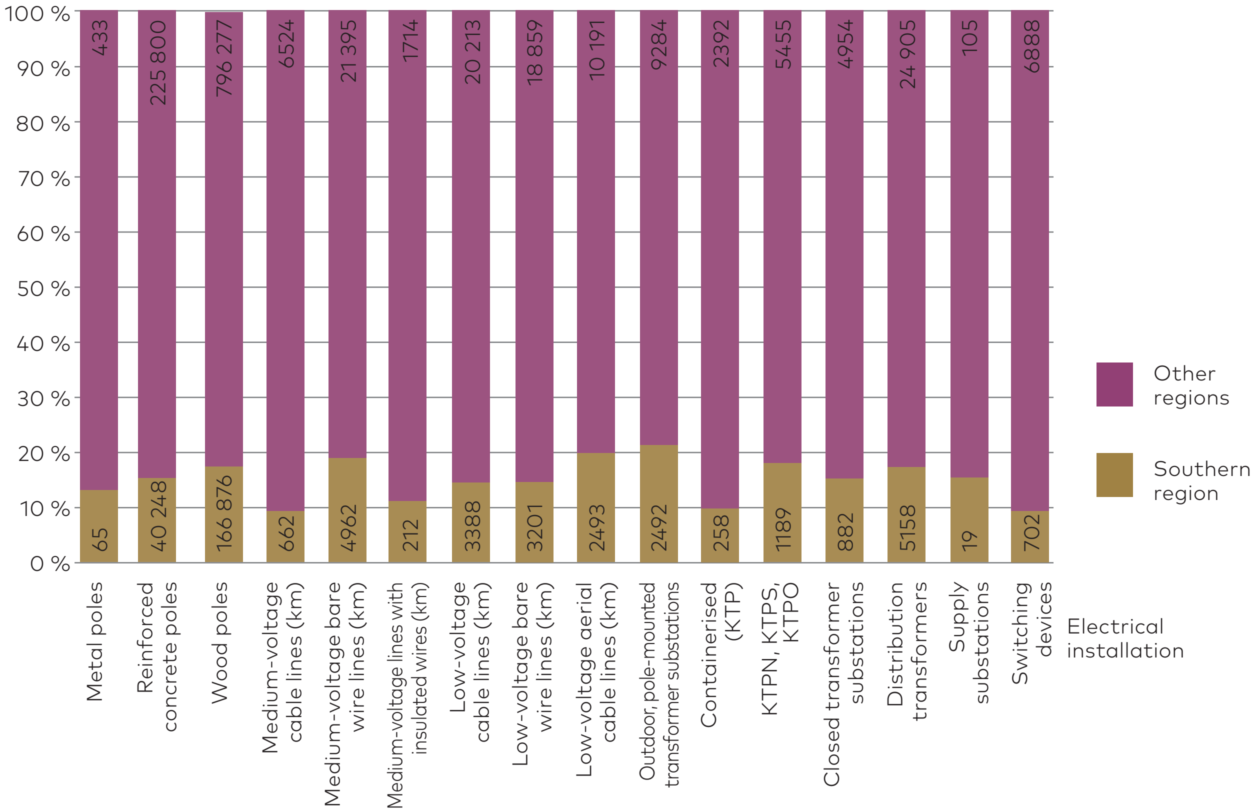


Fig. 1.7. Statistics of electrical installations used in the Southern region of distribution network.

As presented in Fig. 1.7, low-voltage aerial cable lines are often used in the Southern region. These account for 19.7 % of the total length of low-voltage aerial cable lines in distribution network. There are also many outdoor and pole-mounted transformer substations — 21.2 % of the total number. Closed transformer substations in this region amount to 15.1 %, which is the largest number among regions, excluding Riga City region.

5. Central region

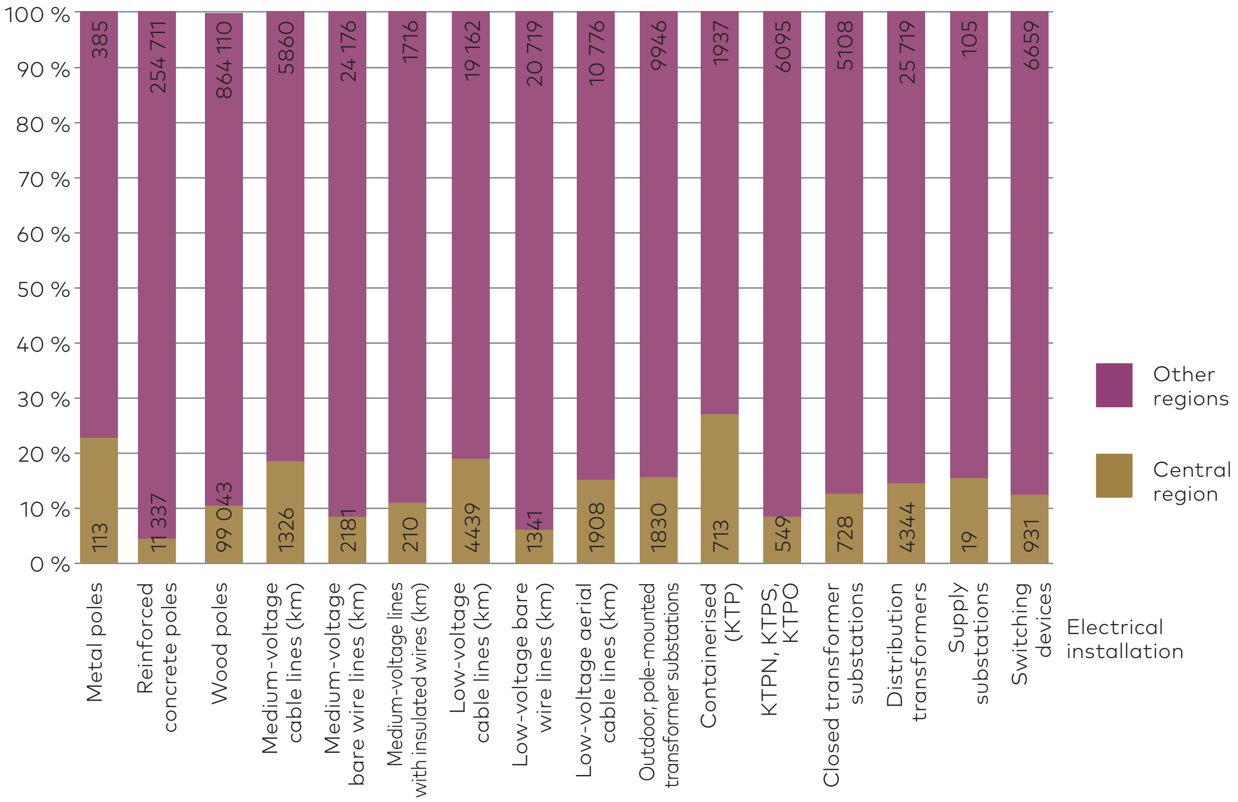


Fig. 1.8. Statistics of electrical installations used in the Central region of distribution network.

According to the electrical installation statistics (Fig. 1.8), it is clear that the infrastructure of electrical grid in the Central region differs from the other regions. Namely, there are comparatively less overhead lines. It can be explained by the fact that population density here is much higher resulting in more cable lines, less outdoor transformers, and more containerised transformer substations. Such proportion of electrical installations should be reached all over the territory of Latvia so that distribution network could improve the network quality.

6. Western region

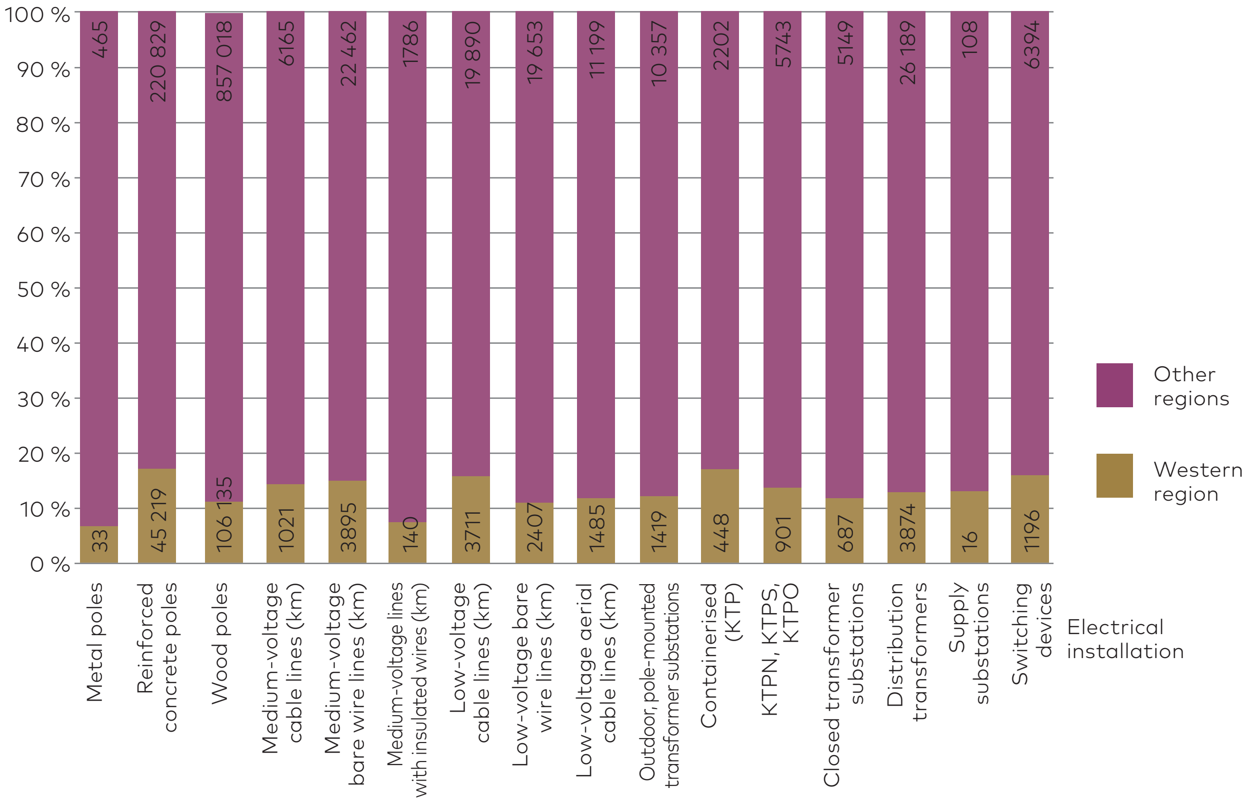


Fig. 1.9. Statistics of electrical installations used in the Western region of distribution network.

There is lower proportion of electrical installations in the Western region, if compared to other regions. Considering the trends in other regions, there are considerably more cable lines in the Western region than bare wire lines, resulting in overall better situation than in other regions. Statistically, there are 15.8 % of switching devices in the Western region, which is many if compared to the number of other electrical installations. Thus, it can be concluded that the infrastructure here is more in order.

