RIGA TECHNICAL UNIVERSITY

Olegs BORSCEVSKIS

METHODS OF PROCESS IMPLEMENTATION ON CHANGE OF VOLTAGE LEVEL IN DISTRIBUTION NETWORKS OF THE LARGE CITIES, TECHNICAL MEANS AND OPTIMIZATION (RIGA CITY MODEL)

Summary of Doctoral Thesis

Riga 2013

RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
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Doctoral student of program “Power Engineering”

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Riga 2013

Borscevskis O. Methods of process implementation on change of voltage level in distribution networks of the large cities, technical means and optimization (Riga city model). Summary of doctoral thesis. - R.: RTU, 2013. - 39 p.

Printed in accordance with decision No. 8/13 of RTU Doctoral Board P-05 (Power and Electrical Engineering Engineering) dated May, 2013.

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

DOCTORAL THESIS
SUBMITTED TO RIGA TECHNICAL UNIVERSITY
TO OBTAIN DOCTORAL DEGREE IN ENGINEERING

Doctoral thesis is proposed for achieving doctoral degree and will be publicly presented on the 6th of June 2013 at 15:00 at Faculty of Electrical Engineering of Riga Technical University, 1 Kronvalda boulevard, in room 117.

OFFICIAL OPPONENTS

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Faculty of Electric Power Engineering and Informatics
Department of Electric Power Engineering
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Assistant Professor, Dr.sc.ing. Antons Kutjuns
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CONFIRMATION

Hereby is confirmed, that I completed the following thesis, presented in Riga Technical University for doctoral degree in engineering independently. This doctoral thesis is not submitted to any other university for achieving scientific degree.

Olegs Borscevskis ………………………

Date: ………………………

The thesis is written in Latvian, includes introduction, 5 chapters, conclusions, list of references, 2 appendixes, 82 figures, 23 tables, 165 pages in total. List of references consists of 113 items.

CONTENTS

TOPICALITY OF THE DOCTORAL THESIS

Any developed state in the world can not be imagined without high power engineering - one of the key segments of industry, including production of electrical energy, its transmission, distribution and consumption.

Electric power engineering is a leading sphere of infrastructure that without any alternative defines the frames of economic development opportunities; therefore it is necessary to provide prevailing increasing of generating power as well as to realize safe and qualitative supply of electric energy. Electrification significantly influences the development of all the fields of economy. Therefore the basic long-time objective of the state development is provision of economy and social sectors with the necessary amount of energy.

The power supply system of Riga city is an integral part of that of the whole state system. The development of the Riga city power supply system is often chaotic thus it is of top importance to elaborate and correctly make the decisions of network realization at initial stages of the design.

The conception of the large cities power supply has been changed with the growing of the cities, the increasing of electric load, development of technique and technical ideas. Not all the decisions in the development of the urban power supply have overcome the verification in time and some of them today have difficulties.

In accordance with the Development plan of Riga city the purpose is the thorough development of economy, using the geographic location of the city, natural possibilities and traditions for strengthening the economic independence of the city as well as improve the quality of people life efficiently applying the natural resources.

It is not possible without the development of electric power engineering and development of the safe system of the city power supply. For its realization it is necessary to define the basic principles of the network organization, order of the building of new system elements as well as the opportunities of interaction of new and old elements of the system.

The growing of communal consumers number in large cities, increasing of the number of storey of dwelling houses and administrative buildings, large amount of point load and separate regions with a high load density results in the necessity to introduce higher level of voltage in the power supply system. These tendencies are typical for Riga city - the capital of Latvia and main administrative, industrial, financial, business and cultural center. The introduction of higher level of voltage should be justified by the economic and technical possibilities and advantages in comparison with the existing power supply system.

Under the conditions of market economy the changing of the distribution network should be realized on the basis of technical economic calculations and the application experience of this voltage level in Latvia, Europe and other states of the world.

All the aspects mentioned above and the topicality of their consideration defines the subject of this paper, its aims and reasons of choice.

GOAL AND TASKS OF THE THESIS

The purpose of the dissertation is to develop the conception of 20 kV voltage introducing in Riga, evaluate the technical and economic possibilities for the gradual or fast changing of voltage, develop the methods of management of voltage level's changing process in the distribution network of the large city.

For the achievement of the purpose the following basic tasks have been considered and solved:

- to analyze the existing 110-20-10-0.4 kV power supply system of Riga city;
- to investigate 20 kV supply voltage application in the European and world states, comparing the condition of the network in Latvia and abroad;
- to develop the technical and economic models of the urban power supply system for the its qualitative and quantitative evaluation;

- to determine the optimal parameters of the power supply system and its technical and economic indices at different load densities in the city and its districts.
- to prove expediency of 20 kV voltage introduction; to consider and analyze technical equipment and means for 20 kV voltage introduction and provision of the network operating regimes.

SCIENTIFIC NOVELTY

The scientific novelty is described with the following aspects:

- the schemes of the power supply with use of 20 kV voltage are investigated at Riga and other European cities; the analysis of a problem to introduce more high voltage is made;
- the introducing conception of 20 kV supply voltage has been developed and justified in Riga city;
- technical economic model with three voltage stages (110-10-0.4 kV un 110-20-0.4 kV) for the optimization of the supply system parameters has been considered;
- the methods and algorithm of the 110/10 kV and 10/0.4 kV, also 110/20 kV and 20/0.4 kV, transformer substations' optimal powers, service areas and radii selection, have been developed;
- according to technical and economic reasons borders of expedient use of voltage of 20 kV depending on load density are defined;
- 110-20-0.4 kV power supply schemes was synthesized and the solutions of construction were justified and economically evaluated;
- the developed 20 kV supply voltage introducing conception and the methods of the optimal parameters selection can be applied also in other large cities realizing a necessary correction for the particular conditions.

METHODS AND MEANS OF RESEARCH RESULTS

The results of the research have been obtained having applied the following methods and means:

- mathematical and geometrical modeling of the objects and creation of the target function;
- the method of technical and economic analysis of researched object;
- method of nonlinear discrete programming to search a minimum of the target function;
- decision-making in the conditions of uncertainty of initial information;
- application of Microsoft Office Excel software to calculate the variants of development of urban power supply system;
- software AutoCAD for the visual representation of calculation results;
- computer program MatLAB, foreseen for intensive calculations, data analysis and its visual representation;
- MathCAD system for the solving of engineering problems and visualization and analysis of the results.

PRACTICAL APPLICATION OF THE RESEARCH RESULTS

The algorithms and methods proposed in the work can be applied:

- in the theoretical and scientific investigations related to the rational construction of urban power supply system and optimization of parameters;
- at the electric power enterprises, organizations, companies working with the development of the urban power supply scheme and the problems of its design;
- for the design of future 110/20 kV transformers substations and 20 kV networks with the use of basic stated interconnections;

- at the departments of maintenance of distribution network operator taking into account the elaborated methods of 20 kV voltage level introducing and recommendations for the effective application of electric equipment, lines and 110/20-10 kV transformer substations.

The results of the research are partly reflected:

- in the contracts with JSC „Latvenergo” No. L7310 (Nr.010000/08-16) "High voltage network scheme of Riga till 2020" (supervisor - professor J. Rozenkrons), -Riga: RTU, 2008 (partnership);
- in contract No.5-21/-2012 from 23.04.2012 with Marupe region Dome "Technical and economic basis of new 110 kV transformer substation in Marupe region” (supervisor– professor J.Rozenkrons), 2012 (partnership).

APPROBATION OF THE WORK

The results of the work are presented and reported at 12 international scientific conferences:

1. The 7th International Conference on Electrical and Control Technologies ECT-2012, 4 – 5 May, Kaunas, Lithuania, 2012.
2. The 10^{th} International Scientific Conference "Control of Power Systems 2012", "Energetika 2012. Power engineering 2012", 14 –18 May, Tatranske Matliare, Slovakia, 2012.
3. The 52nd International Scientific Conference. Power and Electrical Engineering and Environmental Sciences, 14 – 15 October, Riga, Latvia, 2011.
4. The 7th International conference-workshop: Compatibility and power Electronics 2011, CPE 2011, 1–3 June, Tallinn, Estonia, 2011.
5. Compatibility and power Electronics 2011, CPE 2011, Student Forum, 1–3 June, Tallinn, Estonia, 2011.
6. The 6th International Conference on Electrical and Control Technologies ECT-2011, 5 – 6 May, Kaunas, Lithuania, 2011.
7. International conference World Academy of Science, Engineering and Technology, WASET 2011, 27–29 April, Venece, Italy, 2011.
8. 10th International Symposium „Topical problems in the field of electrical and power engineering”, Doctoral school of energy and geotechnology II, 10–15 January, Parnu, Estonia, 2011.
9. The 51st International Scientific Conference. Power and Electrical Engineering and Environmental Sciences, 14-16 October, Riga, Latvia, 2010.
10. XI International Scientific-Technical Conference "Problems of Present-day Electrotechnics-2010", 1 – 3 June, Kyiv , Ukraine, 2010.
11. The 5th International Conference on Electrical and Control Technologies ECT-2010, 6 – 7 May, Kaunas, Lithuania, 2010.
12. The 50th International Scientific Conference. Power and Electrical Engineering and Environmental Sciences, 14 – 16 October, Riga, Latvia, 2009.

The results of the Doctoral thesis are presented in 20 publications:

1. N.Skobeleva, **O.Borscevskis**, S.Guseva, L.Petrichenko. An integrated approach to the formation of service areas for urban substations of differenr voltage // Journal of Energy and Power Engineering 6 (2012) 1358-1362 (JEPE ISSN1934-8975), David Publishing Company, Inc. USA, 2012.
2. S.Guseva, **O.Borscevskis**. Mathematical model for 110/10 kV transformer substations` optimal power choice // Proceedings of the 7th International Conference on Electrical and Control Technologies ECT 2012, 4 – 5 May, Kaunas, Lithuania, -p.202-205.
3. S.Guseva, **O.Borscevskis**, N.Skobeleva. Forecast and load determination of 110/20-10 kV transformer substations for Riga city till 2025 // Proceedings of the 10^{th} International

Scientific Conference "Control of Power Systems 2012", 14 –18 May, Tatranske Matliare, Slovakia, 2012, -p.159-160.

4. S.Guseva, **O.Borscevskis**. The system approach to the transformer substations` in the territory of small cities // Proceedings of the 52nd International Scientific Conference of Riga Technical University on Power and Electrical Engineering, 14 – 15 October, RTU, Riga, Latvia, 2011 (digitālā formātā uz CD).
5. G.Gavrilovs, **O.Borscevskis**. Power transformer diagnostic // Proceedings of the 10th International Symposium „Topical problems in the field of electrical and power engineering", Doctoral school of energy and geotechnology II, 10 - 15 January, Parnu, Estonia, 2011, -p. 224-228.
6. S.Guseva, **O.Borscevskis**, N.Skobeleva, L.Petrichenko. Perspective loads of transformer substations at development of urban power supply systems // Proceedings of the XV International Scientific Conference "Present-day problems of power engineering APE'11", vol. III, 8-10 June, Gdansk-Jurata, Poland, 2011, -p. 51-59.
7. S.Guseva, **O.Borscevskis**, N.Skobeleva, L.Petrichenko. Urban Power supply system's development in conditions of uncertain information // Proceedings of the tenth IASTED European Conference "Power and Energy Systems", Crete, Greece, 2011, CD, -p. 27-31.
8. N.Skobeleva, **O.Borscevskis**, S.Guseva, L.Petrichenko. An integrated approach to the formation of service areas for urban substations of different voltage // Proceedings of the 6th International Conference on Electrical and Control Technologies ECT-2011, 5- 6 May, Kaunas, Lithuania, 2011, -p. 202-205.
9. N.Breners, S.Guseva, N.Skobeleva, **O.Borscevskis**. Directions to increase reliability of maintained transformer equipment`s functioning //Proceedings of the 6th International Conference on Electrical and Control Technologies ECT 2011, 5- 6 May, Kaunas, Lithuania, 2011, -p. 175-178.
10. **O.Borscevskis**, G.Gavrilovs. Useful lifetime and rational replacement of power transformers //Proceedings of the IEEE the 7th International conference-workshop: Compatibility and power Electronics 2011, Tallinn, Estonia, 2011, -p. 40-43.
11. **O.Borscevskis**, G.Gavrilovs. 20kV voltage adaptation problems in urban electrical networks //Compatibility and power Electronics 2011, Student Forum, Tallinn, Estonia, 2011, -p. 68-71.
12. S.Guseva, **O.Borscevskis**, N.Skobeleva, L.Kozireva. Load determination and selection of transformer substations` optimal power for tasks of urban networks' development // Proceedings of the 51st International Scientific Conference of Riga Technical University on Power and Electrical Engineering, Vol. 27, Riga, Latvia, 2010, -p.31-36.
13. S.Guseva, **O.Borscevskis**, N.Skobeleva, N.Breners. The system approach to placement of transformer substations in the power supply system of the city // Proceedings of the 5th International conference on electrical and control technologies ECT-2010, 6-7 May, Kaunas, Lithuania, 2010, -p. 211-214.
14. S.A.Guseva, N.N.Skobeleva, **O.I.Borscevskis**, N.Z.Breners. Geometrical modeling of service areas and distribution of urban transformer substations in the city territory // Proceedings of the XI International Conference "Problems of Present-day Electrotechnics-2010", 1-4 June, Kyiv, Ukraine, 2010 (digitālā formātā uz CD)
15. S.Guseva, N.Skobeleva, **O.Borscevskis**, N.Breners. Rational approach to the formation of urban power supply system in solving of development problems // Proceedings of the Scientific and Technical Union of the Power Engineers, ENERGY FORUM 2010, Varna, Bulgaria, 2010, -p. 211-214.
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17. S.A.Guseva, N.Z.Breners, N.N.Skobeleva, **O.I.Borscevskis**. Применение мониторинга силовых трансформаторов для повышения эффективности функционирования систем

электроснабжения // Proceedings of the XI International Conference "Problems of Present-day Electrotechnics-2010", 1-4 June, Kyiv, Ukraine, 2010 (digitālā formātā uz CD).
18. Guseva S., Skobeļeva N., Breners N., **Borščevskis O**. Pilsētu transformatoru apakšstaciju apkalpes zonu modelēšana // Enerģētika un elektrotehnika, 4.sērija, 24.sējums. – Rīga, RTU, Latvija, 2009, – 24.-31. lpp.
19. S.Guseva, N.Skobeleva, N.Breners, **O.Borscevskis**. Load forecasting till 2020 of existing and perspective transformer substations in Riga // Power and Electrical Engineering, 4.sērija, 25.sējums. – Riga, RTU, Latvia, 2009, – p. 77-80.
20. S.Guseva, N.Skobeleva, N.Breners, **O.Borscevskis**. Determination and distribution of service areas of urban transformer substations with geometrical templates // Latvian Journal of Physics and Technical Sciences, Nr.6 (Vol.46), Riga, Latvia, 2009, - p. 16-26.