7. Riga City region

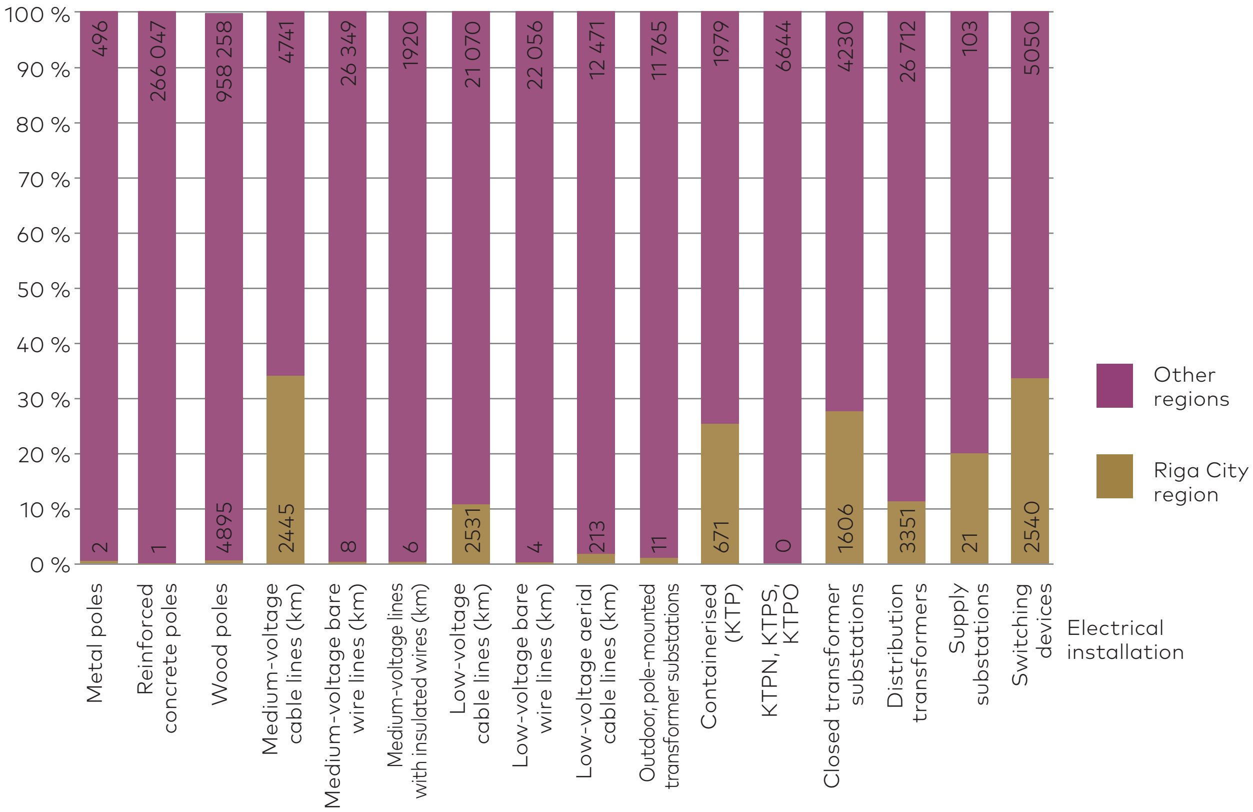


Fig. 1.10. Statistics of electrical installations used in Riga City region of distribution network.

Riga City region is significantly different from the other regions. Power supply networks here must be reliable and ready to ensure additional large power to consumers at any moment. As shown, the length of medium-voltage lines is almost similar to low-voltage lines; therefore, the number of transformer substations is considerably larger than in other bigger regions. It can be explained by the fact that electricity consumption in Riga accounts for half of the total electricity consumption in Latvia and it is not possible to distribute the necessary amount of power using low-voltage lines; thus, there are 2288 transformer substations in Riga City region that distribute electricity to consumers using low-voltage lines. Overhead lines are not used due to development density and safety considerations.

1.2. Types of distribution network conductors

1.2.1. Overhead lines

Overhead line is an electrical installation designed for power transmission by wires that are located outdoors and fixed to poles or engineering brackets with insulators and armature [3]. Overhead lines in distribution network are built using bare wires, insulated wires, and aerial cables.

1.2.1.1. Bare wires

Bare wires have no insulation and are therefore affected by environmental conditions. As an example, wire vibration caused by wind, wire icing, which usually forms at low temperature, thermal expansion and contraction can be mentioned; thus, bare wires used for power transmission must have high mechanical strength and they must be made of materials with good conductivity. Bare wires are made of aluminium, steel, and steel-aluminium. In distribution network, bare wires are used for constructing both low-voltage and medium-voltage networks; they are sub-divided according to the constructive execution (Fig. 1.11) as follows:

a) single-wire conductors;
b) multi-wire conductors that are made by intertwining 7,121,937 strands (depending on the wire cross-section);
c) multi-wire conductors made of two metals.

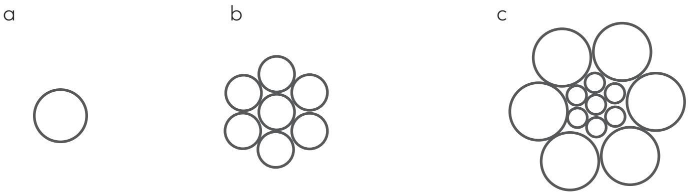


Fig. 1.11. Bare wire constructions used for overhead lines in distribution network [4]: a — single-wire, b, c — multi-wire.

1.2.1.2. Insulated wires

Insulated wires (Fig. 1.12) are used in distribution network for medium-voltage line construction. Compared to bare wires, insulated wires are more expensive but the additional investment in line construction often pays back in terms of maintenance cost. Insulated wires are less affected by environmental conditions resulting in more quality power supply. An insulated wire consists of aluminium alloy wire and insulation material that is resistant to environmental conditions.

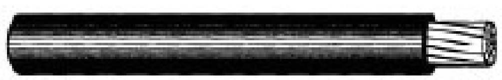


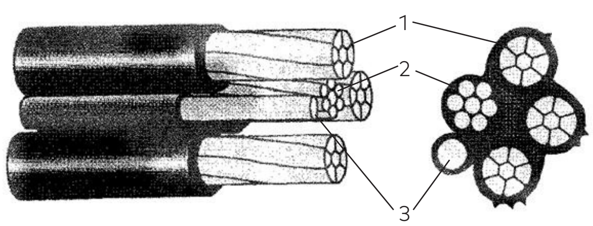
Fig. 1.12. Construction of an insulation wire used for overhead lines in distribution network [5].

1.2.1.3. Aerial cables

Insulated low-voltage wires are called aerial cables. Aerial cables are used in distribution network more and more often due to the following reasons:

1) phase wires are insulated — no need to maintain distance between phases, voltage is not lost if a falling tree branch hits the wire;
2) several low-voltage lines can be installed on one pole;
3) lower operating costs;
4) convenient assembly, no need to use insulators;
5) a new user may be added to the line without interrupting the voltage.

Construction of an aerial cable is presented in Fig. 1.13.



1 — three-phase conductors made of aluminium and consisting of several intertwined conductors
2 — one messenger wire made of aluminium-manganese alloy wires
3 — one insulated wire so that street lighting can be connected

Fig. 1.13. Construction of an aerial cable used in distribution network [6].

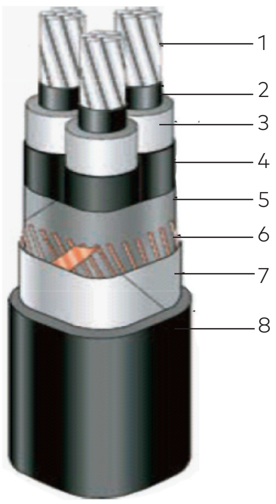
1.2.2. Cable lines

Cable line is a power line that is made using a specially insulated wire — cable, which is laid underground, on building walls, in cable channels, cable ducts, etc. Nowadays, construction of cable lines is getting more popular and the overhead line length in Latvia gradually decreases stepping down to cable lines. Every year AS Sadales tīkls invests in replacing overhead lines with cable lines due to the following considerations:

1) cable lines are mainly buried — this way it occupies less space and they can be installed at places where there is no space for overhead lines, which is of special importance in cities;
2) when cables are buried in rural territories, the risk of voltage interruptions caused by environmental conditions is reduced (including tree branches falling on line wires due to wind and causing short-circuit and wire damage);
3) lines are accessible by unauthorised persons;
4) construction is more expensive if compared to overhead lines; however, the operation is cheaper since no maintenance of power line routes must be ensured.

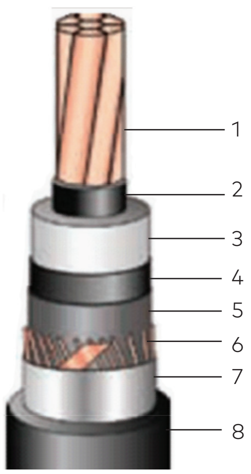
Constructions of cable types used in distribution network most often are as follows:

a) three-core medium-voltage cable (Fig. 1.14);
b) single-core medium-voltage cable (Fig. 1.15);
c) four-core low-voltage cable (Fig. 1.16) [7].



1 – 3 copper or aluminium conductors
2 – shield around the conductor blocking the magnetic field
3 – insulator, which insulates the conductor from other conductors
4 – insulation layer, which blocks the magnetic field
5 – water-absorbing wool, which blocks longitudinal water flow in case of a damage
6 – copper shield, which leads fault current to an earthing installation in substation
7 – aluminium foil, which provides transversal water protection
8 – polyethylene coating, which protects against mechanical damage and provides insulation

Fig. 1.14. Three-core medium-voltage cable [7].



1 – copper or aluminium conductor
2 – shield around the conductor blocking the magnetic field
3 – insulator, which insulates the conductor from other conductors
4 – insulation layer, which blocks the magnetic field
5 – water-absorbing wool, which blocks longitudinal water flow in case of a damage
6 – copper shield, which leads fault current to an earthing installation in substation
7 – aluminium foil, which provides transversal water protection
8 – polyethylene coating, which protects against mechanical damage and provides insulation

Fig 1.15. Single-core medium-voltage cable [7].

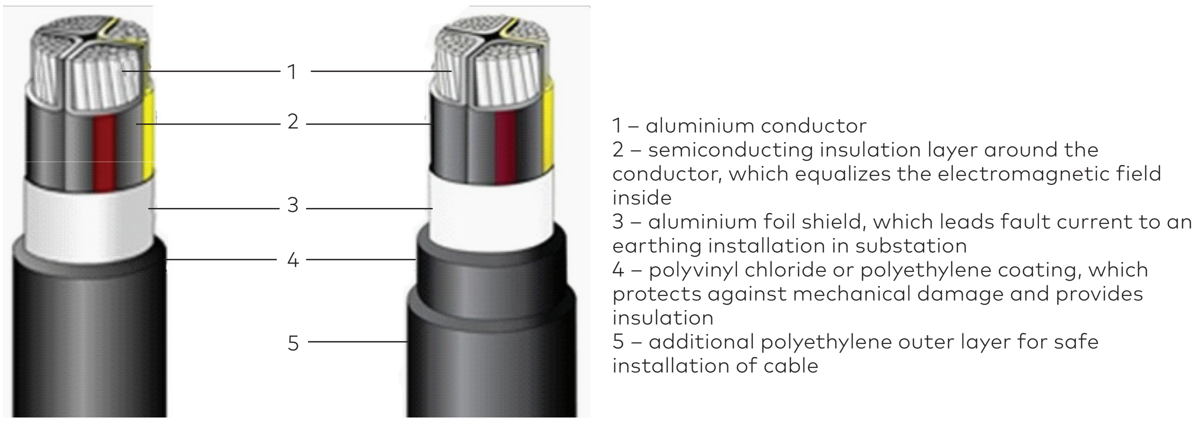


Fig. 1.16. Four-core low-voltage cable [7].

1.3. Proportion of medium-voltage and low-voltage cable types by years

Over time, power supply networks become out-of-date, get damaged or it is simply necessary to build new networks to connect new users. Quality and reliability of electricity transmission depend on careful selection of wires or cables. When planning construction of new or replacing of existing electrical grid, construction and maintenance cost calculation must be done considering the line length and intensity of load to be transmitted. It is also important to take into account the fact that loads tend to increase over time.

Trends in selecting types of power supply lines have changed radically over the years. Figure 1.17 shows that mainly bare wire lines were used from 1980 until 2000, but this proportion reduces later on. Since 2000, AS Sadales tīkls has started active construction of cable lines, usage of insulated low-voltage aerial cable, and insulated medium-voltage wires. Changes in the selection of line types can be explained by the many advantages of cable lines, aerial cables, and insulated medium-voltage wires; using these, distribution network is able to provide more quality electricity in different conditions.

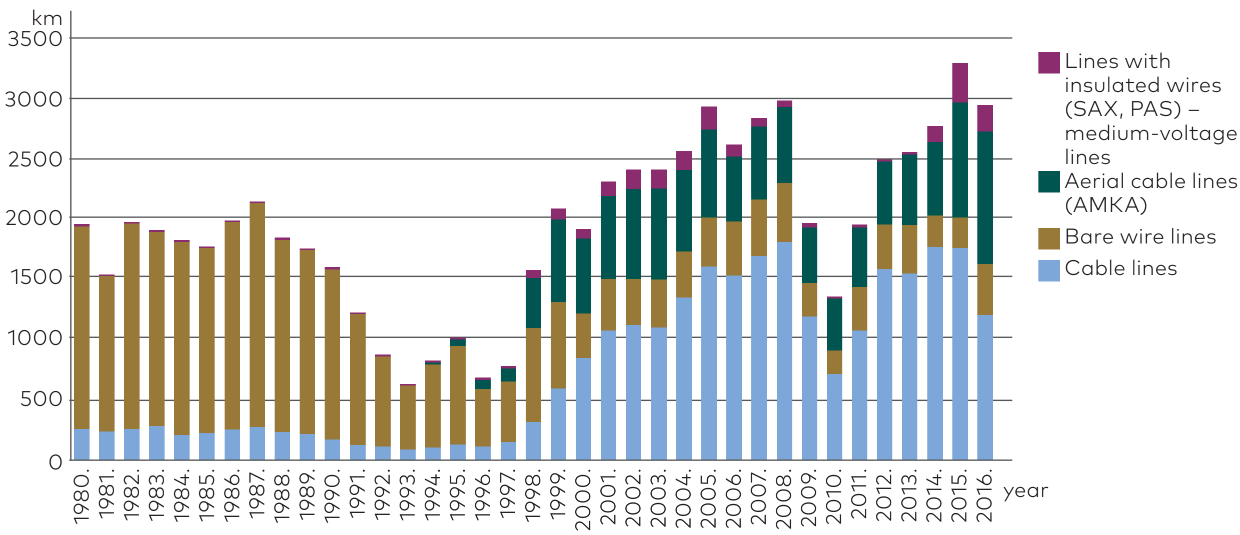


Fig. 1.17. Proportion of medium-voltage and low-voltage lines by years [8].

1.4. Questions for self-test

1. Execution of overhead lines in low-voltage and medium-voltage distribution networks.
2. Regional division of distribution network in Latvia.
3. Structure of a medium-voltage cable.
4. Structure of a low-voltage cable.
5. Why is water-absorbing wool necessary in medium-voltage cables?
6. Comparison of costs: construction of overhead lines and cable lines.

2. POWER QUALITY REQUIREMENTS

2.1. Quality parameters

Any equipment, which uses electricity, needs quality power. All equipment is built pursuant to specific standards to ensure the best economic effect. The standard EN 50160 operates in the European Union, but in Latvia this standard has been transposed into Cabinet Regulation No. 759 "Regulations Regarding Voltage Requirements for Public Power Supply Network". There are six normalised parameters set according to this standard for alternating voltage network [9].

2.1.1. Voltage deviation

Voltage deviation — increase or decrease in the active voltage value caused most often by changes in load. Voltage deviation is determined according to the equation

$$V = \frac{U - U_{nom}}{U_{nom}} 100, \tag{2.1}$$

where V — voltage deviation, %;
U — active voltage in network point, V;
U_{nom} — rated network voltage, V.

According to the standard, the rated value is 230 V in low-voltage networks. An electrical installation works in normal mode if voltage changes by no more than ±5 % of the network rated voltage. Maximum deviation is ±10 % of the rated voltage. When the maximum deviation is exceeded from 10 milliseconds to 1 minute, voltage deviation called voltage dip occurs.

2.1.2. Voltage fluctuation

Voltage fluctuation — pace at which voltage deviation changes in a time unit that exceeds 1 % a second. It is defined as the difference between the largest and smallest network voltage occurring in different moments and expressed as a percentage from network rated voltage [10].

$$\Delta V_{maks} = \frac{U_{maks} - U_{min}}{U_{nom}} 100 = V_{maks} - V_{min}, \tag{2.2}$$

where ΔV_{maks} — voltage fluctuation, %;
U_{maks} — maximum voltage value in network point, V;
U_{min} – minimum voltage value in network point, V;
V_{max} — largest voltage deviation, %;
V_{min} — smallest voltage deviation, %.

2.1.3. Frequency deviation

Frequency deviation — difference between the frequency of a power system at some moment and its rated value [10]. Deviation of a normalised frequency is ±0.1 Hz. Frequency deviation may be established using this equation:

$$\Delta f = f - f_{nom}, \tag{2.3}$$

where Δf — frequency deviation, Hz;
f — frequency in network point, Hz;
f_{nom} — rated frequency, Hz.

2.1.4. Frequency fluctuation

If the pace of frequency change exceeds 0.2 Hz/s, this change is called frequency fluctuation. In normal working conditions, when the Latvian power system works together with the Belarusian and Russian power systems, the rated voltage frequency is 50 Hz.

2.1.5. Three-phase voltage unbalance

Voltage unbalance is caused by unequal single-phase load, which generates negative sequence and zero sequence components of currents and voltages. Unequal load in each of the phase wire generates voltage unbalance and current emerges in the neutral conductor, which means that negative sequence and zero sequence components of voltage are generated in the neutral conductor. The negative sequence voltage is characterised by the negative sequence factor [9]:

$$K_2 = \frac{U_2}{U_1} 100, \tag{2.4}$$

where K_2 — negative sequence factor;
U_1 — effective value of primary frequency voltage, V;
U_2 — effective value of the negative sequence voltage of primary frequency, V.

2.1.6. Current and voltage non-sinusoidality

Deformations of voltage and current curves are caused by the non-linear elements (transformer limbs) present in a power system and semi-conducting elements at users (computers, converters, etc.). Non-sinusoidal currents and voltages are complex periodic fluctuations that consist of a range of harmonic fluctuations of various frequencies. The content of highest harmonic components in a power system is described by factor [9]

$$K_n = \frac{U_n}{U_1} 100, \tag{2.5}$$

where K_n — factor of n^{th} harmonic component;
U_1 — effective value of primary frequency voltage, V;
U_n — effective value of n^{th} frequency voltage, V.

2.2. Conformity of standard characteristics in distribution networks

In some cases, the values of these characteristics may be exceeded because they change according to the available power in normal working conditions of a power supply system, as well as in case of network damage usually caused by external emergency conditions. To find out the voltage of electrical grid, it can be measured at any point of this grid, but this standard lays down, describes, and specifies the main characteristics right on the border of electrical facility belonging. This is the point that is specified in the power supply contract and at which the technical and economic characteristics of electric supply are determined. In distribution network, the border of electrical facility belonging is usually set by the electricity meter.

In 2012, the Public Utilities Commission started testing the compliance of electricity quality with the standard and performed 50 measurements in total. Non-compliance with the voltage standard characteristics was established in 41 objects. The largest number of non-compliances were established for such criteria as voltage fluctuation and voltage non-sinusoidality. A reason for this may be the fact that measurements were mainly performed in rural territories where the power supply lines are long and with insufficient cross-section [11]. Monitoring of the permitted limits of the value of these characteristics is also performed by the system operator, and if necessary the system operator takes measures to improve the network quality as economically as possible. As presented in Fig. 2.1, the number of measurements keep growing year by year allowing establishing of objects where improvements are necessary.

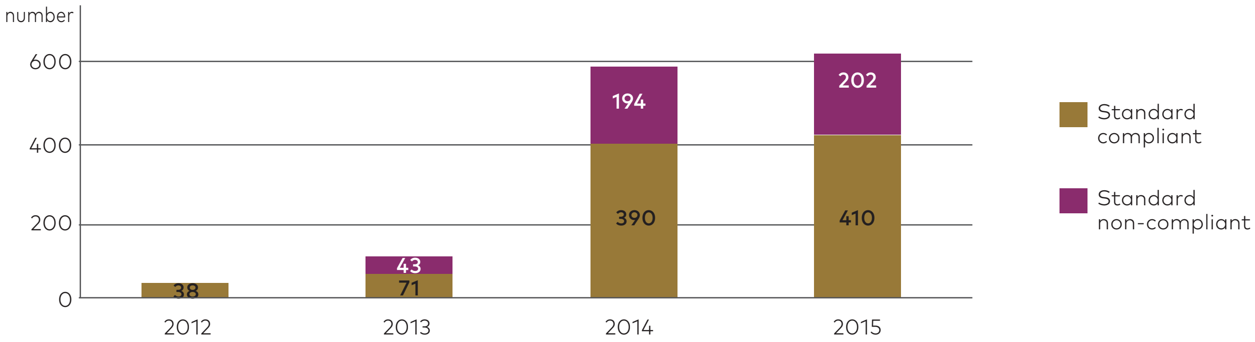


Fig. 2.1. Number of measurements of voltage characteristics [11].

2.3. Questions for self-test

1. Power quality parameters.
2. Give the definition of voltage deviation and determine the permitted voltage values.
3. What monitors the quality parameters of voltage characteristics?
4. What are the causes of three-phase voltage unbalance?
5. What is frequency fluctuation?
6. Which standard sets the electricity quality parameters?

3. POWER SUPPLY RELIABILITY INDICES AND DYNAMICS THEREOF AT DISTRIBUTION NETWORK

3.1. Standard reliability indices

Electricity users expect quality, and this means also reliable power supply; therefore, the most important task of the distribution network is to ensure continuous and quality power supply as efficiently as possible and with as low investments as possible. Reliability of power supply depends on the power interruptions and voltage dips. In Latvia, the reliability of power supply is regulated by the Cabinet of Ministers Regulation No. 50 "Regulations Regarding the Trade and Use of Electricity". The Energy Law prescribes that system operators must ensure continuous operation of their objects and appropriate technical condition thereof. Every year, the system operator provides information to the Public Utility Commission to ensure the control of changes in the reliability level of power supply. Globally, and also in Latvia, to assess the level of power supply reliability, the electricity supply indicators SAIFI and SAIDI are used [13].

1) SAIDI — System Average Interruption Duration Index. SAIDI is measured in minutes or hours for one user of the system over the course of a year. The total system factor is calculated as:

$$SAIDI = \frac{\text{total duration of interruptions a year}}{\text{total number of users}}. \qquad (3.1)$$

2) SAIFI — System Average Interruption Frequency Index. SAIFI is measured in units of interruption for one user of the system over the course of a year. The total system factor is calculated as:

$$SAIFI = \frac{\text{total number of interruptions a year}}{\text{total number of users}}. \qquad (3.2)$$

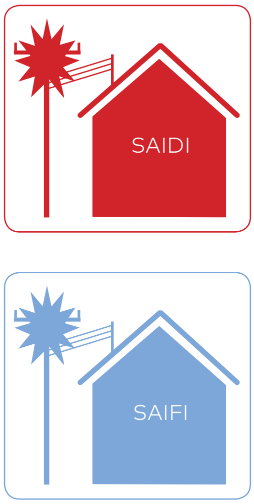


Fig 3.1. SAIDI and SAIFI [6].

3.2. Reliability indices in Latvia and Europe

Figures 3.2 and 3.3 show that the duration and number of interruptions in Latvia tend to decrease. Reliability issues have become especially important after the winter of 2010/2011 when users experienced a lot of power interruptions due to extreme weather conditions. After this extreme situation, power supply operators have modernised their equipment and raised the professional competences. Large investments have been made in maintenance of power supply routes, which has clearly resulted in improved reliability [14]. Duration and number of unscheduled power interruptions per 1 user in Latvia is grouped according to 3 conditions:

1) normal conditions — conditions in which the demanded power is guaranteed;
2) emergency conditions — situation in which much damage due to weather conditions have occurred;
3) all conditions — measurements are not divided into normal and emergency conditions.