STRUCTURE OF THE WORK

The thesis is written in Latvian, includes introduction, 5 chapters, conclusions, list of references, 2 appendixes, 82 figures, 23 tables, 165 pages in total. List of references consists of 113 items.

The first chapter contains the description of network condition of 330, 110, 20-10 and 0.4 kV Riga city power supply system, basic principles of the operation scheme and its technical data, the methods of the rated voltage selection for most of the city networks as well as comparison of indicators for 10 kV and 20 kV voltage networks.

The second chapter summarizes the information about 20 kV voltage application in European and world urban supply systems, in details investigates the condition of each present 110/20-10 kV transformer substation in Riga, contains the analysis of the real load of TS „Bisuciems”, „Zolitude”, „Marupe” and „Tiraine” and gives the prognosis for the period from 2000 to 2026 as well as states the most important unsolved problems.

The third chapter proposes the conception of 20 kV voltage introducing in Riga city, the methods of the determination of the optimal parameters for the urban power supply system (UPSS); it proposes also the developed 110-20-0.4 kV and 110-10-0.4 kV urban power supply system general technical and economic models and related target functions; the first stage of the target function optimization is realized with the local extremes defining. The calculations for the 110/10 kV and 110/20 kV TS optimal power selection are realized with software Microsoft Excel program developed for this purpose.

The fourth chapter contains the second stage of the target function optimization and determination of the important optimal parameters of the 110-20-0.4 kV and 110-10-0.4 kV UPSS within the wide range of the load density. The advantages and disadvantages of the neutral operation regimes of different UPSS are analyzed and the neutral with the grounding through the low resistive active resistance is chosen for the 20 kV cable network as well as the opportunities for the voltage regulations in the 110/20 kV and 110/20-10 kV transformers are analyzed.

The fifth chapter provides the economic expediency of the 20 kV voltage introducing in the Riga city power supply system, describes the technical measures for this introducing, proposes the constructive design of 110/20 kV TS and its technical and economic justification; the network schemes are synthesized there and the opportunities of the 110-20-0.4 kV system application in two new districts of Riga are demonstrated: Dreilini and Rumbula and in Riga suburbs - in Marupe region.

1. DESCRIPTION OF RIGA CITY POWER SUPPLY SYSTEM

A system of power supply in large cities usually is an integral part of state power system. The qualitative power supply of Latvian cities is directly related to 330 kV and 110 kV networks safe operation and rational construction. The applied voltage hierarchy of the Latvian power supply systems (PSS) can be reflected with the diagram in Figure 1.1. [10-14].

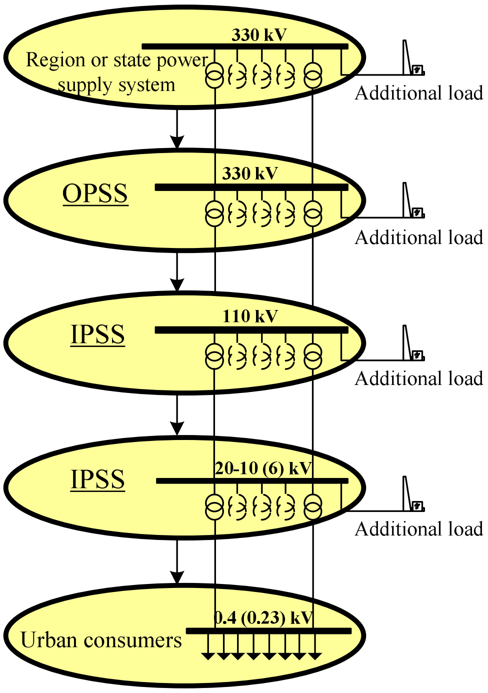

Fig. 1.1. The structure of voltage levels in Latvian power supply system:
OPSS - power supply system outside the cities,
IPSS - power supply system inside the cities

Riga is the capital of Latvia and key industrial, business, culture and financial centre in Baltic, significant port [25]. Riga is one of the largest electrical energy consumers in the Latvian power system. The consumption of the electric power in Riga is demonstrated in Figure 1.2. In 2008 the maximum load of Riga was 545 MW and electric power consumption was 2574 GWh, i.e. approximately 40% of the whole power system's consumption. A large part of the power produced and consumed in the state refers to its capital. Because of the decreased population and economic situation in the state the power consumption is also decreased. In 2010 the maximum load was only 485 MW, but electric power consumption was 2540 GWh. In recent years load growth practically it is not observed.

The safety of the Riga power supply systems depend on 330 kV network realized with overhead wires lines (OHL) of 38.8 km and operating according to the radial principle. 110 kV network is realized with OHL (107.6 km of the city neighbourhood) as well as with cable lines (CL) (6.7 km in the city centre with high density of building).

Riga power supply scheme with 330 kV and 110 kV of overhead wires and cables is shown in Figure 1.3. [23].

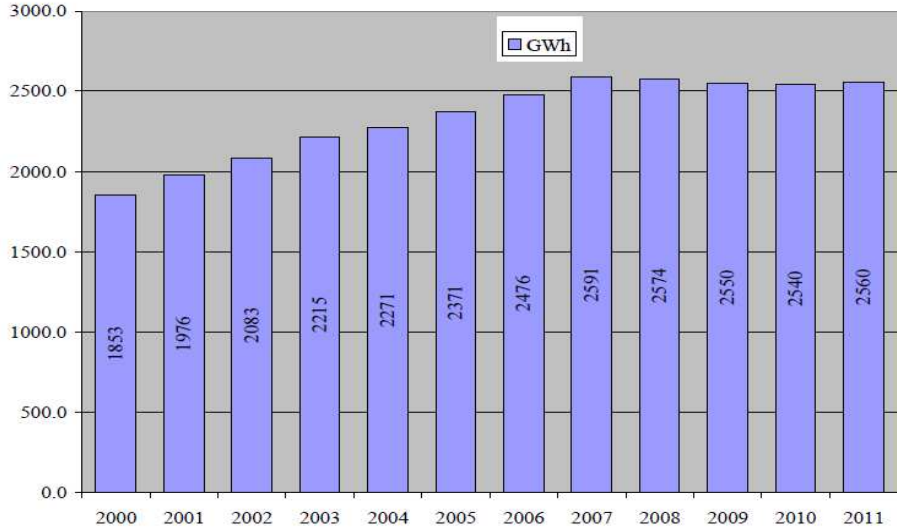

Fig. 1.2. The electric power's GWh consumption of Riga city in the period from 2000 till 2011

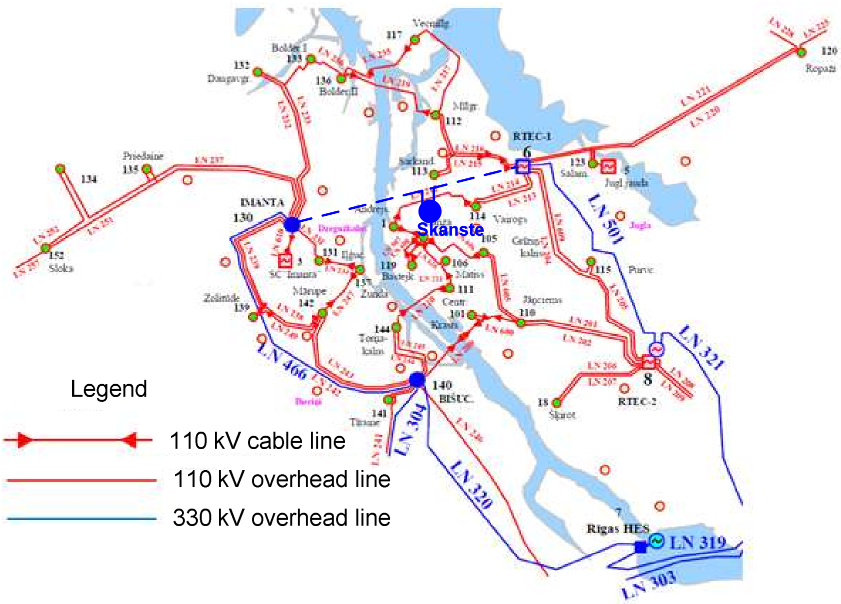

Fig. 1.3. The 330-110 kV network`s power supply scheme of Riga city

Types of the transformer substations (TS) with different supply voltage and networks of different performance in the cities of Latvia are generalized and presented in Figure.1.4.

330 kV network is one of the basic elements of Riga power supply system. Unfortunately the existed 330 kV OHL are old: LN 321- 46 years old (introduced into operation in 1964) and LN 466 - 24 years old (in 1986).

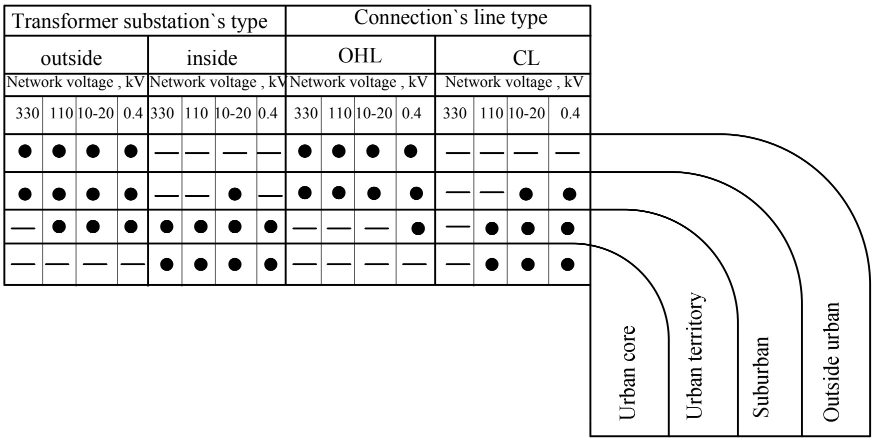

Fig. 1.4. UPSS of different voltage TS and power supply systems in the Latvian cities

The 110 kV network is realized according to the ring scheme with diagonal connections including also Riga TEC-2 located outside the city. The scheme includes four 330/110 kV substations: „Bisuciems", „Imanta", „Riga TEC-1" and the TS „Riga TEC-2" outside the city. 330/110 kV substations have the connections with the 110 kV substations located outside the ring scheme and city borders. For increasing of the safety of Riga power supply system a closed ring among all 330 kV substations should be realized for the 330 kV network. It requires to construct 330 kV connection between TS „RIGA TEC-1" and TS "Imanta", in future new 330 kV TS "Skanste" will be introduced (Figure 1.3. demonstrates 330 kV network connection with dotted blue line).

Riga distribution network of 6-10-20 kV voltage is realized on the basis of cable lines. The networks are built according to a loop-type scheme but operate in a radial regime. A large part of 10 kV cable network has an exceeded service life, its voltage often is 6 kV. The cables have impregnated paper insulation, small cross-sections and many connecting couplings [17]. During last 10-15 years the old cables with insufficient cross-sections and non-checked with increasing voltage cables are changed for middle voltage with PVC and polyethylene (so called plastic) insulation As a result considerably reliability of Riga middle voltage network improved. The existence of considerable number of 20 kV cable lines in Riga city and operating experience of the constructed 20 kV lines and the equipment in Latvia can simplify in future the introducing of higher voltage in large cities with high load density.

The condition of existing distributive points can be estimated as unsatisfactory. From their general amount (78 points) only 25% are fully reconstructed, at 14% of them the equipment is partly changed, but in 61% of the cases no renovations took place at all. Therefore, 25% of the distribution points are physically aged and require a renovation.

In the low voltage system basically the cable lines are applied. In the centre of Riga the reconstruction of networks is still not completed for all the consumers of the energy with non-typical voltage 3x220 V (the old three-phase network without neutral wire) [7,36].

Guaranteeing to city consumers with uninterrupted power supply, providing with qualitative energy of perspective multi-storey residential districts with a high load density, connection of large powerful consumers (USA embassy, Latvian National library, VIP (very important person) office bilding Z-towers in Kipsala etc.) require flexible, safe and effective electric scheme with necessary level of voltage.

The work considers in detail the problem of changing of the voltage level in the distribution network, its technical opportunities and economic feasibility of the transfer to 20 kV voltage. kV

The pre-conditions of 20 kV voltage introducing:

- the existence of large office buildings, cultural, financial and business centers, high power single consumers and multi-storey residential districts with high load density;

- enough amount of 110/10-20 kV TS to provide opportune reserve of power supply in the case of emergency and postemergency operation regime;
- existence of correspondent electric equipment (transformers, switchgears, relays and automation protection, 20 kV cables), solved problem of the network neutral regime.
- stable economic situation in the state, existence of financial, material and working resources.

Advantages of 20 kV voltage. Basic advantages of the 20 kV voltage network in the network capacity, voltage losses, active and reactive power and electric power losses can be explained with the mathematical relations between the network technical parameters [2-4,7]:

$$P_{max} = \sqrt{3} \cdot U \cdot I_{max} \cdot \cos\varphi; \; ; \Delta U = \frac{\sum P_L \cdot R + \sum Q_L \cdot X}{U} \; ; \; \Delta A = \frac{S^2{}_{max}}{U^2} \cdot R \cdot \tau \cdot 10^{-3}, \qquad (1.1)$$

where $P_{\max}$ – is a network capacity; U – network supply voltage; I_{max} – maximum current of the line (usually it is a rated current of the power switch I_{nom}), $\cos\varphi$ - power factor of the network; P_L – active power transmitted in the line; Q_L – reactive power transmitted in the line; R - active resistance of the line; X - reactive resistance of the line.

Comparison of the expressions for 20 and 10 kV voltages results in the conclusion that 20 kV network has two times higher capacity than that of 10 kV with the similar load.

The same relates to the network elements transmitted power. With increasing the voltage twice the losses of the 20 kV line are decreasing twice, active and reactive power and electric energy losses are four times decreasing.

These advantages of the 20 kV distribution network are very important in order to provide safe and qualitative power supply in the districts with high load density, connection of large powerful consumers and development of city network with the growing of the load.

In spite of the fact that 20 kV network have considerable advantages its introduction and application in Riga city power system is very complex and time-taking process that physically and in practice can not be realized quickly. It demands time as well as stage-by-stage, technically prepared and correctly developed approach that should be provided with technical and economic calculations in the conditions of incomplete and uncertain information for the problems of network development.

2. APPLICATION OF 20 KV VOLTAGE IN LARGE CITIES AND NETWORKS OF RIGA

2.1. Application of different rated voltage in large European and world cities

For many years the application of 20 kV voltage in large cities has been a topical discussable question. It is valuable to apply 20 kV voltage in the cities or their suburbs with a high load density and at the industrial enterprises remote from the load centers. Nowadays the rated voltage of 20 kV is included into standards of many states as well as regulations of International Electrical engineering Committees [31].

This paper in details considers and describes basic operational principles of power supply systems of different large European and world cities using 20 kV supply voltage: in Paris, Stockholm, Helsinki, Moscow, Berlin, Dubai. The literature reflects the electrical circuits of these systems, the weak sides of this power supply systems [27,30,33,35].

The same approaches do not exist and no united methodology is developed for the application solving the questions about the increasing of voltage in a city with its own power supply system as each city has its own geographic conditions, schematic topologies of the network, UPSS of buildings, technical and economical conditions.

2.2. Description of the Riga city existing 20 kV voltage network

At the moment the territory of Riga is served by twenty seven 110/20-10 kV substations. Currently the basic supply voltage in Riga is 10 kV. The 20 kV voltage is applied in Riga suburbs: Dreilini region, Vecmilgravis, Bergi, Mangalsala, Vecaki, Jaunciems, Darzini. These networks border with those „suburban" of 20 kV. Switchgears of 20 kV are applied at 330/110/20-10 kV TS „Bisuciems" and 110/20-10 kV TS „Zolitude", „Vecmilgravis", „Marupe" and „Tiraine". Using one line of 20 kV from 110 kV TS „Salamandra" the supply reserve of the water pump station „Baltezers" is realized by means of transformer 6/20 kV.

These substations provide 20 kV voltage CL and OHL lines supplying the territories outside the city. The introducing of the 20 kV voltage in Riga should be started from the border of the city as it will be easier to realize the reserve in 20 kV network. 20 kV voltage network is widely represented in the district around supermarket „Spice" supplied from 110/20-10 kV TS „Marupe".

The principal scheme of TS Nr. 142 "Marupe" is given in fig. 2.1 and 2.2 [7]. At this TS three 110/20-10 kV three-winding transformers are installed. In 2004 during the reconstruction of substation „Marupe" 20 and 10 kV switchgear was changed with additional panels installation. After the renovation an intensive building process has been started in the region of the substation. During the previous years the substation is supplying some new powerful loads: the airport, the USA embassy, supermarkets („Spice", „Spice furniture", etc.). As a result the switchgear of the substation has only few spare panels [24].

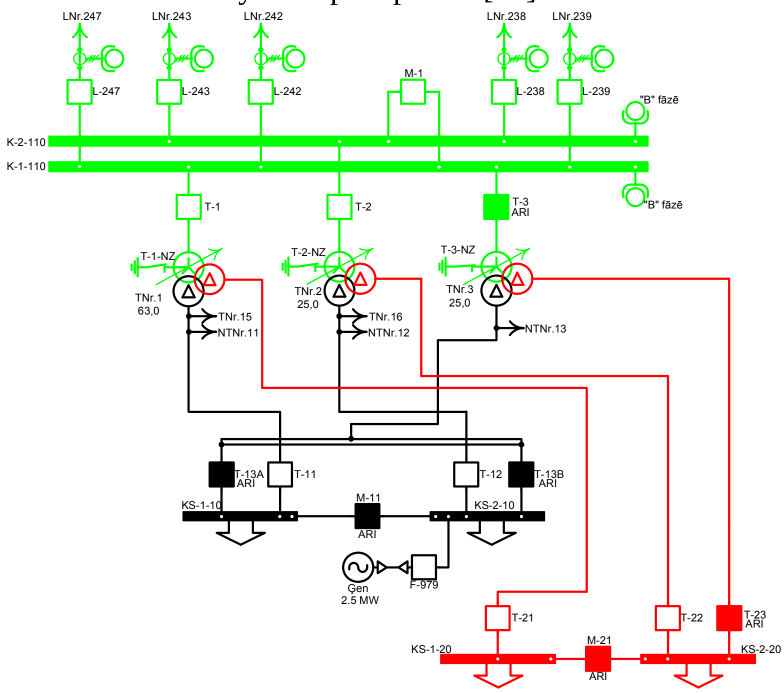

Fig. 2.1. The principal scheme of 110/20-10 kV TS „Marupe"

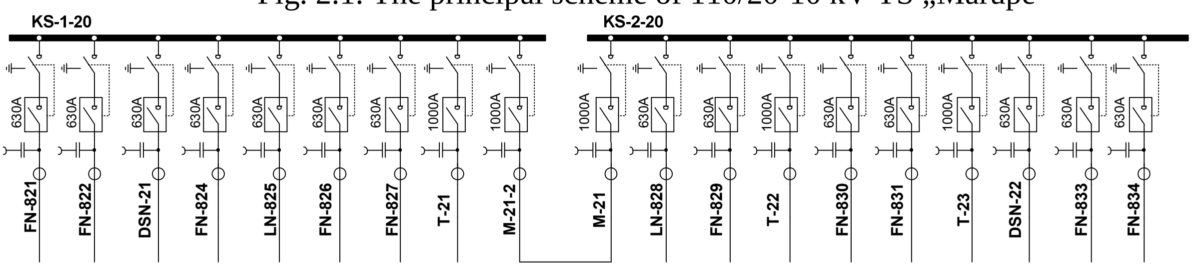

Fig. 2.1. The principal scheme of TS „Marupe" KS-1-20 and KS-2-20

One of the largest consumers connected to TS „Marupe" 20 kV supply voltage is new dwelling houses complex in Ventspils street 60. The multi storey buildings in this region are with very

high load (a simultaneous maximum load is P_{max}=4.1 MW) and high load density σ in the building area – about 44 MVA/km^2 [24].
The supply from the sections of TS „Marupe” 20 kV goes not only to the consumers of Riga but to a half of the territory of Marupe region through two OHL lines from each of 20 kV sections. Unfortunately the connection of new loads in this region is still a large problem as there is no own 110/20 kV TS in the territory of Marupe.
This work contains the analysis of load at 110/20-10 kV TS Nr. 142 „Marupe” from the period from 2000 till 2011 and the load forecast from 2011 till 2026 (figure 2.3). The real load of 110/20-10 kV TS „Marupe” (in accordance with measurement data of „Latvijas Elektriskie tikli” (LET)) in 2000-2011 is given in figure 2.3 with blue color. With an additionally required load of P_{piepr}=14.0 MW in 2012 (JSC “Sadales Tikls” (ST) and LET data) an with the further even 2% load year growing, the load of TS „Marupe” in 2026 will be P_{2026}=56.7 MW, but with the 3% load year growing it is – P_{2026}=66 MW in 2026.

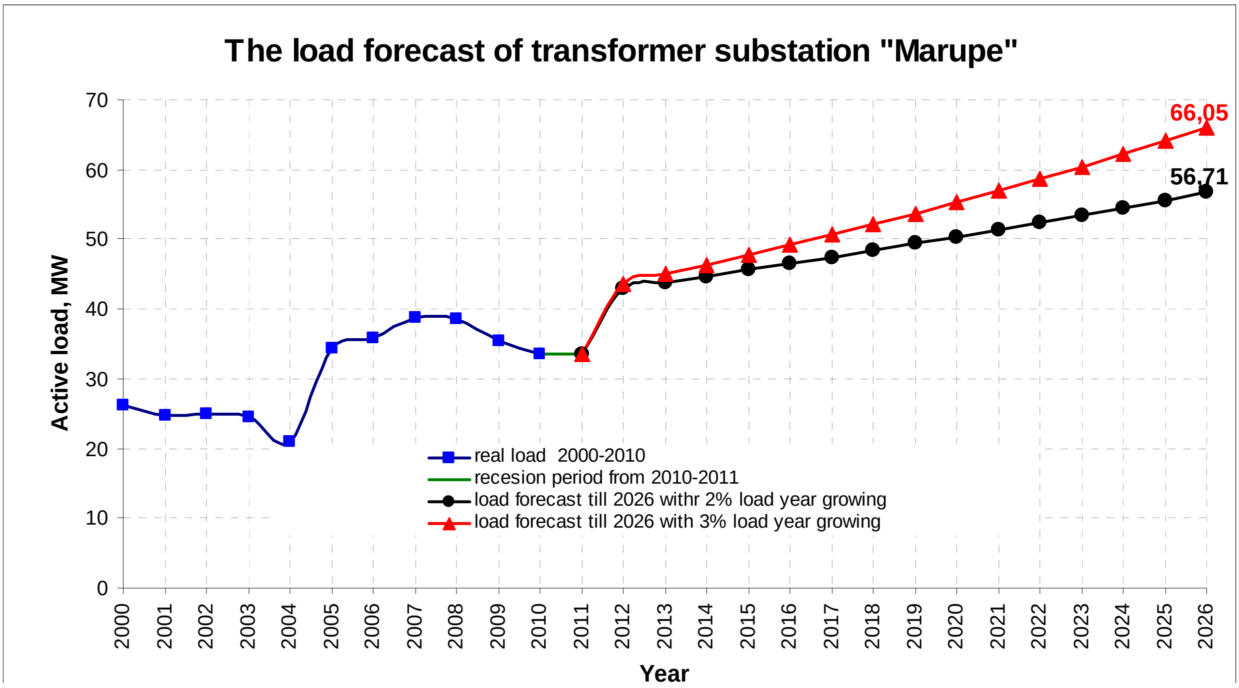

Fig. 2.3. The load forecast of 110/20-10 kV TS „Marupe” from 2000 till 2026

It means that any of the accepted scenario will require changing of the 110/20-10 kV transformers power. As the substation already contains one transformer with power S_{nom}=63 MVA the other two transformers with power S_{nom}=25 MVA are required to be changed for those with S_{nom}=63 MVA. One such three-winding transformer costs about 850000 *EUR*. The transformers of such high power will require additional measures for limitation of short-circuit currents.
The 110/20-10 kV TS of Riga city (Marupe, Zolitude, Tiraine, Bisuciems) widely applying 20 kV voltage for the supplying of the consumers are considered in details in the thesis. The condition of each 110/20-10 kV TS and main unsolved problems are analyzed [18,24].
The increasing of the electrical power consumption in the communal sphere, higher multi-storey buildings, modern offices development, building of banks and commercial spaces, presence of point-type load increase the load density within particular districts or in the whole city. The calculations made in [28] demonstrate that the load density in the central districts of Riga can achieve 30 MVA/km^2. The stabilization of the economical situation in the state positively influences the increasing of load and consumption of electrical power. Under these conditions in some districts of the city (in prospect in Riga as a whole) a significant transfer of the power

supply system of Riga from 110-10-0.4 kV to 110-20-0.4 kV is taking place. Such transfer is technically possible as somewhere the 20 kV voltage networks and 110/20-10 kV transformer substations have been already installed and personnel have already experience in its maintenance.

3. BASIC PRINCIPLES OF PROCESS IMPLEMENTATION ON VOLTAGE LEVEL CHANGING IN THE DISTRIBUTION NETWORKS

3.1. Conception of process implementation on 20 kV voltage introducing

The introducing of 20 kV voltage in Riga city is a very complex and labour intensive process that can not be physically and practically realized very quickly. In the city the network of 110-10-0.4 kV is developed, but in some districts 20 kV voltage is applied. Within transition to 20 kV voltage the question of technical and economic expediency of its introducing in all the city should be solved as well as that of saving, reconstruction of the currently used elements and creation of new elements in transition period for realization of a whole 110-20-0.4 kV UPSS. It requires a gradual and correctly developed approach based on the technical and economic calculations under the condition of initial incomplete and uncertain information as well as time required for the transition.

The paper considers a developed conception for introducing 20 kV voltage in Riga instead of that of 10 kV reflected in Figure 3.1.

The conception for the development of 20 kV voltage in Riga city includes:

- the profound analysis of the existing 110-20-10-0.4 kV UPSS and preparation of the currently used 110-10 kV network for the transition to 110-20-0.4 kV (1st block);
- building of a new 110/20 kV transformer substations and new 110 kV cable lines for TS connection to the network (2nd block);
- building of a new 20/0.4 kV transformer substations (points) and new 20 kV network starting with the borders of Riga city where it is already exists (3rd block).

The realization of tasks and measures of each block requires the solution of theoretical and practical problems.

The theoretical tasks of the 1st block:

- selection of the optimal power of the new 110/10 kV substations for the development of the existing network, especially in the central districts before emergence of conditions for transition to new voltage system;
- determination of service area and service radius of the new 110/10 kV substations.

Practical measures of the 1st block:

- delivery of new equipment and cables to provide the development of existing 110-10-0.4 kV UPSS and transition to a new 110-20-0.4 kV UPSS;
- as far as possible gradual replacement of 110/10 kV transformers with new of 110/20 kV.

The theoretical tasks of the 2nd block:

- choice of the rational scheme of 110 kV network;
- selection of optimal power for new 110/20 kV substations;
- determination of service area and service radius of 110/20 kV substations.

The practical tasks of the 2nd block:

- selection of 110/20 kV TS constructive execution.

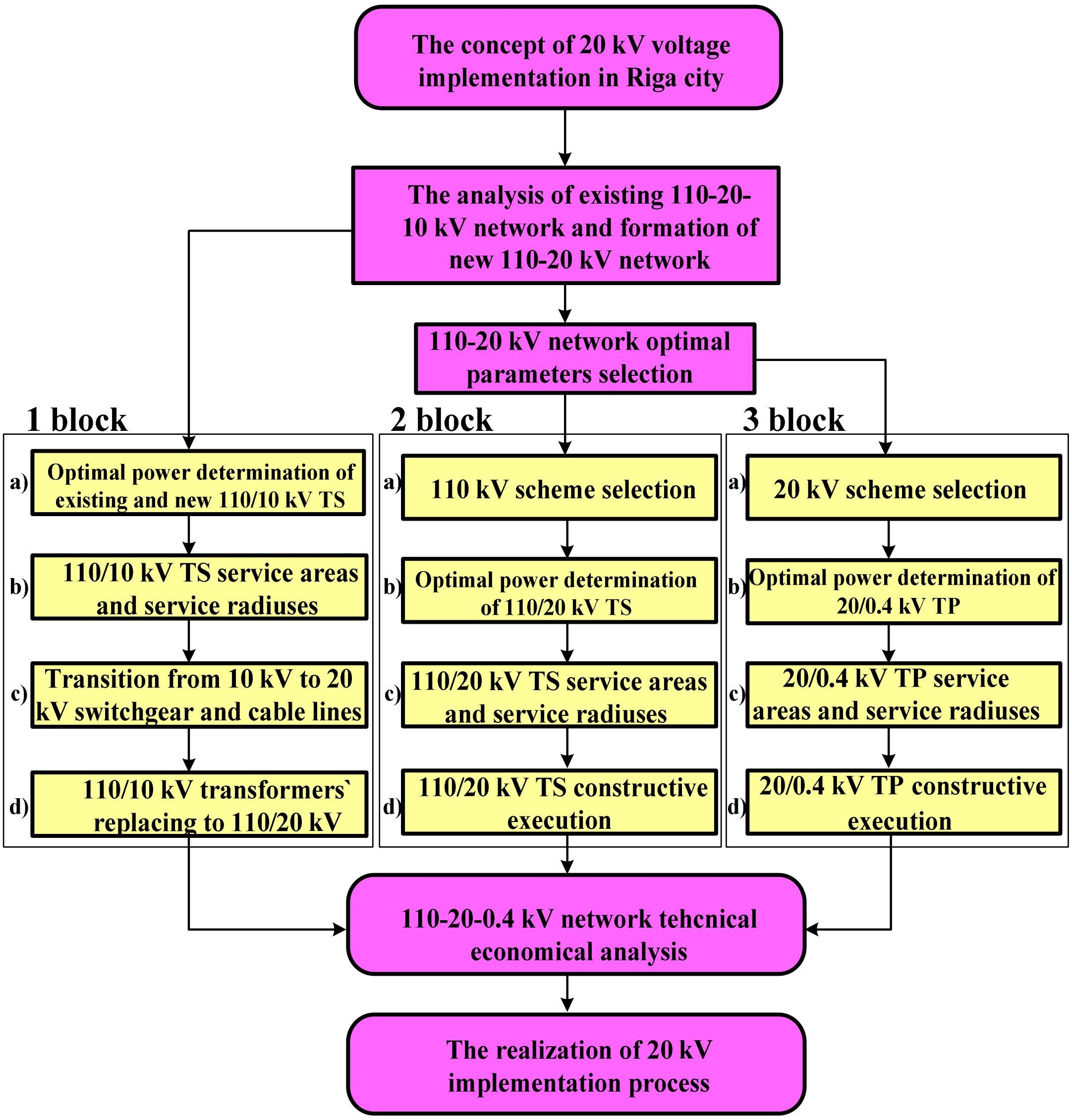

Fig. 3.1. Block diagram of conception of 20 kV voltage introducing in Riga city

The theoretical tasks of the 3rd block:

- choice of the rational scheme of 20 kV network;
- selection of optimal power of 20/0.4 kV transformer substations or points (TP);
- determination of service area and service radius of 20/4 kV substations or points.