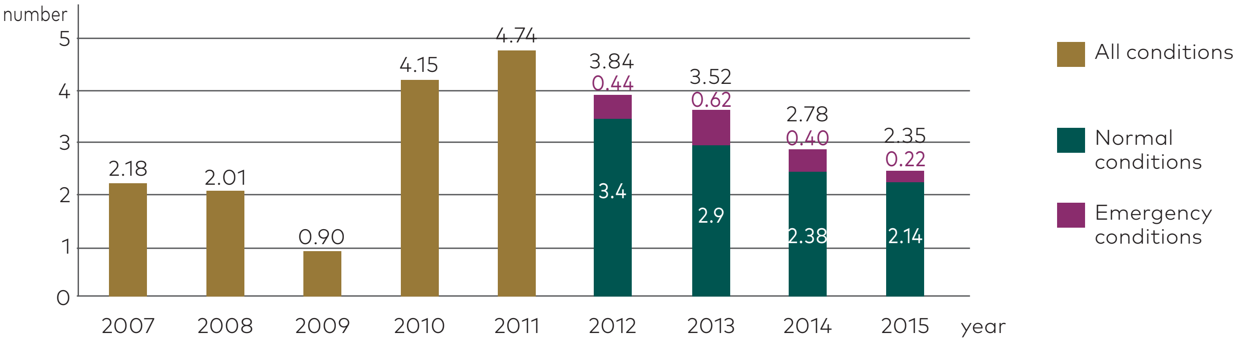


Fig. 3.2. Duration of unscheduled power interruptions per user in Latvia in 2015 [11].

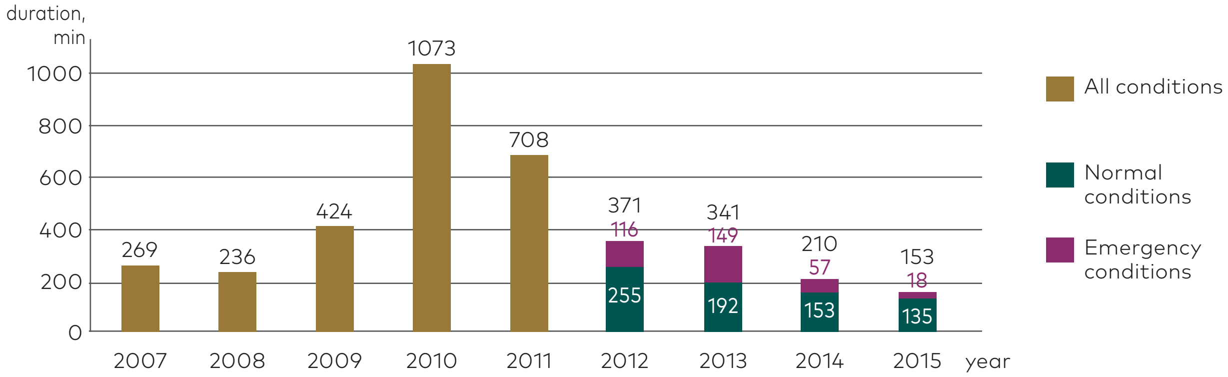


Fig. 3.3. Number of unscheduled power interruptions per user in Latvia in 2015 [11].

The duration and number of unscheduled power interruptions per user in Latvia tend to decrease in the latest years; however, we still rank at the top of the European level. As shown in Fig. 3.4, the average duration of power supply interruptions in the world is 88 minutes, while in Latvia this indicator is 153 minutes, which is nearly two times more. Denmark ranks the highest with 11 minutes a year, but Poland is the last one with 255 minutes a year. In comparison to neighbouring countries, the situation is as follows: Lithuania is below the average global level (72 minutes a year) and Estonia is slightly above the average — 102 minutes a year.

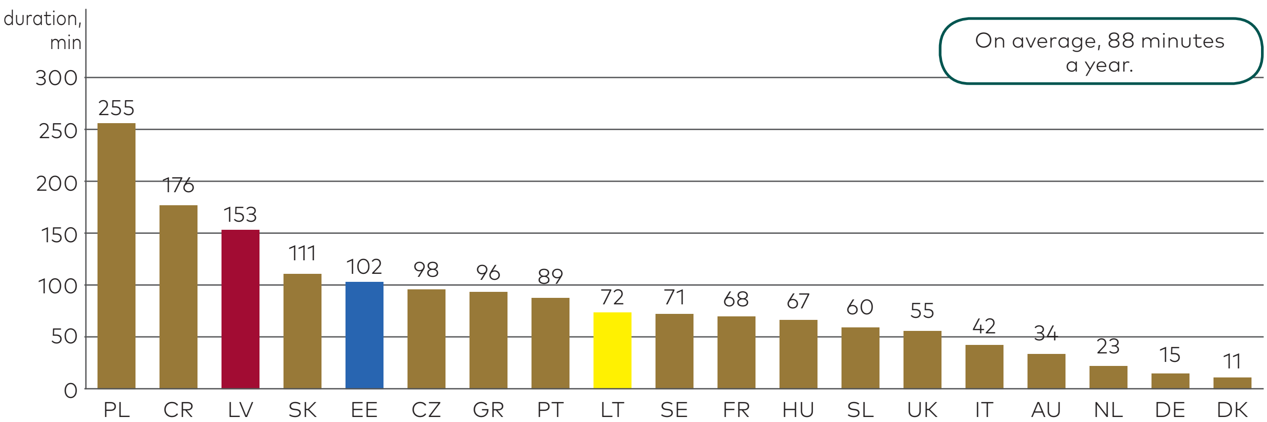


Fig. 3.4. Duration of unscheduled power interruptions per user in Europe in 2015 [15].

According to Fig. 3.5, the average number of power interruptions per user in Europe is 1.3 times a year. Latvia ranks low also in this indicator of power supply reliability, compared to other European countries. The frequency of power supply interruptions in Latvia is 2.4 times a year. The Netherlands and Denmark has the least interruptions — just 0.3 times a year, but Poland — 3 times a year, which is the highest indicator among the European countries.

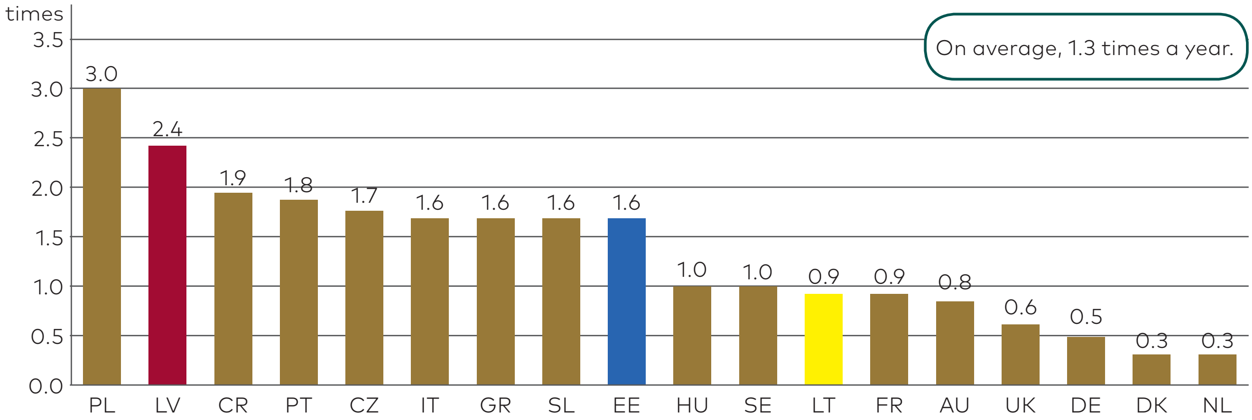


Fig. 3.5. Frequency of unscheduled power interruptions per user in Europe in 2015 [15].

3.3. Questions for self-test

1. What parameters does the power reliability indicator depend on?
2. SAIDI index.
3. SAIFI index.
4. What are the values of reliability indices in Latvia compared to the European countries?
5. Which standard regulates reliability?

4. MEASURES FOR IMPROVING DISTRIBUTION NETWORK QUALITY

4.1. Improvement of voltage quality in distribution network

The basic goal of electrical grid operation is to provide users with quality and reliable electricity; but over the years the grid:

- wears out;
- must be developed in case of changes in load when it is necessary to connect new users;
- must be restructured due to technical condition, damage, and quality.

To improve the voltage quality, distribution network performs efficient selection of technical solution as economically as possible. Selection of technical solution depends on the technical condition of the existing electrical grid, distance between the users' objects and the distribution transformer, load intensity, and environmental factors.

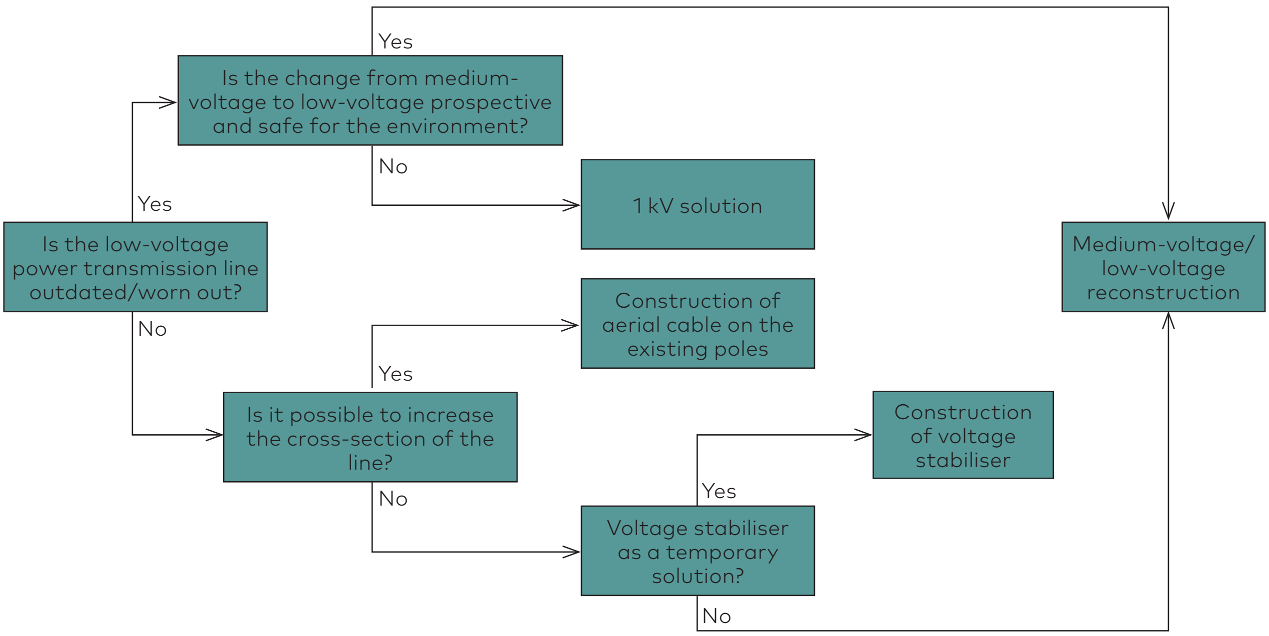


Fig. 4.1. Technical solution selection algorithm.

Objects must be assessed first, taking into account the current and prospective situation, and then the appropriate technical solution must be developed (Fig. 4.1). If the electrical grid is not technically outdated, then the most appropriate technical solution is to construct an aerial cable line with larger cross-section on the existing poles if the service life of the poles is expected to be more than 10 years. If it is not possible to increase the cable cross-section, voltage stabiliser is used as a temporary solution.

4.1.1. Solutions involving voltage stabiliser

Often in rural territories where the electrical grid is long and branched, long power lines with insufficient cable cross-section go to consumers causing low-quality voltage. Voltage for consumers that are closer to the transformer substation is within the normal range, while at the end of the line it is not sufficient any more (Fig. 4.2).

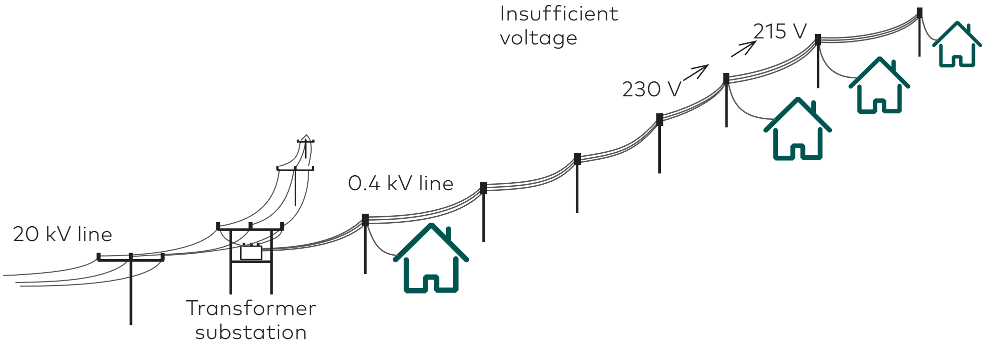


Fig. 4.2. Visualisation of low-quality voltage of overhead line.

If the distance to a consumer does not allow to ensure appropriate voltage quality in 0.4 kV power transmission line or if the poles do not allow to construct an aerial cable line of necessary cross-section, voltage stabilising device can be considered as a temporary solution (Figs. 4.3 and 4.4). If new connections to the line are not planned or if the voltage drop is seasonal, then such device is an appropriate technical solution for settling problems related to voltage quality issues for a small number of consumers. Distribution network uses this solution also to gain additional time for replanning the line and increasing the power of the line.

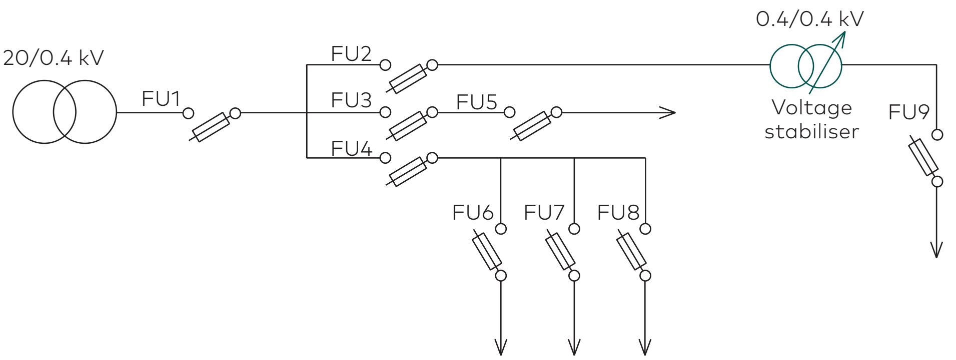


Fig. 4.3. Circuit diagram for constructing voltage stabiliser in an existing low-voltage overhead line.

Voltage stabiliser constantly measures line voltage and changes it if necessary. Operation of the stabiliser is based on a small autotransformer in which semi-conducting switches change the transformation ratio by increasing or decreasing the voltage if necessary. Stabiliser is installed close to those consumers for whom voltage improvement is needed. Devices can be installed quickly and are ready to work at once.

Fig. 4.4. Voltage stabiliser.

4.1.2. Solutions for 1 kV distribution networks

In practice, distribution network traditionally constructs 20 kV medium-voltage lines, transformers, and 0.4 kV low-voltage networks; additionally, a 1 kV line can be built, which is an alternative in cases when the power line runs through woods, when the cost of constructing medium-voltage cable or aerial cable line is high, or when there is a comparatively new cable or aerial cable line that can be transformed into 1 kV line.

Technology of 1 kV network, which is defined as a low-voltage network, is used in Scandinavian countries, and Latvia has started using such solutions comparatively recently. The main difference from the 400 V network is that an additional transformer is necessary to transform 1000 V voltage to 400 V voltage. Such solution is usually used to improve power supply quality most often in rural territories, where long low-voltage lines go to consumers and no increase in the used load intensity is planned.

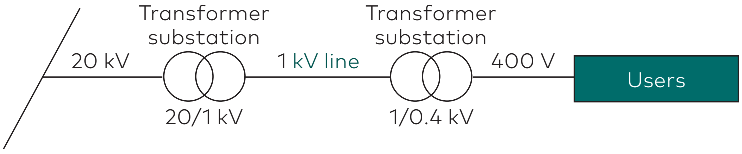


Fig. 4.5. 1 kV circuit diagram.

Advantages of using this technology [16] are as follows.

a) It can be calculated applying the power formula:

$$P = \sqrt{3} IU \cos\varphi = \sqrt{3} \frac{U^2}{R_L} \cos\varphi, \quad (4.1)$$

where P — power transmitted by the electrical grid;
I — current in the line, A;
U — voltage in the line, V;
R_L — resistance of the power line, Ω;
cos φ — power factor.

$$\text{For 400 V system } P_{400V} = \sqrt{3} \frac{400^2}{R_L} \cos\varphi; \quad (4.2)$$

$$\text{For 1000 V system } P_{1000V} = \sqrt{3} \frac{1000^2}{R_L} \cos\varphi; \quad (4.3)$$

Comparison of 1000 V voltage and 400 V voltage:

$$\frac{P_{1000V}}{P_{400V}} = \frac{\sqrt{3} \cdot 1000^2 \cdot R_L \cdot \cos\varphi}{\sqrt{3} \cdot 400^2 \cdot R_L \cdot \cos\varphi} = \frac{1000^2}{400^2} = 6{,}25, \quad (4.4)$$

thus, the same power can be transmitted in 1000 V network over a 6.25 times longer distance than in 400 V network, or power of 2.5 times larger intensity can be transmitted over a 2.5 times larger distance. Taking into account the voltage loss, the power that can be transmitted or the extension of line in real life varies from 4 to 5 times.

b) Already built cable or aerial cable lines can be used, because low-voltage cables and aerial cables are designed for voltage up to 1000 V.

c) Technology is more economical if used in objects where it is necessary to place transformers closer to power points in case raising of power voltage values is needed.

d) Reliability and quality of power supply grow as damage of 1 kV line does not result in outage of 20 kV line.

Conditions for construction of 1 kV network [16]:

a) possible to construct using the existing low-voltage cables or aerial cables;

b) maximum power of 1/0.4 kV transformer is 50 kVA;
c) if it is economically justifiable to place 20/0.4 kV transformer in load centre so that the length of low-voltage lines does not exceed 1 km, then 20/0.4 kV solution must be used;
d) in all cases when a 1 kV technical solution is considered, it must be benchmarked against the construction of a medium-voltage electrical grid considering both the construction and maintenance cost and the impact on safety.

4.2. Reconstructions in distribution networks

If it is more expensive to repair power transmission lines than to reconstruct them in the long term and the described solutions lack prospects, then improvement of network quality and voltage quality is performed by reconstruction. Reconstruction — the rebuilding of a structure or a part thereof by changing the dimensions of the structure or a part thereof and changing or retaining the functions, or changing the functions without changing the dimensions [17]. In order to perform reconstruction at an object, the technical condition of this object, network quality indicators, and the design and construction costs must be assessed carefully. The following must be considered when developing guidelines for assessing the technical solution for object reconstruction.

1. Reliability of distribution network object must be assessed including:
   - elimination of operationally dangerous defects;
   - elimination of dangerous defects.
2. Wear and tear must be assessed (both in physical and financial terms), which basically includes:
   - assessment of worn constructions and equipment at transformer substations;
   - elimination of discrepancies of power line cross-section;
   - prevention of large number of damages.
3. Commercial aspect must be assessed, which basically includes:
   - considering the number of users (actually, this value determines also the value of reliability parameters SAIDI and SAIFI);
   - considering the consumption.

Fig. 4.6. Worn electrical installations in distribution network objects.

Thus, key questions for object assessment are set according to the planned solution.

1. In relation to the electrical grid maintenance:
   - key question — “Can the object wait for reconstruction?”;
   - if the answer to the key question is “cannot wait for reconstruction”, then the electrical grid is repaired;
   - all other answers indicating that the electrical grid can wait for reconstruction are reviewed individually and implemented or not implemented depending on the situation.
2. In relation to the electrical grid renovation:
   - key question — “Is the electrical grid worn out?”;
   - if the answer to the key question is “is worn out” then the electrical grid is

reconstructed;
- all other answers indicating that the electrical grid can still be operated are reviewed individually depending on the situation.

3. In relation to user complaints regarding electrical grid:
   - key question — “Is the complaint justified?”;
   - if the complaint is justified, then the situation must be evaluated and fixed.

Fig. 4.7. New electrical installations in distribution network following reconstructions.

4.3. Maintenance of power line routes

Interruptions and loss of power supply in the distribution network largely depend on weather conditions, because a great part of the total length of distribution network lines in Latvia is overhead lines that are directly affected by weather conditions. To ensure that electrical grid is in safe condition, AS Sadales tīkls surveys the power lines regularly, assesses the technical condition of power lines, and identifies the trees that endanger the safety of power lines [18]. One of the most common causes for power supply interruptions is falling of trees or branches on overhead lines resulting in short-circuit or damage to wires.

One of the most important tasks of AS Sadales tīkls is to efficiently remove trees and branches that increase the risk of power supply interruption from power line routes. The total length of power line routes to be maintained by cleaning is approximately 21,000 km. AS Sadales tīkls constantly increases the amount of investment and has a goal to clean about 5500 km a year by 2019.

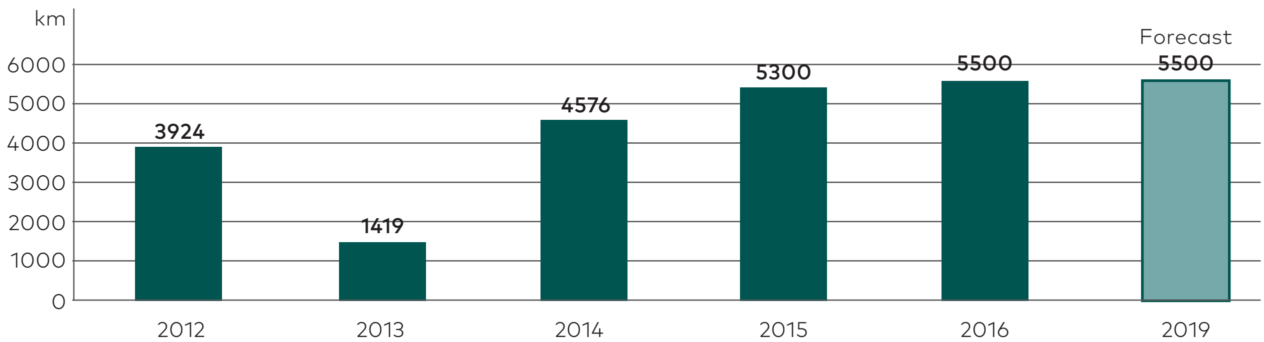


Fig. 4.8. Amount of the power lines cleaned by AS Sadales tīkls [15].