The practical tasks of the 3rd block:

- selection of 20/0.4 kV TP constructive execution.

The solutions for the theoretical and practical tasks of the conception of transition to 20 kV voltage are considered in chapters 3 - 5.

3.2. Methods of the optimal parameters determination of the urban power supply system

The problems of the determination of optimal parameters for the power supply systems were considered and investigated in many scientific papers. A large role in the investigation of these questions belongs to the Latvian and foreign scientists and engineers: V.Venikov, A.Glazunov, V.Blok, G.Pospelov, V.Fedin, V.Kozlov, V.Dale, Z.Krisans, S.Guseva [31,32].
The analysis of the scientific literature results in the conclusion that there is a lack of acceptable methods for the evaluation of modern multi-stage urban power supply systems because of changes in the building principles and approaches to technical and economic analysis. Source [28] contains the evaluation of optimal power of 110/10 kV TS within the frames of perspective 110 kV

scheme selection in Riga city till 2020, but it is an indicative approach having some simplifications and being not suitable for the detailed analysis of modern multi-stage UPSS.
Solving the problems of power supply of large cities and the tasks of new voltage level introducing it is of top importance to select correctly an optimal power of a new 110/20 kV transformer substations, its number and location in the city territory as well as to evaluate the effectiveness of transition to new voltage level. In addition during the period of transition there is no reservation of 110/20 kV TS and 20 kV lines, especially in the centre of the city. Therefore during the transition to the new voltage the existing 110-10 kV network will remain and even be developed. With the increasing of the load new 110/10 kV TS should be built also in the existing new voltage system. Simultaneously the optimal power of the new TS, their number and location in the territory of the city should be evaluated. The full solution of this problem is considered as a complicated and labour intensive task taking into account that it takes place under the conditions of incomplete and uncertain information (on the characteristics of new equipment, rate of development, order of the building, terms of the objects handing-over, etc.).
In the promotional paper for the solution of the development tasks a general technical and economic model was developed for the determination of the parameters of 110-10-0.4 kV and 110-20-0.4 kV UPSS and for the analysis of the technical and economic indicators. The solution of the task is realized on the basis of the comparison the variants of UPSS development [9,11].
In the creation of technical and economic model of the 110-10-0.4 kV, as well as 110-20-0.4 kV UPSS of Riga city the following states, simplifications and assumptions are considered:

1. 110/10 kV and 110/20 kV two - transformers TS is the substations of an inside type with 110 kV input cables and 10-20 kV output cables.
2. 110 kV network is realized using ring scheme, 20 kV network using dual-beam radial scheme, 10 kV network using loop-type scheme with division in a point of th flow section, 0.4 kV network in all the variants is realized according to the loop-type scheme with point of division (the principal scheme of the network is in Figure 3.2).
3. 20-10/0.4 kV TP (more often two-transformers) is a compact transformer substation with small building square (till 15m^2). All 0.4 kV outputs from 20-10/0.4 kV TP to the consumers are cable type.
4. In the calculations of optimization for the cities with different storey buildings the following range of the load density is assumed: σ=3÷24 MVA/km^2.

The methods developed for the determination of the optimal parameters of the urban power supply system (UPSS) contains two components and is shown in Figure 3.3 in two blocks:

- the 1st block considers the determination of the optimal power for 110/10 kV and 110/20 kV TS according to the load density in developed districts;
- the 2nd block considers the determination of the optimal power for 10/0.4 kV and 20/0.4 kV TP knowing the optimal power of 110/10 kV or 110/20 kV TS from the calculations at the 1st block.

The latter task is considered in detail and solved in chapter 4 [9].

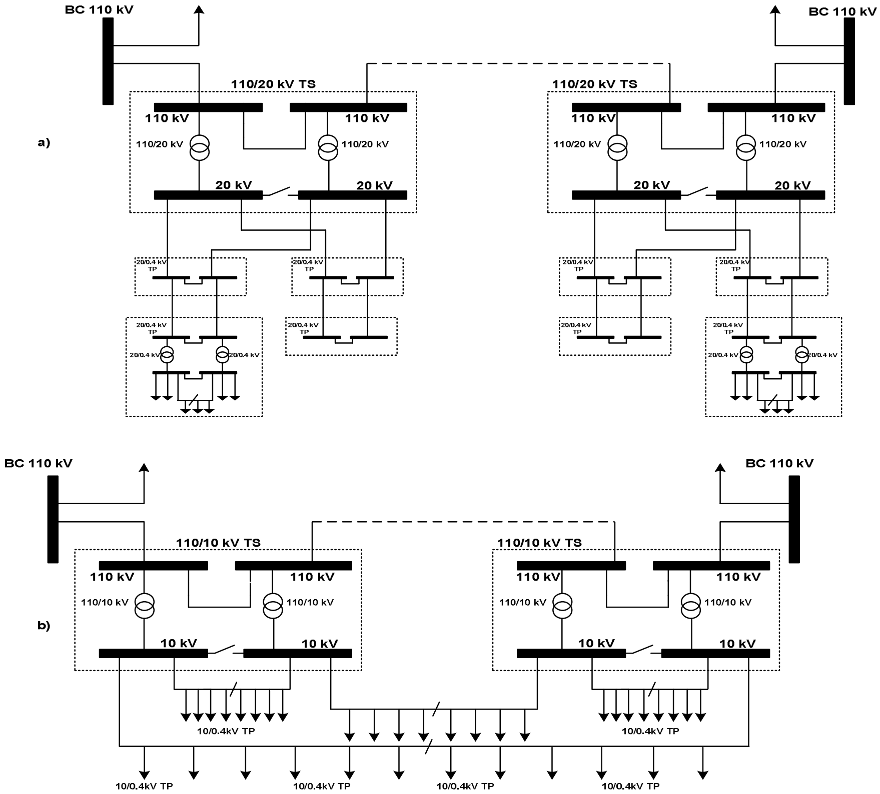

Fig. 3.2. The principal schemes of the urban networks:
a) 20 and 0.4 kV dual-beam radial circuit for the 110-20-0.4 kV UPSS,
b) 20 and 0.4 kV loop-type circuit for the 110-10-0.4 kV UPSS.

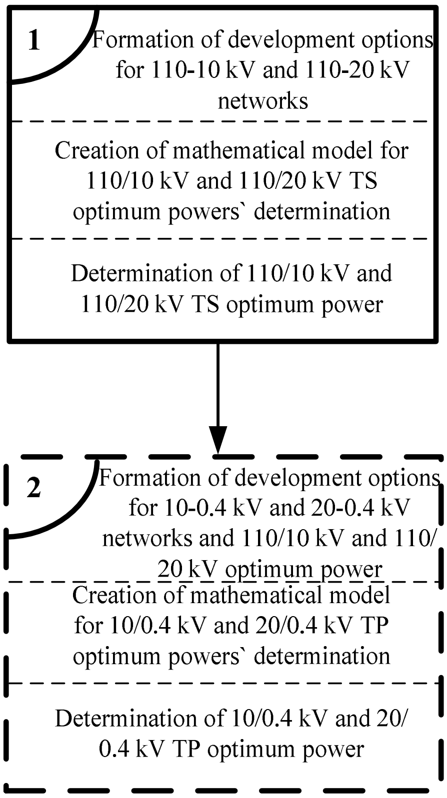

Fig. 3.3. 110-10-0.4 kV and 110-20-0.4 kV UPSS
the components of the methods of TS and TP optimal power determination

3.3. Technical and economic models of 110-10-0.4 kV and 110-20-0.4 kV urban power supply systems

For the analysis of currently used 110-10-0.4 kV and new 110-20-0.4 kV UPSS the technical and economic models have been realized. For the evaluation of systems the total capital investments are selected as a correspondent target function under the condition of incomplete initial information.

The total capital investments K_Σ on the building of power supply system in the city or its districts include those for the building of 110/10 kV or 110/20 kV transformers substations and 10/0.4 kV or 20/0.4 kV transformers points, as well as for the TS, TP and consumers connection to the networks with necessary cable lines.

The target function of total capital investments for the network n variants in its general view is the following [9,17,26]:

$$K_{\Sigma,n} = f(A_i, S_{TSnom,i}, S_{TPnom,i}, \sigma_i) = \\ = K_{\Sigma TS} + K_{\Sigma AL} + K_{\Sigma TP} + K_{\Sigma VL} + K_{\Sigma ZL}, \qquad (3.1)$$

where $K_{\Sigma TS}$ – is the capital investments for the building of 110/10 kV or 110/20 kV transformer substations; $K_{\Sigma AL}$ – capital investments for 110 kV cable line building for 110/10 kV or 110/20 kV TS connections; $K_{\Sigma TP}$ – capital investments for 10/0.4 kV or 20/0.4 kV transformer points (TP) building; $K_{\Sigma VL}$ – capital investments for 10 kV or 20 kV cable line building for 10/0.4 kV or 20/0.4 kV TP connection; $K_{\Sigma ZL}$ – capital investments for 0.4 kV cable line building for connection of consumers to the 0.4 kV network.

The target function (3.1) and its components are expressed from the variable $S_{TSnom,i}$ (110/10 kV or 110/20 kV TS transformers' rated power) and $S_{TPnom,i}$ (10/0.4 kV or 20/0.4 kV TP transformers' rated power) with the given but variable load densities σ_i in the city (or its districts) with square $\Pi_{city,i}$, and constants A_i depending on the initial technical and technical economic parameters of the network.

The geometrical models of the networks and their elements and mathematical relations between the parameters of the network are used for the creation of the UPSS technical and economic model [15,16].

The total load of the city or its components (district, etc.) S_{city} is expressed in the following way:

$$Scity = k_{o,v} \cdot \sum_{i=1}^{n_{TS}} S_{TS,i} = \sigma_{vid} \cdot \Pi_{city} = \sigma_{vid} \cdot \sum_{i=1}^{n_{TS}} \Pi_{TS,i}, \qquad (3.2)$$

where $S_{TS,i}$ – is a load of the i-th transformer substation; n_{TS} – the number of TS in the city or its components; Π_{city}– the square of the city territory; σ_{vid} – an average load density in the city or its district; $\Pi_{TS,i}$ – *the* i-th TS service area (zone); $k_{o,v}$– simultaneity factor of the TS load maximum and maximum of power system at the different hierarchy of voltage levels ν, depending on TS number.

The real service area (zone) of the transformer substation $\Pi_{TS,i}$ are modeled with the idealized equivalent square of the equilateral (correct) hexagon type (Figure 3.4). The following mathematical relations (3.3) exist among the hexagon's basic geometric sizes and technical parameters of the transformer substation [19-21].

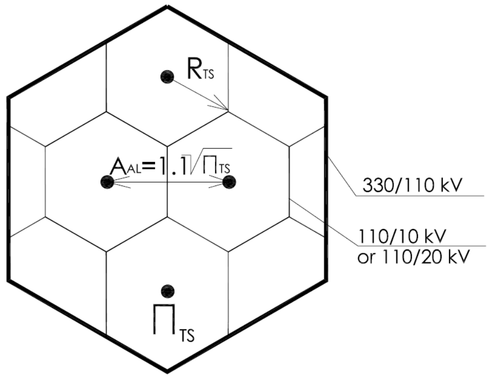

Fig. 3.4. The ideal model of transformer substation's service area for different voltage levels

$$
\begin{aligned}
\Pi_{TS} &= \frac{n_{tr}\cdot\beta_{piel,TS}\cdot S_{TS,nom}}{\sigma_{vid}} = 2.6\cdot R_{TS}^{2} \\
R_{TS} &= 0.62\cdot\sqrt{\frac{n_{tr}\cdot\beta_{piel,TS}\cdot S_{TS,nom}}{\sigma_{vid}}} = 0.62\cdot\sqrt{\Pi_{TS}} \\
A_{AL} &= 1.1\cdot\sqrt{\frac{n_{tr}\cdot\beta_{piel,TS}\cdot S_{TS,nom}}{\sigma_{vid}}} = 1.1\cdot\sqrt{\Pi_{TS}} \quad .
\end{aligned}
\tag{3.3}
$$

In (3.3) the following symbols are assumed: Π_{TS} – is the service area (zone) of the transformer substation; R_{TS} – radius around the hexagon or the service (operation) radius of the substation; A_{AL}– theoretically minimum distance between the neighbour substations; n_{tr} – the number of transformers at one TS; $S_{TS,nom}$ – rated power of the TS transformers; $\beta_{piel,TS}$ – admissible load factor of the TS transformer.

The geometrical models assumed for the city 10 kV and 20 kV electrical network schemes from fig. 3.2 are shown in Figures 3.5 and 3.6.