The width of cleaning zone under the power line routes is determined by the Cabinet Regulations and the Protection Zone Law of the Republic of Latvia. Protection zones along all types and ownership electrical power networks and the equipment and structures thereof shall be specified in order to ensure operation and reliability of the electrical power networks and the equipment and structures thereof [19]. Protection zones along the distribution network overhead lines outside cities shall be the following [19]:

a) along overhead lines of electrical power network the rated voltage of which is up to 1 kV — 6.5 m from the axis of the line in which the power line route is 2.5 m from the axis of the line on each side;
b) along overhead lines of electrical power network the rated voltage of which is 10–20 kV — 30 m from the axis of the line in which the power line route is 6.5 m from the axis of the line on each side.

In cleaning the power line routes (Fig. 4.9) motor saws and brush-cutters are usually used. In vertical trimming of trees retractable chainsaws and lifting equipment are used. The work involves trimming of trees in the protection zone and trimming of dangerous trees outside the protection zone. Also tree cutter and tractors are used in cleaning the routes, which considerably raises the work efficiency; using the cutter it is possible to cut trees in the diameter of up to 10 cm [20].

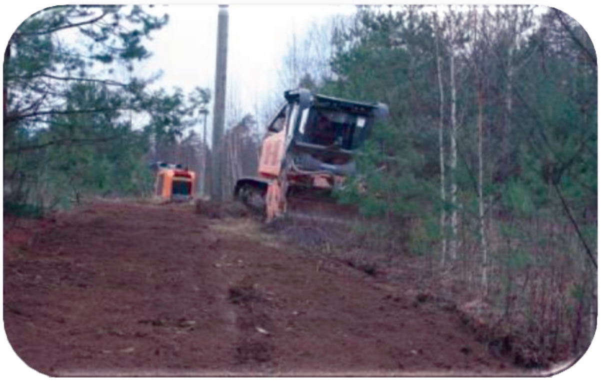


Fig. 4.9. Cleaning of power line routes [14].

4.4. Questions for self-test

1. Measures for improving voltage quality in distribution network.
2. Does the power supply reliability and quality improve using 1 kV distribution network?
3. What are the main reasons for worsening of indicators of power supply reliability?
4. What technologies are used in cleaning power line routes?
5. In what cases is voltage stabiliser used?
6. What is a protection zone and which regulatory enactment regulates the width of protection zones?

5. DEVELOPMENT TRENDS OF DISTRIBUTION NETWORKS

5.1. Smart networks

In the latest years, one of the most widespread development directions of distribution network is raising smartness of the distribution network using smart technologies. Currently, various smart network projects are developed and implemented in the world although there is no single definition of a smart network. AS Sadales tīkls defines a smart network as a network that is capable of self-diagnosis and self-healing and that sends, receives, and processes data on the situation of the network and separate elements and parameters thereof and power flows independently and exchanges information with intelligent electronic devices, manufacturers, system operators, dealers, and consumers in the future [23].

One of the main tasks of the European Union is to ensure effective use of natural resources by laying increasing emphasis on the renewable power sources and by decreasing the carbon dioxide emissions. It means that a consumer may become a generating source in the future resulting in a two-directional power flow: to and from a consumer. If the existing network was not modernised, possibilities of power saving and energy efficiency would not be used, and the energy market would develop much more slowly.

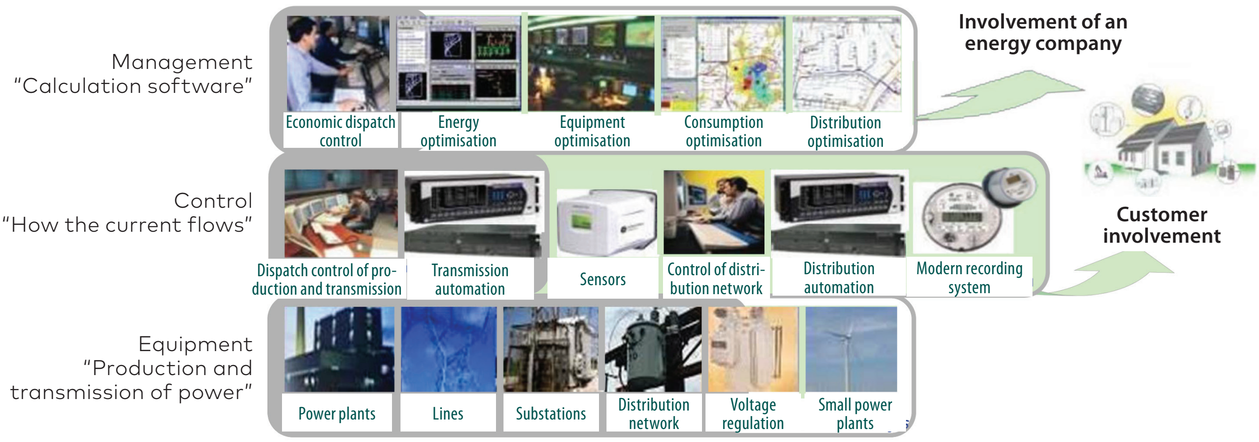


Fig. 5.1. New communication infrastructure for complex integration of equipment and information [24].

Figure 5.1 shows the target infrastructure of distribution network. By introducing smart networks, important advantages emerge: the possibility to quickly localise and eliminate network damage, to manage the small power stations much safer, the possibility to optimise energy flow by reducing power loss, and the interactive data exchange between a consumer and distribution operator.

5.1.1. Smart meters

Similarly to other operators of electricity distribution system in the European Union, traditional meters are replaced by smart meters step by step also in Latvia to improve the customer service and reduce costs. Smart electricity meter is a device that records consumption of electric energy and provides information on power consumption at the object by hours and that is managed remotely allowing to service the meter without an on-site visit [25]. Since 2007, about 260,000 traditional meters have been replaced with smart meters in distribution network. The ratio of traditional and smart meters is presented in Fig. 5.2.

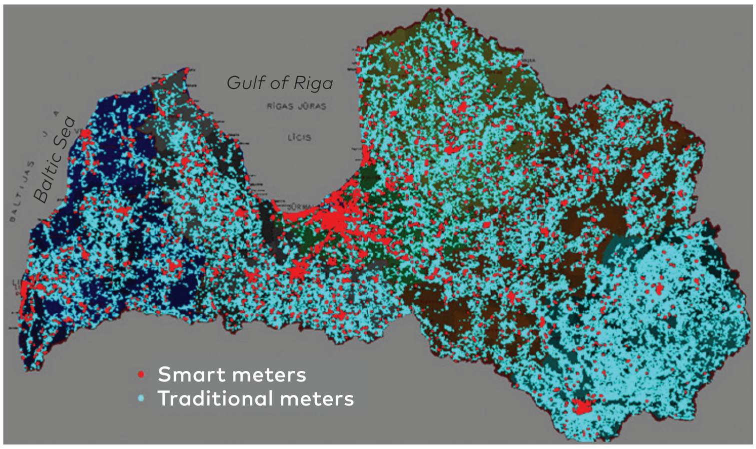


Fig. 5.2. Ratio of smart and traditional meters in distribution network [26].

While it can be observed that replacement of meters is more often done in cities and towns, all traditional meters must be replaced with smart meters pursuant to the Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency providing the following:

- at least 80 % of consumers should be equipped with intelligent metering systems by 2020;
- complete introduction of intelligent metering systems must be completed by 2022;
- electricity meter recording load curves and time-current zones must be installed where the benefits exceed costs in the long term [26].

A smart meter, using a two-directional communication fulfils the following functions:

- registers the consumed real and reactive electricity;
- registers load curve;
- registers events (voltage interruptions, voltage deviations, damaging of meter);
- ensures remote disconnection of power supply.

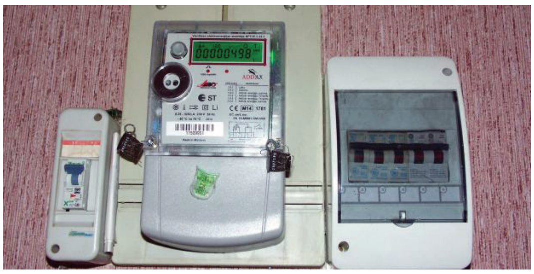


Fig. 5.3. A smart meter used by AS Sadales tīkls.

Advantages provided by the use of a smart meter are as follows.

1. Customer does not have to read the meter, and invoice is received automatically. Detailed consumption information is available to the consumer with a possibility to receive instant information on network damages.
2. Reduced expenses for AS Sadales tīkls allowing to disconnect power supply to a consumer remotely if necessary, without visiting the object. Ensured automation and monitoring of processes thus reducing the loss and allowing for efficient improvement of smart network.
3. Payment services are facilitated for an electricity dealer as readings are sent in time and invoices are prepared automatically.

5.1.2. Automation of power lines

5.1.2.1. Smart switches

To ensure operative identification of the damaged spot and restoration of voltage in the undamaged part of the network thus decreasing the duration of power interruptions caused by unscheduled outages, AS Sadales tīkls installs damage indicating devices and remotely operated power switches or the so-called smart switches in medium-voltage lines. Power outages in medium-voltage network are often caused by falling branches or unplanned line damage. By installing the remotely controlled power switches, it is possible to divide a wide and branched network into smaller districts, thus gaining several advantages:

- the number of disturbed consumers reduces;
- time for localising the damaged place reduces;
- more commutation possibilities;
- improved reliability of power supply.

Fig 5.4. Remotely managed power switch [27].

5.1.2.2. Damage indicators

To ensure faster identification of the damaged place, damage indicators that are connected to the dispatch control system are installed in addition to remote power switches. In case of damage, the dispatch control system receives a notification in which the specific damaged link of medium-voltage line is indicated. This information allows to inform the service team of the faulty power line link to eliminate the damage instantly. Every year AS Sadales tīkls installs approximately 1000 damage indicators, and there are more than 8000 devices in operation in the medium-voltage network currently [28]. Damage indicators are installed in strategic places where power lines branch. To ensure better location of the damaged spot in the real life, when a damage is identified, the device signalises using a flash-light that can be spotted from a 200–300 m distance by day and a 2–3 km distance at night. The device is placed 3–5 m below the power line wires and its operation is based on measuring the electromagnetic field around the wires. If voltage decreases or increases suddenly or is lost, the device signalises. To inform the dispatch control system remotely, a GSM modem is attached to the device ensuring information exchange.

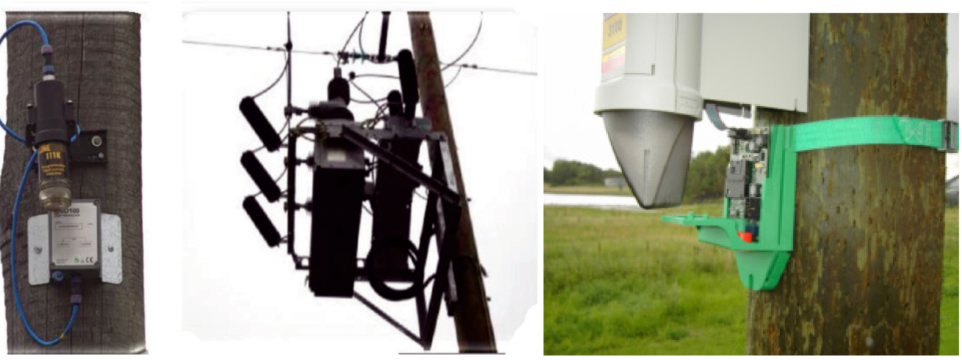


Fig. 5.5. Damage indicators used by AS Sadales tīkls [27].

5.1.2.3. Dispatch control system

For more operative actions, AS Sadales tīkls uses a dispatch control system that allows remote management and control of distribution network and storage of the collected data. Dispatch control is a process in which a system operator authorises changing of the loads of generator devices and operational modes and energy parameters of network elements, according to the dispatch control instructions given by the dispatch control staff of system operator.

Fig. 5.6. Seven regional dispatcher centres as of 1 August 2012 [30].