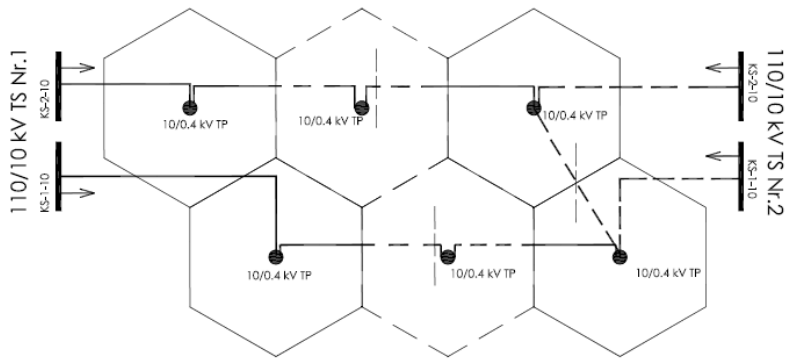

Fig. 3.5. The model of 10 kV network with 10/0.4 kV TP and 10 kV loop-type cable lines

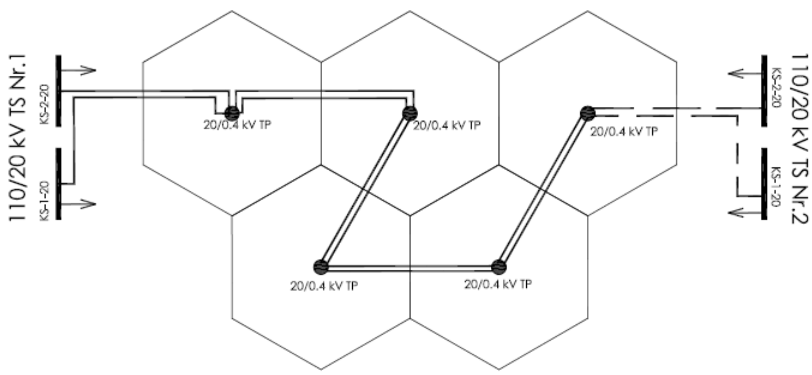

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Fig. 3.6. The model of 20 kV network with 20/0.4 kV TP and 20 kV dual-beam cable lines

Taking into account the assumed models and mathematical relations among the network parameters the general technical and economic models of 110-10-0.4 kV and 110-20-0.4 kV UPSS target functions (3.4) and (3.5) dependent on variables S_{TS} and S_{TP} are obtained in the work.

The target function for 110-10-0.4 kV UPSS [9]:

$$K_{\Sigma 110-10-0.4} = A_1 \cdot \sigma_{vid} \cdot S_{TS,nom}^{-1} + A_2 \cdot \sigma_{vid}^{0.5} \cdot S_{TS,nom}^{-0.5} + A_3 \cdot \sigma_{vid} \cdot S_{TP,nom}^{-1} + A_{4(10)} \cdot \sigma_{vid}^{0.5} \cdot S_{TS,nom}^{0.5} \cdot S_{TP,nom}^{-1} + A_{5(10)} \cdot \sigma_{vid}^{0.5} \cdot S_{TP,nom}^{1.5} \quad (3.4)$$

The target function for 110-20-0.4 kV UPSS:

$$K_{\Sigma 110-20-0.4} = A_1 \cdot \sigma_{vid} \cdot S_{TS,nom}^{-1} + A_2 \cdot \sigma_{vid}^{0.5} \cdot S_{TS,nom}^{-0.5} + A_3 \cdot \sigma_{vid} \cdot S_{TP,nom}^{-1} + A_{4(20)} \cdot \sigma_{vid}^{0.5} \cdot S_{TS,nom}^{0.5} \cdot S_{TP,nom}^{-1} + A_{5(20)} \cdot \sigma_{vid}^{0.5} \cdot S_{TP,nom}^{1.5} \quad (3.5)$$

The target functions of 110-10-0.4 kV and 110-20-0.4 kV UPSS differ with constants $A_{4(10)}$, $A_{4(20)}$, $A_{5(10)}$, $A_{5(20)}$, the values of which define technical, economic and technical economic parameters of the network. The expressions for all the constants of the target function are given in Table 3.1.

Table 3.1

Constants of the UPSS target function

Nr.	Constants of the target function
1	$A_1 = 1.1 \cdot \Pi_{city} \cdot K_{TS}$
2	$A_2 = 2.1 \cdot K_{ipAL} \cdot \Pi_{city}$
3	$A_3 = 0.84 \cdot K_{TP} \cdot \Pi_{city}$
4	$A_{4(10)} = 3.6 \cdot K_{ipVL} \cdot \Pi_{city}$
5	$A_{4(20)} = 2.53 \cdot K_{ipVL} \cdot \Pi_{city}$
6	$A_{5(10)} = 6.87 \cdot K_{ZL} \cdot \Pi_{city}$
7	$A_{5(20)} = 9.69 \cdot K_{ZL} \cdot \Pi_{city}$

The target functions are non-linear functions with integer variables. A non-linear discrete programming method is applied for the searching of an optimal solution. The optimal solution of the target function meets the condition of the minimum total capital investments: $K_{\Sigma,n}=min$.

The block scheme of 110/10 kV or 110/20 kV TS optimal power determination is given in Figure 3.7 and includes the following basic components for the *n*-th variant of the UPSS realization:

- input data for the obtaining of the results;
- defining of the total capital investments $K_{\sum TS,n}$ and $K_{\sum AL,n}$ for the building of 110/10 kV or 110/20 kV TS and 110 kV cable line for the TS connection to 110 kV network;
- determining of the total capital investments $K_{\sum TP,n}$, $K_{\sum VL,n}$ for the building of 10/0.4 kV or 20/0.4 kV TP with connection correspondingly to 10 kV or 20 kV cable lines;
- determining of the total capital investments $K_{\sum ZL,n}$ for the building of 0.4 kV cable line from 10/0.4 kV or 20/0.4 kV TP to the consumers;
- determination of the total capital investments of the UPSS development variant;
- calculations of the target function minimum $K_{\Sigma,n}=min$ and fixing of optimal power $S_{TS,opt}$.

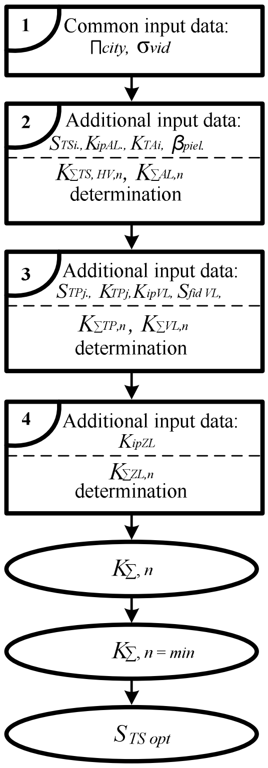


Fig. 3.7. Block diagram for determining of the optimal power of 110/10 kV or 110/20 kV TS

The optimal power of 110/10 kV or 110/20 kV TS is searched by target functions (3.4) and (3.5) with the possible values of the variable parameters in accordance with TS and TP transformers' rated power scale:

$S_{TS,nom}$= 16, 25, 32, 40, 63, 80 MVA;

$S_{TP,nom}$= 0.1, 0.16, 0.25, 0.4, 0.63, 1.0, 1.6 MVA;

and with the variable parameters:

Π_{city}= 74 and 148 km^2;

σ_{vid} = 3, 6, 9, 12, 15, 18, 21, 24 MVA/km^2.

For the determining of the target function constants A_1-A_5 the values of technical and technical economic parameters and factors are assigned n_{tr}, k_{01}, k_{02}, K_{TS}, K_{TP}, K_{ipAL}, K_{ipVL}, K_{ipZL}, λ_{AL}, λ_{VL}, λ_{ZL} (λ – are the factors of the networks configuration) having obtained them from the technical projects or based of the theoretical assumptions.

The optimal solution of the target function is achieved at the minimum total capital investments for UPSS building for the variants system's development.

All the calculations were made with a purposefully developed program in Microsoft Excel environment [9,11] according the block diagram scheme presented in Figure 3.7. The results were obtained changing the initial data and parameters for the power supply system with different areas of the city and their load densities. Analyzing the results of the calculations some most important UPSS parameters are summarized and represented graphically.

Fort the analysis of the urban power supply system it is applied the total capital investments specific parameters per 1 km^2 of the city area.

110-10-0.4 kV and 110-20-0.4 kV specific parameters of the UPSS capital investments per 1 km^2 (Ls/km^2) are calculated according to the expressions:

$$K_{ip\Sigma 110-10-0.4} = \frac{K_{\Sigma 110-10-0.4}}{\Pi_{city}}, \tag{3.6}$$

$$K_{ip\Sigma 110-20-0.4} = \frac{K_{\Sigma 110-20-0.4}}{\Pi_{city}}, \tag{3.7}$$

where $K_{\Sigma 110\text{-}10\text{-}0.4}$, $K_{\Sigma 110\text{-}20\text{-}0.4}$ - are the total capital investments for 110-10-0.4 kV or 110-20-0.4 kV UPSS building.

The optimization calculations for target functions (3.6) and (3.7) at the variable parameters $S_{TS,nom}$ and $S_{TP,nom}$ possible values and assumed parameters Π_{city}=74 km^2 and σ_{vid} =3÷24 MVA/km^2 are given in the form of graph in Figure 3.8. – 3.9.

For example, the 110-10-0.4 kV UPSS total capital investments per 1 km^2 (Ls/km^2) depending on 110/10 kV TS power, using 10/0.4 kV TP with power S_{TP}=2x1000 kVA, are illustrated in Figure 3.8.

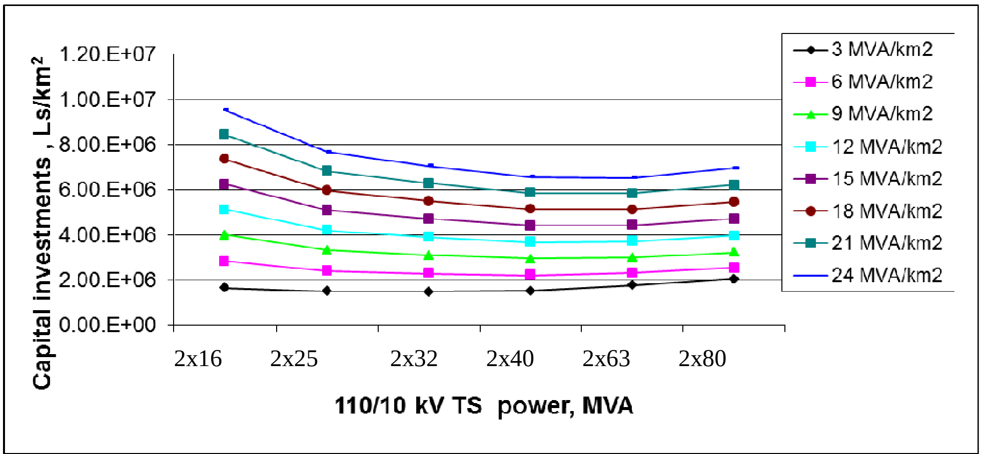


Fig. 3.8. The 110-10-0.4 kV UPSS total capital investments per 1 km^2 (Ls/km^2) depending on 110/10 kV TS power , using 10/0.4 kV TP with power S_{TP}=2x1000 kVA

Analyzing the results presented in figure 3.8 the conclusion can be made that for 110-10-0.4 kV UPSS it is economically profitable to use 110/10 kV TS with power S_{TS}=2x32 MVA, if the load density in the city and its borders is $3 \leq \sigma_{vid} \leq 6$ MVA/km^2, 110/10 kV TS with power S_{TS}=2x40 MVA, if the load density is $6 < \sigma_{vid} \leq 12$ MVA/km^2, and 110/10 kV TS with power S_{TS}=2x63 MVA, if the load density is in the range $12 < \sigma_{vid} \leq 24$ MVA/km^2.

The 110-20-0.4 kV UPSS total capital investments per 1 km ^{2} (Ls/km^2) depending on 110/20 kV TS power, using 20/0.4 kV TP with power S_{TP}=2x1000 kVA, are illustrated in figure 3.9.

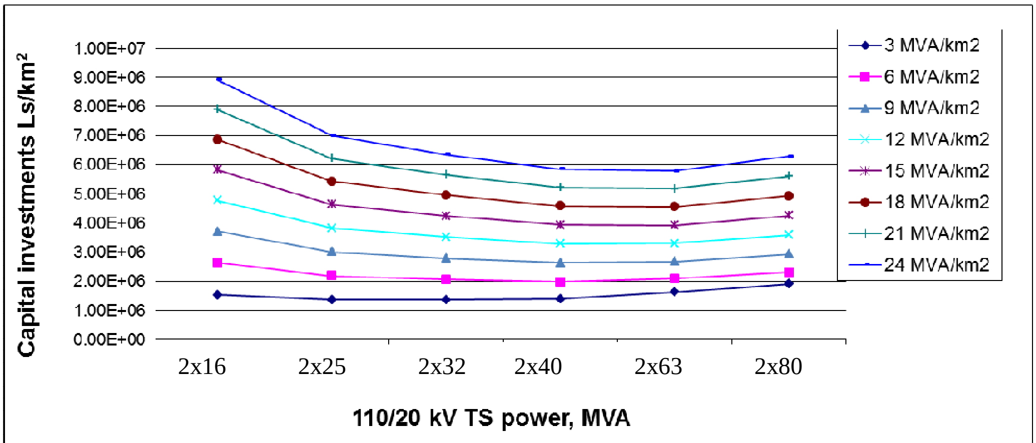


Fig. 3.9. The 110-20-0.4 kV UPSS total capital investments per 1 km^2 (Ls/km^2) depending on 110/20 kV TS power, using 20/0.4 kV TP with power S_{TP}=2x1000 kVA

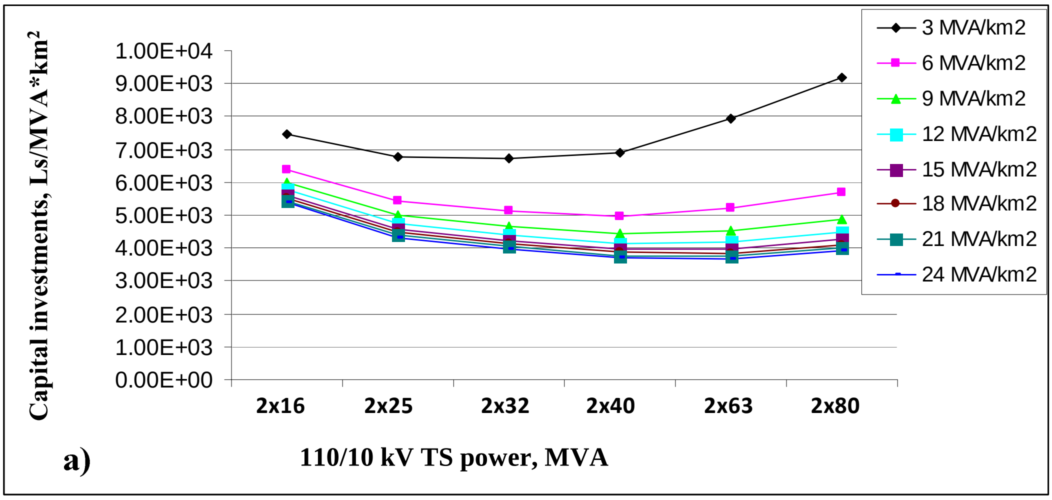
The results in figure 3.9 show that it is economically profitable for 110-20-0.4 kV UPSS to use 110/20 kV TS with power S_{TS}=2x32 MVA, if the load density in the city and its borders is $3 \leq \sigma_{vid} \leq 6$ MVA/km^2, 110/20 kV TS with power S_{TS}=2x40 MVA, if the load density is $6 < \sigma_{vid} \leq 12$ MVA/km^2, and 110/20 kV TS with power S_{TS}=2x63 MVA, if the load density is in the range $12 < \sigma_{vid} \leq 24$ MVA/km^2.

Comparing the results reflected in Figures 3.8.-3.9 the conclusion can be made that at high load densities from $\sigma_{vid} \geq 12$ MVA/km^2 using 20 kV voltage the total capital investments of the electric supply system per 1 km ^{2} (Ls/km^2) do not differ (the difference in less than 5%). It means that with the high load densities ($\sigma_{vid} \geq 12$ MVA/km^2) it is more profitable to use 110-20-0.4 kV urban power supply system as this UPSS has higher network capacity and development opportunities from the technical and economic point of view.
For the higher identification of the optimization results the dependence of the total capital investments on the load density per 1 MVA of the transmitted power and per 1 km^2 of the occupied territory (Ls/MVA ·km^2) has been constructed.
110-10-0.4 kV and 110-20-0.4 kV city electric supply system unified parameters (Ls/MVA·km^2) are calculated according to the expressions:

$$K_{unif\Sigma 110-10-0.4} = \frac{K_{\Sigma 110-10-0.4}}{\Pi_{city} \cdot S_{city}} \quad , \tag{3.8}$$

$$K_{unif\Sigma 110-20-0.4} = \frac{K_{\Sigma 110-20-0.4}}{\Pi_{city} \cdot S_{city}} \quad . \tag{3.9}$$

110-10-0.4 kV and 110-20-0.4 kV urban power supply system unified parameters according to 110/10 kV or 110/20 kV TS power, applying in the distribution network 10/0.4 kV or 20/0.4 kV TP with power S_{TP}=2x1000 kVA, are demonstrated in Figure 3.10.



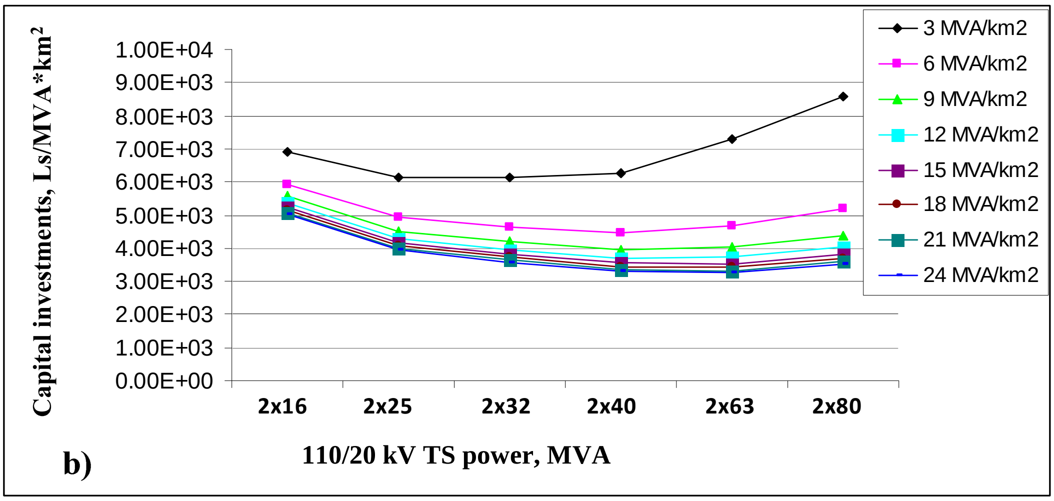


Fig. 3.10. UPSS unified parameters (Ls/MVA·km^2)
depending on TS power applied in the distribution network
a) 10/0.4 kV TP with power S_{TP}=2x1000 kVA;
a) 20/0.4 kV TP with power S_{TP}=2x1000 kVA;

Analyzing the results included into Figures 3.10. a) and b) it is obvious that they prove the conclusions made on the basis of the total capital investments specific values (Ls/km^2) about the transformers rated power application 110-10-0.4 kV and 110-20-0.4 kV in the UPSS. The analysis of the obtained results proves that for existing 110-10-0.4 kV or new 110-20-0.4 kV UPSS, it is economically profitable to use 110/10 kV or 110/20 kV TS with rated power S_{TS}=2x32 MVA, if the load density in the city or its borders is $3 \leq \sigma_{vid} \leq 6$ MVA/km^2, TS with rated power S_{TS}=2x40 MVA, if the load density is $6 < \sigma_{vid} \leq 12$ MVA/km^2, and TS with rated power S_{TS}=2x63 MVA, if load density is within the range $12 < \sigma_{vid} \leq 24$ MVA/km^2.

4. OPTIMAL PARAMETERS OF 10-20 KV NETWORK AND OPERATION REGIMES

4.1. Determination of the 10-20 kV network optimal parameters

During the stage of 20 kV voltage introducing, in the 3rd chapter (Figure 3.3, 1st block of block diagram) the UPSS target functions (3.4) and (3.5) local extreme points were obtained minimizing the function according to variable $S_{TA\,nom,i}$ (at $S_{TP\,nom,i}$ = const) in the range of load density σ=3-24 MVA/km^2 for each optimization cycle (the set of the calculation results R_1 from all the existing solutions R). The minimum of the function corresponds to the determined 110/10 kV and 110/20 kV TS power that optimal for the investigated urban power supply system [9].

The searching for the substation optimal power is an important task but it is only the first stage of the methods of the 110-10-0.4 kV and 110-20-0.4 kV urban power supply system optimal parameters determination. During the second stage of the optimization (Figure 3.3, 2nd block of block diagram) it is necessary to extract in the optimization cycles the minimum from the total capital investments values at $S_{TP\,nom,i}$ = const, that corresponds to the minimum of the target function at variables $S_{TS\,nom,i}$ and $S_{TP\,nom,i}$ at the same time, providing the extension of the task solution segment (the set of the optimization results R_2).

Optimal variables $S_{TS\,opt,i}$ and $S_{TP\,opt,i}$ values with minimum UPSS total capital investments unified parameters form the segment of the target function optimization results (set R_3).

The target function (3.4) and (3.5) optimization process can be generally illustrated as an operation order:

$$\text{The initial set } R \xrightarrow[\text{at } S_{TS\,nom}(S_{TP\,nom}=const)]{optimization,} R_1 \xrightarrow[with\ S_{TP}(S_{TA\,opt})]{optimization} R_2 \xrightarrow[S_{TS\,opt},\ S_{TP\,opt}]{optimization} R_3 \text{ (set of solutions)}$$

Extension of the solution segment during the optimization can be demonstrated also in the form of graph:

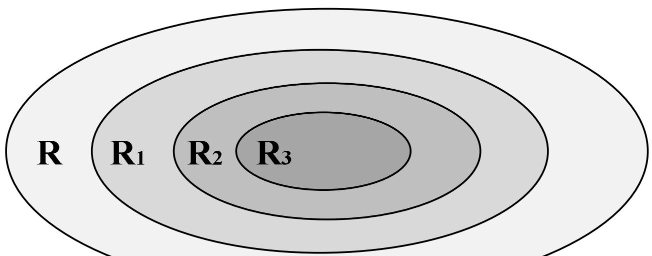


Fig. 4.1. Graphic interpretation of the solution segment extension

All the results of calculations necessary for the analysis during the second stage of the TS and TP optimal power determining have already been realized during the first stage. During the analysis of the results in the 4th chapter UPSS optimal parameters were obtained being presented in Tables 4.1 and 4.2.

Table 4.1

110-10-0.4 kV UPSS optimal parameters within the range of the load density

σ, MVA/km^2	$S_{TS\,opt}$, MVA	$S_{TP\,opt}$, MVA	$K_{\Sigma\ ip,\ min}$, $Ls/\ km^2$	$K_{\Sigma\ unif,\ minmin}$, $Ls/MVA \cdot km^2$
3	2x32	2x0.63	$1.47 \cdot 10^6$	$6.64 \cdot 10^3$
6-9	2x40	2x0.63	$(2.2\text{-}2.95) \cdot 10^6$	$(4.95 – 4.42) \cdot 10^3$
12-15	2x40	2x1.00	$(3.69\text{-}4.42) \cdot 10^6$	$(4.15 – 3.98) \cdot 10^3$
18-24	2x63	2x1.00	$(5.13\text{-}6.53) \cdot 10^6$	$(3.85 – 3.68) \cdot 10^3$

Table 4.2

110-20-0.4 kV UPSS optimal parameters within the range of the load density

σ, MVA/km^2	S_{TS}, MVA	S_{TP}, MVA	$K_{\Sigma\ ip,min}$, Ls/km^2	$K_{\Sigma\ unif,\ minmin}$, $Ls/MVA \cdot km^2$
6-9	2x40	2x1.00	$(1.79\text{-}2.4) \cdot 10^6$	$(4.45 – 3.95) \cdot 10^3$
12-15	2x40	2x1.00	$(3.0\text{-}3.6) \cdot 10^6$	$(3.70 – 3.53) \cdot 10^3$
18-24	2x63	2x1.00	$(4.19\text{-}5.35) \cdot 10^6$	$(3.41 – 3.26) \cdot 10^3$

The obtained during the optimization process UPSS minimum unified parameters $\boldsymbol{K}_{\Sigma\ \boldsymbol{uinf,\ min}}$ graphical dependences on the TP rated power presented in Figure 4.2. From the graphs it is obvious that at the high load densities and high TP preset power 110-10-0.4 kV and 110-20-0.4 kV UPSS unified parameters are approximate similar.

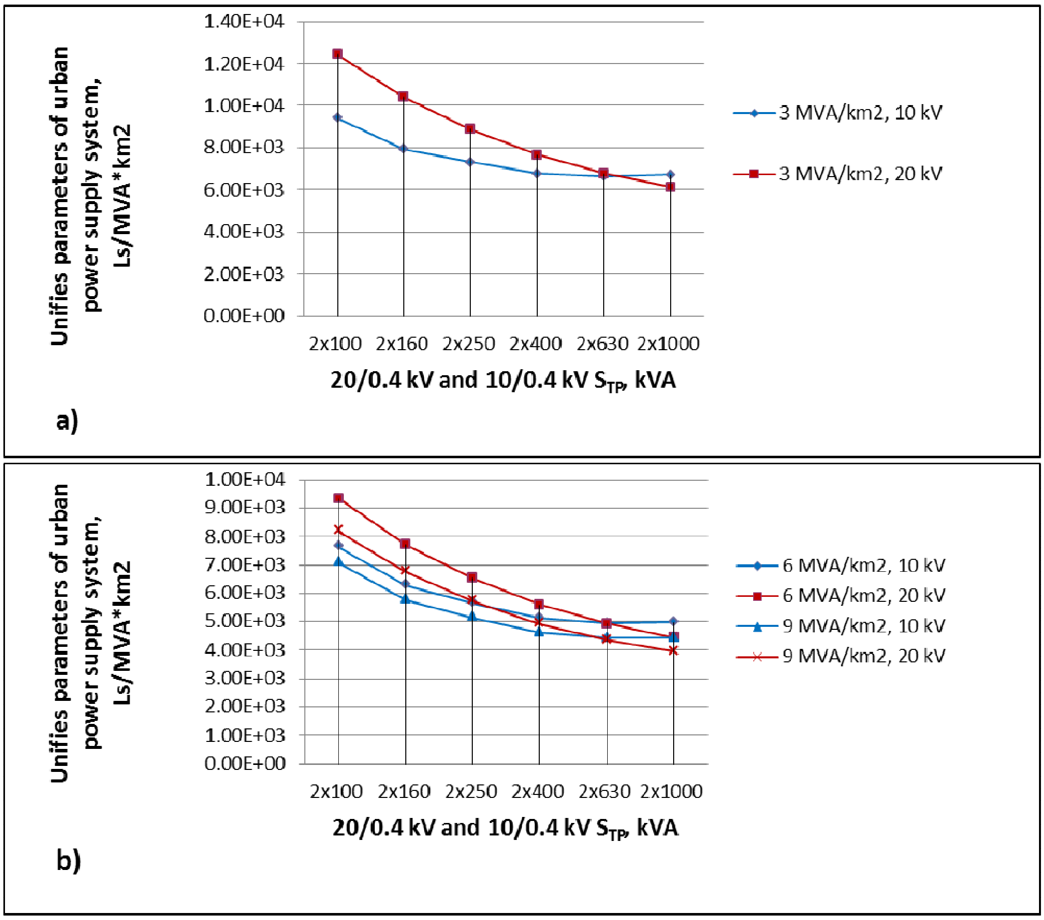


Fig. 4.2. The graphical dependences of UPSS minimum unified parameters on the TP rated power at the load density: a) σ=3 MVA/km^2; b) σ=6-9 MVA/km^2.

The 4th chapter of the Thesis presents the UPSS minimum unified parameters graphical dependences on those of TP rated for the other load density ranges (σ=12-15 MVA/km^2, σ=21-24 MVA/km^2).

The analysis of the calculations and optimization resulted in the obtaining of important UPSS parameters.

Figure 4.4 presents comparatively possible number of 10/0.4 kV and 20/0.4 kV TP in the 110-10-0.4 kV and 110-20-0.4 kV urban power supply system depending on TP power with the city area Π_{city} =74 km^2, 110 kV TS power S_{TS} = 2x40 MVA and load density σ_{vid} = 9 MVA/km^2.

Figure 4.5. represents an overview of the service radius in polar coordinates (in accordance with (3.30)) one TS with power 2x40 MVA at different 20/0.4 kV TP and 10/0.4 kV TP power in the city with load density σ_{vid}=9 MVA/km^2 .