In 2016, the optimisation of the dispatch control centres was completed. It was consolidated, and 1390 medium-voltage objects were connected to the dispatch control system to ensure efficient monitoring and remote control of the electrical grid [31].

Advantages of the optimisation of dispatch control system:

- remote monitoring of substations;
- improved operational work;
- regulated data transmission network.

5.2. Questions for self-test

1. Explain the term “smart network”.
2. Explain the term “smart circuit breaker”.
3. Explain the term “smart meter”.

6. DIFFUSED GENERATION IN ELECTRICAL GRID OF AS SADALES TĪKLS

6.1. Ratio and trends of diffused generation

Year by year the amount of diffused generation increases in the electrical grid, and the question of the impact of these power stations on the voltage quality is becoming more and more topical. According to the statistics (Fig. 6.1), the number of various power stations tend to increase over the years. It is apparent that the number of CHP plants, solar panels and wind power stations has increased over the last years, while the increase of small hydro-electric power plants has slowed down. Of course, it raises the energy independence, but also puts more burden on the distribution network.

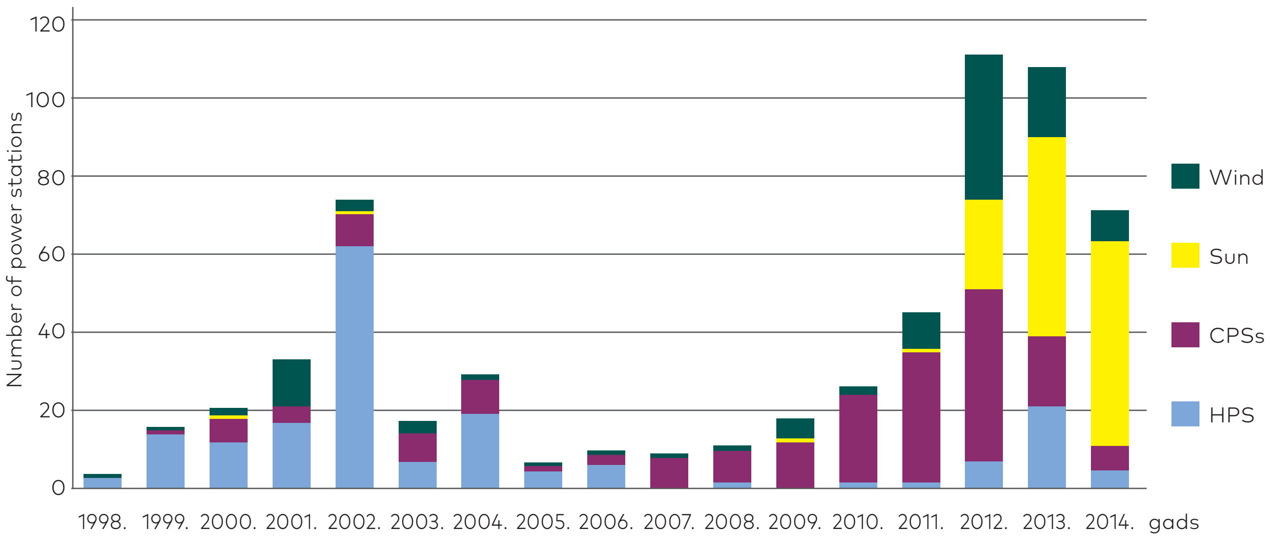


Fig. 6.1. Annual increase in the number of power station connections [12].

The trend that is presented in Fig. 6.1 has changed over the last two years. While there was a rapid increase in the number of new electrical power generators starting around 2008 and 2009, these numbers started dropping following 2012 when the increase reached its maximum. In general, no amendments have been made to regulations regarding permits for increasing electricity production capacities or the introduction of new production equipment permits since 2009.

To launch electricity production, decision from the Ministry of Economics must be received regarding permission to introduce new electricity production equipment (issued pursuant to Section 22 of the Electricity Market Law and Cabinet Regulation No. 883 "Regulations Regarding Permits for Increasing Electricity Production Capacities or the Introduction of New Production Equipment"). To transfer the electricity into the power transmission or distribution network or to sell it, the decision of the Public Utility Commission No. 1/10 "Regulations Regarding Registration of Energy Producers and Traders", which entered into force in 2014, must be observed by the merchants the total trade volume of which exceeds 4000 MWh a year.

6.2. Amount of diffused generation

Nowadays, there is a widespread opinion in the society that the so-called "green energy" or renewable power sources can save our planet. Sun and wind are often mentioned as the main *savers*. It is possible that technologies allowing transformation of these natural resources into available electrical power are still far from their full potential. But considering our climatic conditions, solar energy is not for us in terms of large-scale power production, which does not relate, of course, to separate households that have chosen to place solar batteries on the roof, as shown by the number of generating units that use solar energy and are connected to the network of AS Sadales tīkls (Fig. 6.3). Development of such small units is also supported by various financial support programmes of the European Union. However, there is no reason to speak of the popularity of "solar parks" in Latvia in more general sense, contrary to the situation in other European countries located more south. Although the situation in relation to wind power is better, the scandals that have broken around some recently implemented projects cast a shadow on this type of power generation. In addition, it is hard to imagine that the popular tourist object and one of the main symbols of Latvia — the beach of the Baltic Sea — gets scattered with wind parks even if they are located in the sea some hundreds of meters from the shore. This idea is not widely supported.

One of our values is wood or timber, to be more specific. And it is the basis for the development of the aforementioned CHP plants. Not all trees are carpentry timber, and the others are successfully turned into heat first, and then into electricity indirectly through fermentation gas. Although mass cut-out of woods takes place since the collapse of the Soviet Union, in the last decade entrepreneurs have started considering instant reforestation mainly by using fast-growing tree species that would yield profit as soon as possible. It is a pity that mass sale of our woods has started, but it is even more sad that the largest dealers are not Latvians but foreigners who historically have more means. This does not promote sustainable economic development, but is a short-term plaster on the economic problems of Latvia.

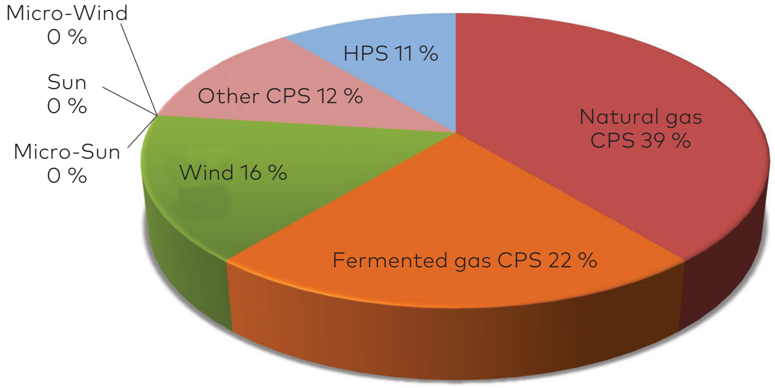


Fig. 6.2. Installed generating power in distribution network (277.2 MW in total) [12].

The installed generating power in distribution network is presented in Fig. 6.2, but the number of generating units connected to the distribution network — in Fig. 6.3.

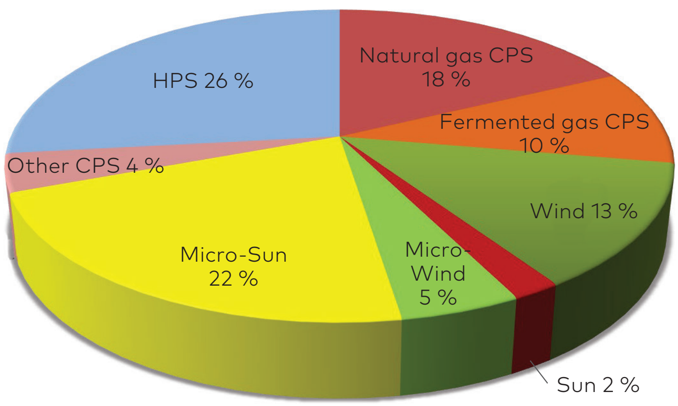


Fig. 6.3. Number of generating units connected to distribution network (573 in total) [12].

6.3. Location of diffused generation

There were slightly more than 600 electricity generating units registered in the GIS of AS Sadales tīkls in May 2016. This number includes also the Central or large generating units in the cascade of hydroelectric stations on the Daugava River, as well as other large power producing plants. However, the number thereof is not too big to prevent us from grasping the general picture of diffused power generation, as shown in Fig. 6.4.

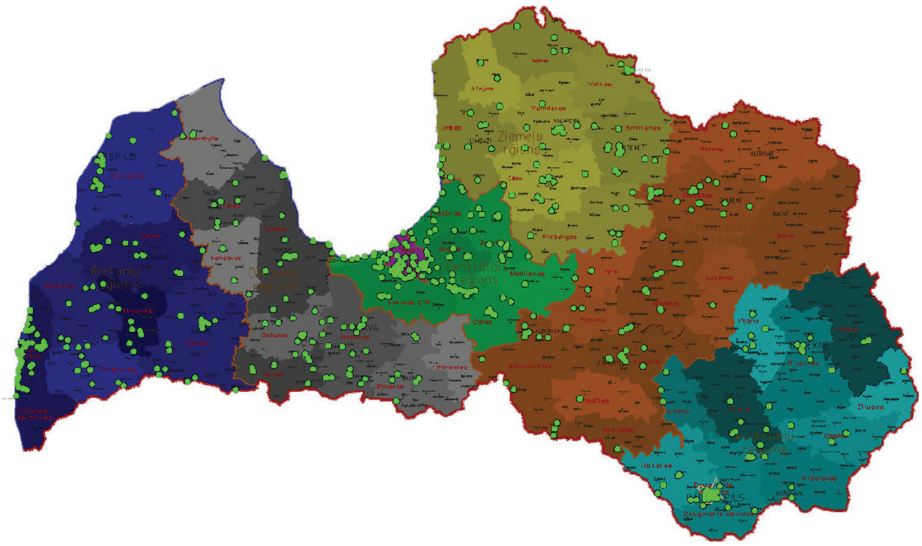


Fig. 6.4. Location of electrical power generating units in the territory of Latvia.

To raise the quality of the supplied electricity, AS Sadales tīkls implements important projects dealing with power quality improvement. The company continues reconstruction of the power supply network and infrastructure maintenance, which raises the reliability and quality of the power supply. Also Daugavpils city is not an exception in this regard; therefore, in 2014 the Board of AS Sadales tīkls discussed the issue concerning the electrical grid possessed by AS Sadales tīkls in Daugavpils city, within which medium-voltage network reconstruction in Daugavpils was planned. The main reason might be the high indices of SAIDI, but it is worth paying attention to the proportion of the diffused generation in the territory of Daugavpils city. It is worth studying the medium-voltage network in Daugavpils city, as the electricity generated by the generators connected at one of the substations significantly exceeds the amount of power consumed, thus resulting in additional loss for AS Sadales tīkls.

6.4. Impact of diffused generation on the electrical grid of AS Sadales tīkls

Situation when the electricity generated by the diffused generation sources that are connected to the distribution network is transferred into the distribution system or higher voltage level becomes more and more frequent. Usually the reason behind this is rather simple — the amount of electricity used is less than produced. Thus, the historical power distribution network does not always comply with the regular and initially predicted cycle, which usually operates in radial mode when the electricity from transmission system is received in distribution substation and then transferred to the consumer. In this case the aforementioned two-directional power flow emerges and electricity is transferred into the power transmission system managed by AS Augstsprieguma tīkls in some cases.

Such change is related to not only the technical aspects but also the financial considerations, since AS Sadales tīkls has to pay both for the installed power of transformers and the electricity returned to the transmission system. Thus, such additional costs affect the electricity tariffs that directly influences the power consumers. In addition, it is difficult to forecast such expenses and it is therefore impossible to ensure fixed cost of power distribution. Any rise of the tariff (as reduction of the tariff is not as topical usually) is widely debated on by the society.