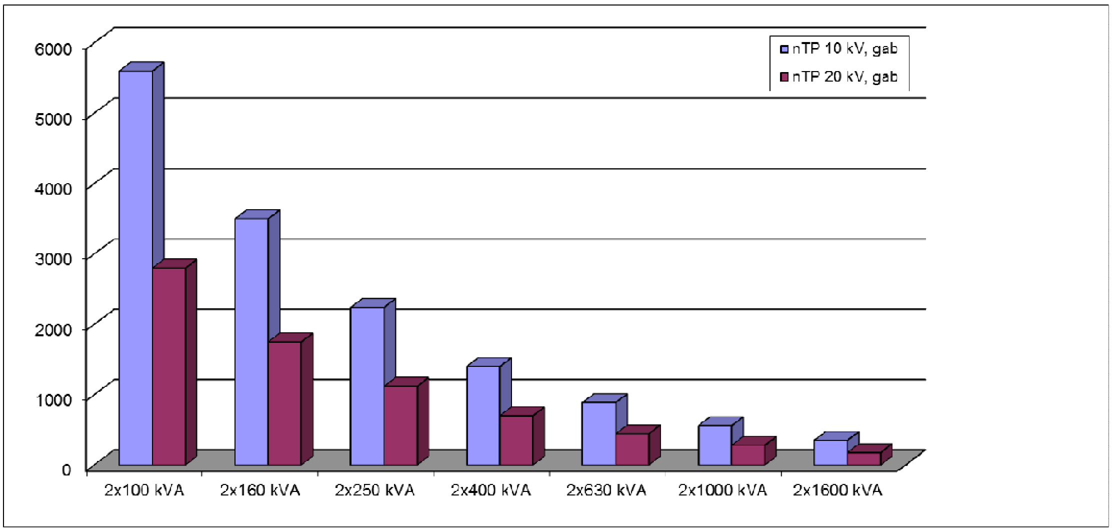


Fig. 4.4. Dependence of the number of 10/0.4 kV and 20/0.4 kV TP in the 110-10-0.4 kV and 110-20-0.4 kV UPSS on the TP power.
(at Π_{city} =74km^2, S_{TS} = 2x40 MVA un σ_{vid}=9 MVA/km^2)

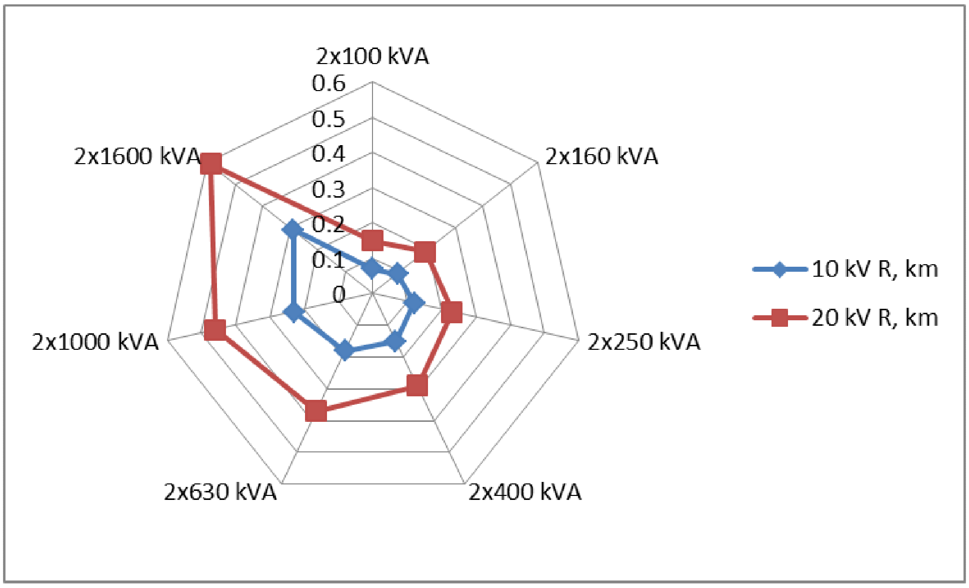


Fig. 4.5. Graph representation of 20/0.4 kV TP and 10/0.4 kV TP service radius of one 2x40 MVA TS at the load density σ_{vid}=9 MVA/km^2

Analysis of the obtained results allows to conclude that in the modern 110-10-0.4 kV urban power supply systems with optimal power TS it is economically profitable to apply 10/0.4 kV TP with power S_{TP}=2x0.63 MVA, if the load density in the city and its borders is $3 \leq \sigma_{vid} \leq 9$ MVA/km^2, TP with power S_{TP}=2x1.0 MVA, if the load density is $9 < \sigma_{vid} \leq 24$ MVA/km^2 ; in the 110-20-0.4 kV UPSS with optimal power TS it is economically profitable to use 20/0.4 kV TP with power S_{TP}=2x1.0 MVA, within the whole assigned load range of the optimization process: $3 \leq \sigma_{vid} \leq 24$ MVA/km^2.

4.2. Analysis and selection of the operation regime of 20 kV network neutral

The solution of the problem of introducing of the 20 kV voltage in Riga city requires the selection of a new operation principle of the 20 kV network neutral. The Thesis overviews all operation regimes of neutrals applied in Riga. The network neutral grounded through an active resistance with low resistivity is considered in more details. This neutral provides the safe operation of the power supply system with high grounding currents that are typical for Riga city. Briefly this regime of the neutral is called „NOSPE" from the German phrase „Niederohmige Sternpunkterdnung" [1].

Using the German and Great Britain experience as well as results of the investigations made in Latvian power system the city 10 kV cable networks will be gradually transformed to low resistive neutral operation regime. Low-resistive neutral equipment consisting of three-winding grounding transformer and grounding resistor R_{ZR} is connected behind the powerful 110/20-10 kV transformer.

Main advantages of low-resistive neutral:

- if the network operates with neutral grounded through low-resistive active resistance then in the case of a damage the increasing of voltage there is the lowest from those existing in the indirectly grounded neutrals of other UPSS (usually the level of voltage in the case of damage is within the range $1.8 \div 3.1 U_f$);
- the principle of the neutral grounding allows to avoid high over voltages and simply define the location of grounding;
- in comparison with the neutral grounded through the compensation coil, NOSPE neutral grounding construction does not depend on the changes of the network length;
- the neutral does not occupy a plug of a middle voltage terminal as it is connected at once behind the terminals of 110/20-10 kV transformer;
- in comparison with other neutral grounding UPSS this one is cheap and easy realized, being very simple in maintaining (the level of oil of the transformer should be tested only) and not requiring permanent service.

Disadvantages of low-resistive neutral:

- it can not be applied in middle voltage air lines and hybrid (CL and OHL) networks without additional safety and relay protective measures because of insufficient potential smoothing [22];
- in comparison with the neutral grounded through the compensating coil the grounding connection can cause higher grounding equipment potential to the ground for a short time that causes the disconnection of the damaged line by the relay protection.
- the network with low-resistive neutral requires relay protection of different UPSS.

The application of NOSPE neutral proved that it is the safest neutral regime in the networks with high grounding currents. In the 110-20-0.4 kV UPSS cable lines the application of the NOSPE neutral grounding regime is necessarily as it allows safe use of the urban power supply system.

4.3. The opportunities of the voltage regulation in 110-20-10-0.4 kV power supply system

During the period of realization of 110-20-0.4 kV UPSS the existing 110-20-10-0.4 kV system remains. Therefore the new system also requires the regulation of the voltage like in the existing one.

At the supply centers of 10 kV as well as 20 kV distribution network the 110 kV transformers with the equipment of voltage regulation with load (RZS) serve as a basic mean for this purpose [5,6,34]. RZS application gives a possibility of automatic switching of the branches during day-night period without disconnection of the transformer from the network changing so the transformer factor under the loading condition and therefore provide coordinated voltage regulation at the supply centre of the distribution network.
Both the existing network and new 20 kV voltage introducing process face the problem of voltage regulation in the 110/20-10 kV three-winding transformers independently on the transformers rated power. Three-phase transformers contain 110 kV higher voltage (HV) winding, 20 kV middle voltage (MV) and 10kV lower voltage (LV) windings, but RZS equipment is included into HV winding. The two winding transformers and those with split windings meet no significant problems with voltage regulation by means of RZS equipment. RZS equipment is installed in HV winding applying modern automatic voltage regulators changing also the voltage in MV winding [2].
In 110/20-10 kV TS three voltage regulation regimes are applied in the Latvian power system.

- ***Stabilization regime.*** This regime usually is applied at 110/20-10 kV substations with 20 kV and 10 kV voltage to which the consumers with irregular load are connected (for example, to 10 kV an industrial load is connected, but to 20 kV – a household load).
- ***Compensation regime.*** Usually the regime is used at 110/20-10 kV substations supplying the powerful consumers with a unified load. The higher load is at the terminals of the transformer the higher is the setup of the voltage regulator.
- ***Day-night regime.*** 110/20-10 kV substation is provided with summer and winter regulation schedules within the day-night loading regime, and in accordance with those the parameters of the voltage regulator are preset. All the voltage regulation automatic equipment of the Riga city 110/20-10 kV TS operates under the condition of day-night loading.

Basic unsolved problems of the existing voltage regulation automation:

- in the three-winding transformers applied in Latvia the voltage can be regulated only according to one secondary voltage. In some cases the 20 kV winding is followed in what voltage-less condition the transformer factor of this winding can be changed regarding to 110 kV winding;
- it is hard to select correctly the regime of the voltage regulation for 110/20-10 kV TS if the loading schedules are different (e.g. 10kV terminals are connected to the industrial load, but 20 kV – household load);
- the voltages of both windings of the transformers with those split are not the same and in practice with uneven load they can differ for 4%;
- it is desirable to regulate the voltage of 110/20-10 kV TS with three-winding transformers by means of two regulators correspondingly at the sides of 20 kV and 10 kV. Latvia still has no transformers with such voltage regulators as it increases the expenses for the 110/20-10 kV transformer;
- quite often the main reason of the automation disconnection thickening of the transformer oil under the condition of poor cooling. The voltage regulator should be able to operate at any possible oil temperature or applying the oil that does not thicken.

The modern voltage regulation equipment should be applied at 110/20-10 kV TS for the simultaneous 20 kV and 10 kV voltage regulation in the 110/20-10 kV transformers windings. This equipment is very expensive and significantly increases the expenses of three-winding 110/20-10 kV transformer. In the 110/20 kV TS and 110/10 kV transformers this problem is absent therefore the standard voltage regulation equipment can be applied in this case.

5. THE ECONOMIC EXPEDIENCY EFFECTIVENESS AND TECHNICAL OPPOTUNITY OF 20 KV VOLTAGE INTRODUCING

5.1. The economic expediency of 20 kV voltage introducing into Riga city power supply system

Each technical measure should be feasible from the technical and economical point of view. The analysis of the economic expediency of the 20 kV voltage introducing into the power supply system of Riga the 110-10-0.4 kV and 110-20-0.4 kV UPSS was carried out were on the basis of the comparison of the variants of UPSS development. Obtained as a result of minimization of the target functions (3.4) and (3.5), the unified total capital investments for the building of the above mentioned system were assumed for the comparison of the technical and economic parameters According to the results of Supplementary 1 the dependence of the unified total capital expenses of UPSS $K_{\Sigma}=f(\sigma)$ on the load density in the city (or its district) is investigated within the range of TS powers S_{TS} = (2x32–2x63) MVA and TP power range S_{TP}=(2x400 – 2x1000) kVA. For the detailed analysis of the dependence the unified total capital expenses for the 110-10-0.4 kV and 110-20-0.4 urban power supply system are compared for the same TS and TP rated power, that is demonstrated in Figure 5.1, a-f .

Analysis of Figure 5.1 results in the conclusions that 110-10-0.4 kV UPSS with 110/10 kV TS with power S_{TS} =(2x32–2x63) MVA and 10/0.4 kV TP with power S_{TP} =2x400 kVA is economically more profitable than 110-20-0.4 kV UPSS with similar power 110/20 kV TS and 20/0.4 kV TP within the whole range of the load density with present prices for building of network of network and installations.

The economic parameters of 110-10-0.4 kV and 110-20-0.4 kV UPSS, applying 110/10 kV TS or 110/20 kV TS with power S_{TS} =(2x32–2x63) MVA and 10/0.4 kV or 20/0.4 kV TP with power S_{TP} =2x630 kVA, are practically similar within the whole range of investigated load density. In fact these are the boundary values for the transition from 110-10-0.4 kV UPSS to 110-20-0.4 kV UPSS [6].

110-20-0.4 kV UPSS with 110/20 kV TS with power S_{TS} =(2x32–2x63) MVA and 20/0.4 kV TP with power S_{TP} =2x1000 kVA is economically more profitable than 110-10-0.4 kV UPSS with similar power 110/10 kV TS and 10/0.4 kV TP within the whole range of the load density.

Taking into account the dependences in Figure 5.1. and results of table 4.2. 110-20-0.4 kV UPSS is economically feasible starting with load density $\sigma \geq 12$ MVA/km^2 at 110/20 kV TS with power S_{TS}=(2x40–2x63) MVA and 20/0.4 kV TS with power S_{TP}=2x630 kVA with present prices for building of network and installations.

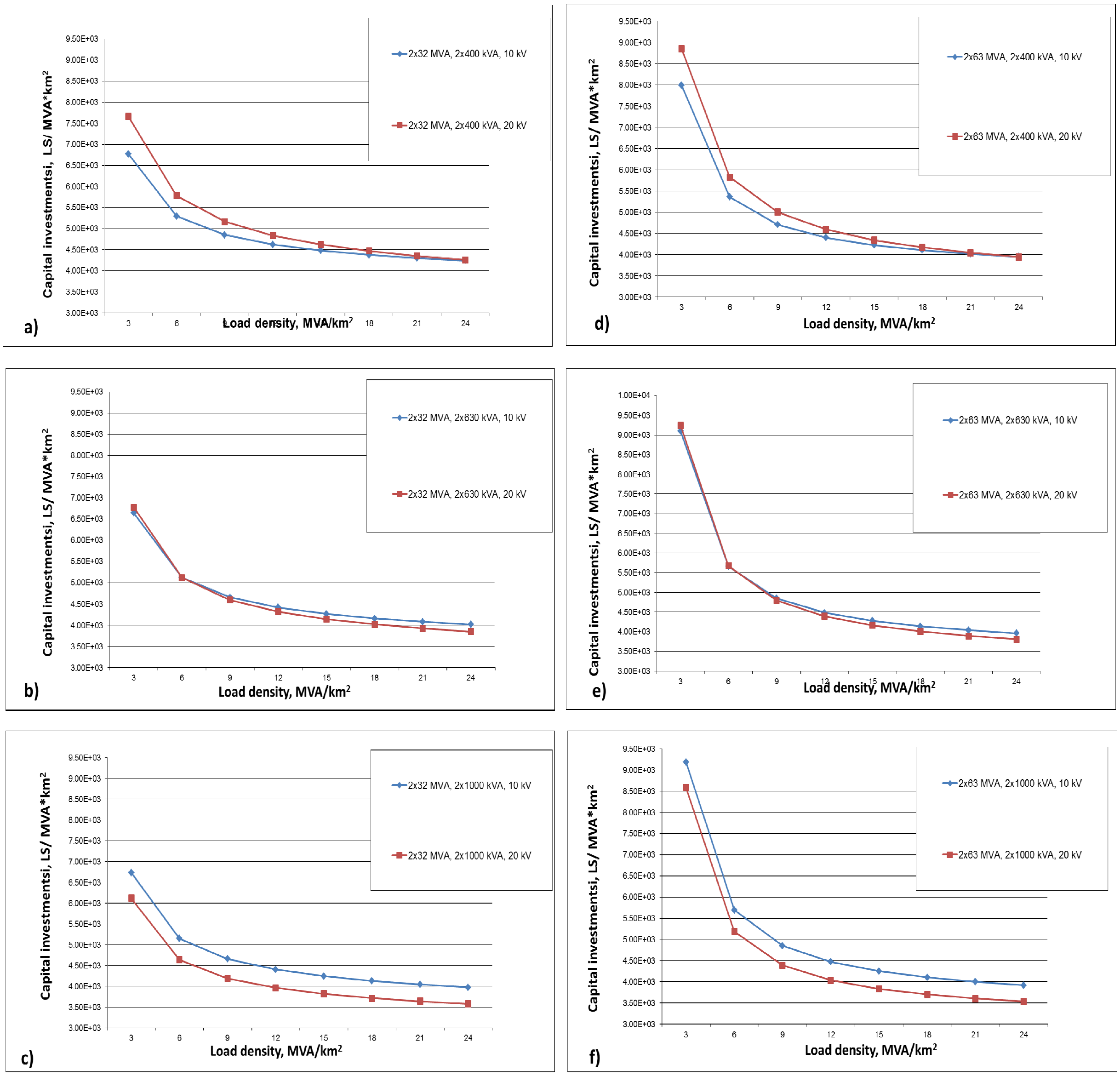


Fig. 5.1. 110-10-0.4 kV and 110-20-0.4 kV UPSS unified total capital expenses (Ls/MVA*km^2) in the dependence on the load density, using
110/10 kV or 110/20 kV TS with power S_{TS}=(2x32–2x63) MVA and
10/0.4 kV or 20/0.4 kV TP with power S_{TP} =(2x400–2x1000) kVA

5.2. Technical measures for 20 kV voltage introducing

5.2.1. Features of the proposed "dual-beam" scheme of 20 kV and 0.4 kV network

Developing a new circuit with new level of rated voltage it is of top importance to select correctly the topology of supply and distribution network and to provide further development of this circuit. For the regular reserve at the side of 20 kV voltage the most complicated problem is not enough number of 110/20 kV TS at the borders of Riga, already really applying 20 kV voltage, and absence of 110/20 kV TS in the centre of the city. In the new 20 kV networks the safest and most effective from the safety point of view are those of double-leg topologies. The proposed and developed 20-0.4 kV ideal "dual-beam" power supply scheme of 110-20-0.4 kV UPSS is shown in Figure 5.2.