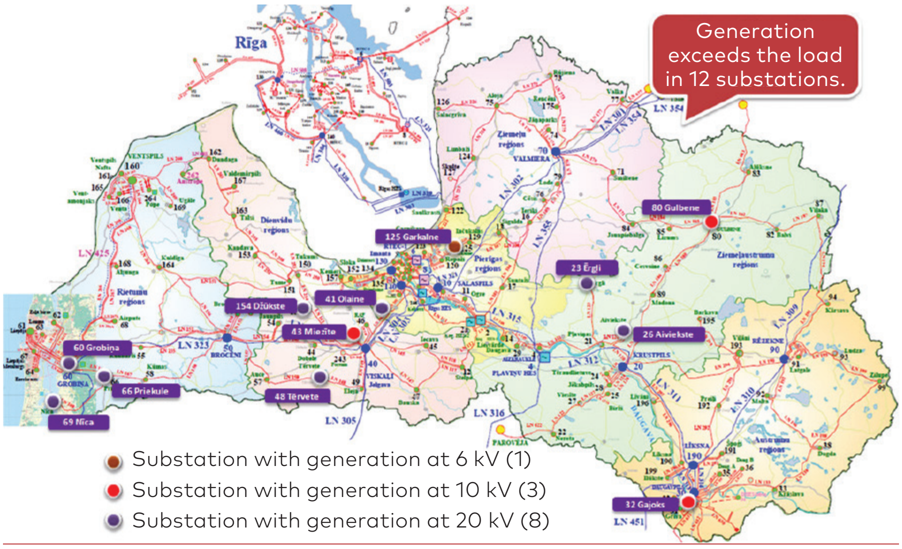


Fig. 6.5. Substations in which generation exceeds consumption.

According to the information at the disposal of AS Sadales tīkls, in 2014, generation sources connected to 12 substations (Fig. 6.5) produced more than consumed by the consumers' electrical installations connected to the substations.

6.5. Questions for self-test

1. Impact of diffused generation on the distribution network.
2. Location of electrical power generating units in the territory of Latvia.
3. Installed generating power in distribution network.

LIST OF LITERATURE

[1] Latvenergo. *Vizītkarte*. [tiešsaiste]. Pieejams: http://www.latvenergo.lv/lat/par_mums/isuma_par_koncernu/vizitkarte/ [Skatīts 2018. g. 27. jūlijā].
[2] M. Budahs un M. Zviedrītis. *Elektrisko sadales tīklu elektroietaišu ekspluatācija*. Rīga, 2012. 8. lpp.
[3] A. Vanags. *Elektriskie tīkli un sistēmas*. Rīga, 2007. 62.–65. lpp.
[4] A. Baltiņš. *Elektriskie tīkli*. Zvaigzne, 1973. 30.–31. lpp.
[5] Mācību centrs Liepa. *Rīgas valsts tehnikums, Elektroniskie materiāli*, Rīga, 2008. 35 lpp. [tiešsaiste]. Pieejams: http://mcliepa.lv/macibumateriali/Elektriskie%20materiali/Elektrotehniskie_materiali.pdf [Skatīts 2018. g. 27. jūlijā].
[6] A. Pinkulis. *Sadales tīklu izaicinājumi un attīstība,* konferencē "Latvenergo koncerna attīstība brīvā tirgus apstākļos", 2012. gada 7. novembris. Rīga. [tiešsaiste]. Pieejams: http://www.latvenergo.lv/portal/page/portal/Latvian/files/2012/konference_07_11.pdf [Skatīts 2018. g. 27. jūlijā].
[7] M. Budahs un M. Zviedrītis. *Elektrisko sadales tīklu elektroietaišu ekspluatācija*. Rīga, 2012. 70.–75. lpp.
[8] ST fiziskie rādītāji par 2016. gadu (dati sagatavoti 16.01.2017).
[9] A. Knipšis. *Elektrisko pārvades tīklu elektroietaišu ekspluatācija*. 11.–12. lpp.
[10] LZA Terminoloģijas komisija. *Akadēmiskā terminu datubāze*. [tiešsaiste]. Pieejams: http://termini.lza.lv/term.php?term=frekvences%20 novirze&list=novirze&lang=LV [Skatīts 2018. g. 27. jūlijā].
[11] Sabiedrisko pakalpojumu regulēšanas komisija. *Pārskats par elektroenerģijas pakalpojumu kvalitāti 2015. gadā*. [tiešsaiste]. Pieejams: https://www.sprk.gov.lv/uploads/doc/EDKvalitatesParskats2015.pdf [Skatīts 2018. g. 27. jūlijā].
[12] Sabiedrisko pakalpojumu regulēšanas komisija. Elektroenerģijas sadales pakalpojumu kvalitātes pārskats 2013. gadā. [tiešsaiste]. Pieejams: https://www.sprk.gov.lv/uploads/doc/KvalitatesParskatsSadale2013.pdf [Skatīts 2018. g. 27. jūlijā].
[13] Mahadiscom. What are SAIF. [tiešsaiste]. Pieejams: http://mahadiscom.com/emagazine/mar06/what%20are%20saifi.shtm [Skatīts 2018. g. 27. jūlijā].
[14] Diena. *Sadales tīkls gatavojas sezonas*. [tiešsaiste]. Pieejams: https://www.diena.lv/raksts/sodien-laikraksta/sadales-tikls-gatavojas-ziemas-sezonai-14114365 [Skatīts 2018. g. 27. jūlijā].
[15] A. Staltmanis. Prezentācija *Elektroapgādes kvalitātes uzlabošana AS «Sadales tīkls»*. 25.04.2016. [tiešsaiste]. Pieejams: https://static.elektrum.lv/files/Leonardo_EnergyEfficiency_Seminars_Event/10/Elektroapgades_kvalitates_uzlabosana_AS_Sadales_tikls200416.pdf [Skatīts 2018. g. 27. jūlijā].
[16] Latvenergo. *Latvijas energostandarts*. [tiešsaiste]. Pieejams: http://www.latvenergo.lv/files/text/energostandarti/LEK_139.pdf [Skatīts 2018. g. 27. jūlijā].
[17] MK noteikumi Nr. 112. *Vispārīgie būvnoteikumi*. [tiešsaiste]. Pieejams: https://m.likumi.lv/doc.php?id=42807 [Skatīts 2018. g. 27. jūlijā].
[18] Sadales tīkls. *Elektrolīniju trašu tīrīšana ST*. [tiešsaiste]. Pieejams: https://www.sadalestikls.lv/lat/klientiem/informacija_mezu_ipasniekiem/elektroliniju_trasu_tirisana/ [Skatīts 2018. g. 27. jūlijā].
[19] Latvijas likums. *Aizsargjoslu likums*. https://likumi.lv/doc.php?id=42348 [Skatīts 2018. g. 27. jūlijā].
[20] Latvenergo. *Energoforums Nr. 2 (26)*. [tiešsaiste]. Pieejams: https://www.latvenergo.lv/portal/page/portal/Latvian/EnergoForums1/EF_04_2012.pdf [Skatīts 2018. g. 27. jūlijā].
[21] Dzirkstele. *Sāk tīrīt elektrolīniju trases*. [tiešsaiste]. Pieejams: http://www.dzirkstele.lv/vietejas-zinas/sak-tirit-elektroliniju-trases-8820 [Skatīts 2018. g. 27. jūlijā].

[22] Youtube. *Lidojuma laiks – Elektrolīniju trašu tīrīšana no gaisa, izmantojot helikopteru pakalpojumus*. [tiešsaiste]. Pieejams: https://www.youtube.com/watch?v=iO_eSwUNiyI [Skatīts 2018. g. 27. jūlijā].
[23] Latvenergo. *Energoforums Nr. 4 (32).* [tiešsaiste]. Pieejams: https://www.latvenergo.lv/portal/page/portal/Latvian/EnergoForums1/Energoforums_nr4.pdf [Skatīts 2018. g. 27. jūlijā].
[24] A. Tiesnieks. *Viedie tīkli un to attīstības iespējas Latvijā*. [tiešsaiste]. Pieejams: http://www.rea.riga.lv/files/Vide_un_Energija_21-10-2011_Arturs_Tiesnieks.pdf [Skatīts 2018. g. 27. jūlijā].
[25] Sadales tīkls. *Biežāk uzdotie jautājumi*. [tiešsaiste]. Pieejams: https://www.sadalestikls.lv/lat/skaititaji/biezak_uzdotie_jautajumi/ [Skatīts 2018. g. 27. jūlijā].
[26] I. Grinbergs. *Viedo skaitītāju ieviešanas un nolasīšanas izaicinājumi*. [tiešsaiste]. Pieejams: https://www.e-st.lv/files/st_grinbergs_viedie_tirgotajiem_20_10_2015.pdf [Skatīts 2018. g. 27. jūlijā].
[27] Ā. Dandens. *Viedo elektroenerģijas skaitītāju ieviešana klientiem*. [tiešsaiste]. Pieejams: http://www.rea.riga.lv/files/Vide_un_Energija_2014_REA_seminars_17-10-2014_Aris_Dandens.pdf [Skatīts 2018. g. 27. jūlijā].
[28] Delfi. *Latvija – līdere viedā elektrotīkla attīstībā Baltijas valstīs*. [tiešsaiste]. Pieejams: http://www.delfi.lv/news/elektrozinas/latvija-lidere-vieda-elektrotikla-attistiba-baltijas-valstis.d?id=48006009 [Skatīts 2018. g. 27. jūlijā].
[29] Sabiedrisko pakalpojumu regulēšanas komisijas padomes lēmums Nr.1/4. *Tīkla kodekss elektroenerģijas nozarē* [tiešsaiste]. Pieejams: https://likumi.lv/doc.php?id=257943 [Skatīts 2018. g. 27. jūlijā].
[30] G. Kacēns. Prezentācija *Dispečeru Centru izveide ST*. 26.10. 2010. Jelgava.
[31] Sadales tīkls. *Sadales tīkla 2016. gada pārskats*. [tiešsaiste]. Pieejams: https://www.sadalestikls.lv/files/newnode/parskati/ST__2016_gada_parskats.pdf [Skatīts 2018. g. 27. jūlijā].
[32] Latvijas likums. *Standartizācijas likums*. [tiešsaiste]. Pieejams: https://likumi.lv/doc.php?id=50425 [Skatīts 2018. g. 27. jūlijā].
[33] Latvijas amatniecības kamera. *Standartizācija*. [tiešsaiste]. Pieejams: http://www.ueapme.com/business-support%20II/Training%20Tools/NORMAPME/Standardisatioin/LV-Standardisation.pdf [Skatīts 2018. g. 27. jūlijā].
[34] Latvijas Vēstnesis. *Latvijas Nacionālās standartizācijas sistēmas koncepcija*. [tiešsaiste]. Pieejams: https://www.vestnesis.lv/ta/id/52723 [Skatīts 2018. g. 27. jūlijā].
[35] Latvijas Nacionālā standartizācijas institūcija "Latvijas standarts" (LVS). *Latvijas standartizācijas sistēmas struktūrshēma*. [tiešsaiste]. Pieejams: https://www.lvs.lv/page?slug=latvijas-standartizacijas-sistemas-struktursheма [Skatīts 2018. g. 27. jūlijā].
[36] Latvijas Nacionālā standartizācijas institūcija "Latvijas standarts" (LVS). *Standartizācijas likums*. [tiešsaiste]. Pieejams: https://www.lvs.lv/page?slug=standartizacijas-likums [Skatīts 2018. g. 27. jūlijā].
[37] Sadales tīkls. *Normatīvie dokumenti*. [tiešsaiste]. Pieejams: https://www.sadalestikls.lv/lat/par_as_sadales_tikls_/normativie_dokumenti_2/ [Skatīts 2018. g. 27. jūlijā].