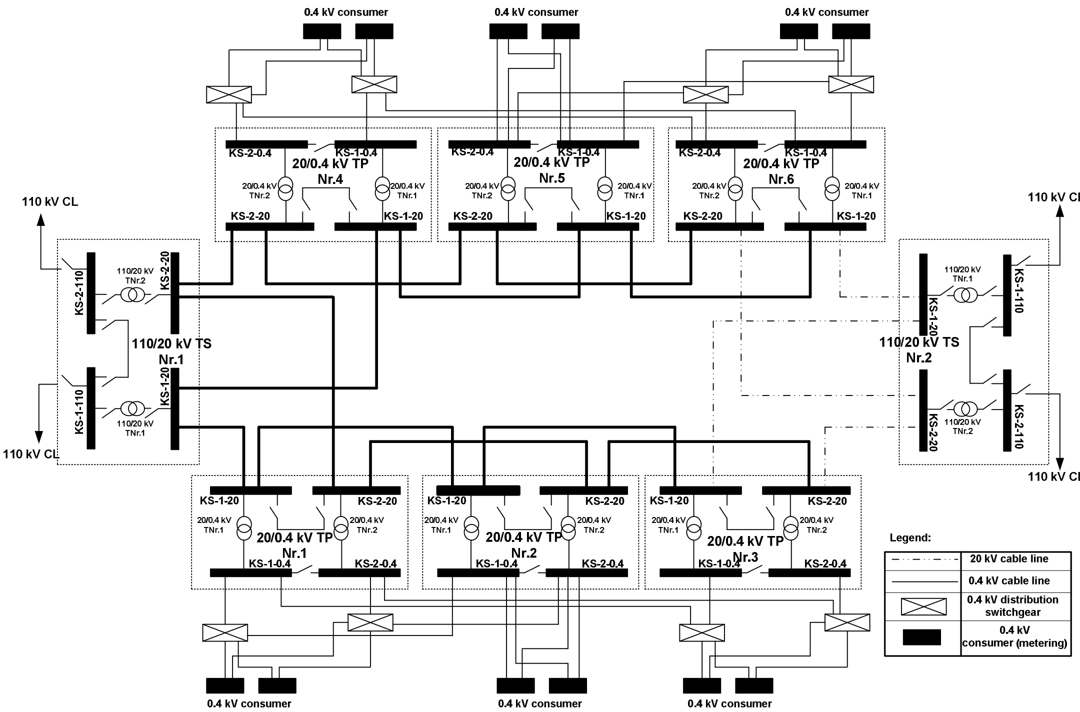


Fig. 5.2. Ideal "dual-beam" power supply scheme of 110-20-0.4 kV UPSS

The advantages of “dual-beam” scheme:

- the scheme is very safe from the power supply point of view as there is a reserve of middle voltage line from 110/20 kV TS, TP transformers as well as low voltage 0.4 kV network reserve. It means that with one damage of transformer or supply cable the consumers will not remain without voltage as it will be provided through the second circuit;
- at the 20 kV as well as 0.4 kV sides so called section circuit breakers are installed: at the 20 kV side - with the help of load switches, at the side of 0.4 kV with the help of fuses without any automation (ARI);
- the scheme allows without special problems the transit connection of low powerful consumers (single-transformer 20/0.4 kV TS with transformer till *S=630 kVA*), introducing 20/0.4 kV TS into one of the supply cables;
- the reserve 110/20 kV TS if necessary can distribute 20 kV at the joint points of the supply line to decrease the length of the lines and consequently losses of voltage, power and energy.

The disadvantages of “dual-beam” scheme:

- it is expensive enough and complicated in its construction as “dual-beam” scheme has two supplying cables from one or two 110/20 kV TS and two 0.4 kV lines form 20/0.4 kV TP;
- for the improvement of the safety of the “dual-beam” scheme it is undesirable to lay the 20 kV cables between 110/20 kV TS and 20/0.4 kV TP into one trench in 0.2 m distance one from another; but at least for 1.0 m to avoid a mechanical damage of the cable that is not realized in practice because of the high cost of the excavation and road surface renovation works.

5.2.2. The opportunities to purchase the110/20 kV two-winding transformer

For the new 110-20-0.4 kV urban power supply system the 110/20 kV two-winding transformers should be used. Nowadays the Latvian power supply system applies three-winding 110/20-10 kV or 110/20-6 kV transformers of different producers but the number of 110/20 kV two- winding transformers is insignificant. The paper overviews the technical parameters of

110/20 kV transformers of different power form the handbooks of the producers and Internet web pages. Taking into account that today the high-power transformers are made to order their technical parameters can differ [6,8].

5.2.3. Application of the middle voltage commutated transformers

During the period of 20 kV voltage introducing at the places where supply voltage is 10 kV and it should be kept the commutated 20-10/0.4 kV transformers being able to operate at 10kV as well as 20 kV network voltage can be applied. In this case a significant simplification can be provided for the transition from 10 to 20 kV and the number of the consumers disconnections is decreasing. If to compare with the standard of 10/0.4 kV transformers they are 30% more expensive but do not almost differ in size that also significantly simplifies their application in compact TS as well as those of mast type and TS of close-type.

5.2.4. The experience of 20 kV voltage switchgear equipment application in the networks

A very important step in the 20 kV voltage introducing is the application of 20 kV switchgear (RMU – ring main unit) at all the compact, close-type and mast type 10/0.4 kV transformers substations at 20 kV operation voltage. The promotion paper overviews in details the type of the switch gears applied in Latvia, as well as their advantages and disadvantages [29].

5.2.5. Medium voltage cables with polyvinyl chloride (XLPE) insulation

The medium voltage cables with XLPE insulation suitable for application in 110-20-0.4 kV UPSS are widely overviewed in the paper. The constructive type of the cable, its admissible current and area of application are in details considered in the work. The experience of the exploitation and technical parameters of the cables results in the conclusion that 20 kV cables can be successfully applied even at 10 kV to simplify the further transition to the 20 kV level.

5.3. Technical and economic justification of the proposed 110/20 kV TS

It is of top importance already at the initial stage of the project to select correctly the constructive model of 110/20 kV TS and its location that is problematic enough due to the high building density of Riga and private territories.

From 1991 five 110/20-10 kV TS are built in Riga: 110/10 kV TS „Bastejkalns”, 110/10 kV TS „Hanza”, 110/10 kV TS „Zunda”, 110/20-10 kV TS „Zolitude”, 110/10 kV TS „Matiss”. All the TS mentioned above are of close type with 110 kV KL inputs, 110 kV GIS (gas insulation switchgear), 110/20-10 kV transformers. 20-10 kV and all the relay protection (RP) and direct current (DC) equipment is protected from the outside impacts. The constructive models and operation circuits of all the TS developed from 1991 are analyzed. As the result of this analysis the construction of 110/20 kV TS is selected, the operation schemes and the variants of the perspective substations connection/switching are proposed in the paper.

The author proposes the 110/20 kV TS of closed type with two 110/20 kV transformers with split windings and two 20 kV sections. If necessary (in the case of load increasing) the number of sections of TS average voltage can be extended to four. The 110/20 kV TS neutral grounding regime is NOSPE. The principal scheme of the proposed 110/20 kV transformer substation is shown in Figure 5.3.

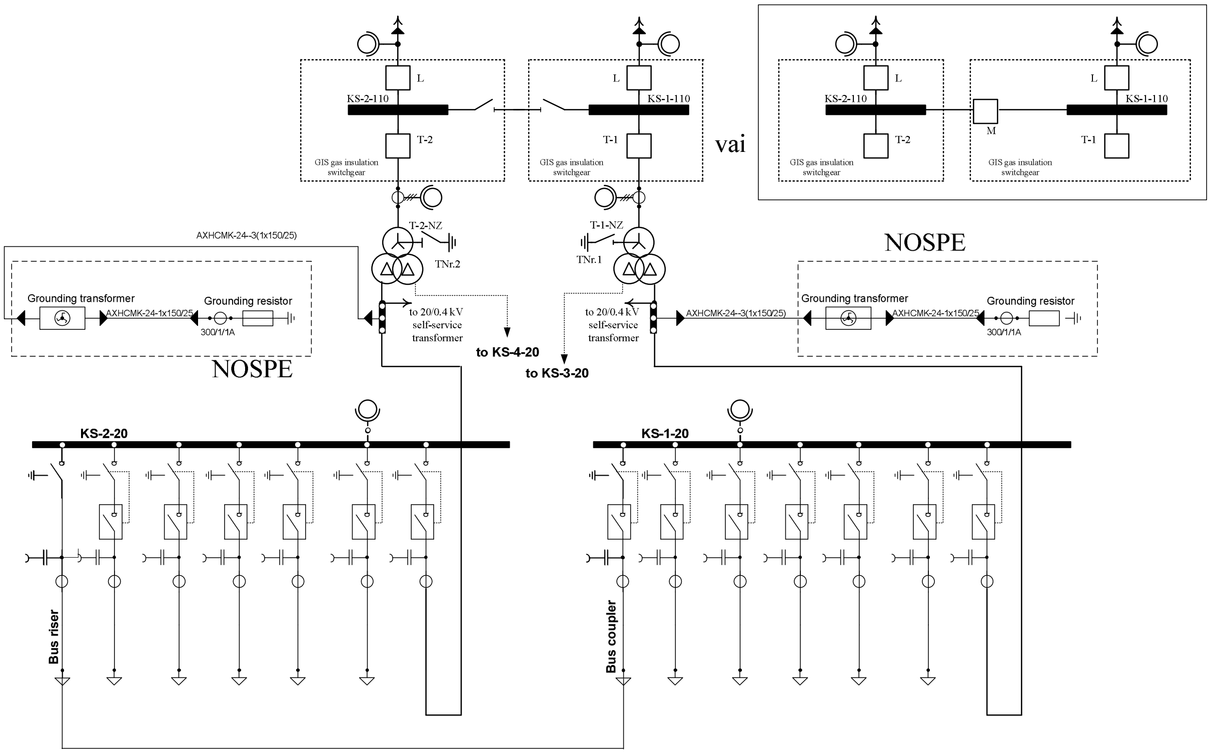


Fig. 5.3. The principal scheme of the proposed 110/20 kV TS

The prices for the 110/20 kV TS building depend on the equipment especially at the 110 kV side. Using so called GIS the prices of the 110 kV switchgear are automatically 2 times increased. Similarly at the side of the middle voltage: gas insulated switchgear is 1.5 times more expensive than those air insulated.

The prices defined for the building of 110/20 kV TS with 2x32 and 2x63 MVA transformers in accordance with the scheme in Figure 5.3 are reflected in Table 5.1 [15].

Table 5.1.

Approximate prices of the 110/20 kV TS building

Nr.	Item of the equipment	Prise, Ls
	110 kV side	
1.	Power transformer with S_{TS}=2x32 MVA, S_{TS}=2x63 MVA	2x(700·10^3), 2x(850·10^3)
2.	GIS equipment	2x(800·10^3)
3.	RP and configuration	1x(10·10^3)
4.	Power transformer installation with S_{TS}=2x32 MVA, S_{TS}=2x63 MVA	2x(100·10^3) 2x(150·10^3)
	20 kV side	
5.	terminals of 20 kV switchgear output line	12x(1.5·10^3)
6.	terminals of the 20 kV switchgear transformers and section circuit breakers	4x(2.0·10^3)
7.	Former of the low resistive neutral	2x(2.0·10^3)
8.	Auxiliary transformers	2x(1.0·10^3)
9.	20 kV DC equipment (rectifiers, accumulative batteries, etc.)	1x(2.0·10^3)
10.	RP and configuration	1x(10·10^3)
11.	110/20 kV TS building and improvement	2500·10^3
	Total: with S_{TS} =2x32 MVA with S_{TS} =2x63 MVA	**5754·10^3, 6154·10^3**

In accordance with the information of AS "Sadales tikls" RPR the building price of one of the previously fully built TS of closed type of 110/10 kV TS "Matiss" with power S_{TS} = 2x32 MVA totally with 110 kV and 10 kV switchgear was $5600 \cdot 10^3$ Ls. In addition that fact should be taken into account that this 110/10 kV TS has quite complicated and non-standard constructive model: KS-1-10 and KS-2-10 sections are located on the ground floor, KS-3-10 and KS-4-10 on the first floor. This price does not include the expenses for the 110/10 kV TS "Matiss" connection to the middle voltage network that were $400 \cdot 10^3$ Ls.

5.4. The examples of the 20 kV voltage introducing in Riga and its suburbs

The conception of 20 kV supply voltage introducing into the networks described in chapter 3 and 4 of the promotional paper is applied in the elaboration of perspective 110/20 kV substations and 20/0.4 kV networks as possible variants for the development of the Riga city power supply system. With the high building density in the centre of Riga and because of the disadvantages of 110/20 kV substations the gradual introducing of 20 kV supply voltage can be started from the borders of the city and suburbs where at some places the 20 kV network exists. The paper proposes and overviews some solutions for the 110/20 kV substations, their connection to 110 kV network, selection of new power of TS and other problems related to the development of power supply system and further transition to 110-20-0.4 kV system. Marupe region (close to the borders of Riga city), a new planned residential area „Rumbula" and Dreilini region are selected as those where the theoretical ideas of the work can be applied [7,24].

Three examples of the 20 kV voltage introducing in Riga and its suburbs are described in the promotional work: solutions for Marupe, Dreilini and Rumbula power supply where soon introducing of 20 kV supply voltage is planned.

GENERAL CONCLUSIONS

1. The urban power supply system of a large city like Riga should be economically effective, safe, flexible and ready to supply existing and new consumers at any instant.
2. Conception of 20 kV voltage introducing in Riga power supply system is developed.
3. General technical and economic models and correspondent target functions of 110-20-0.4 kV and 110-10-0.4 kV urban power supply systems are developed.
4. The optimization of UPSS target functions (3.4) and (3.5) are made with non-linear discrete programming method and purposefully developed program in Microsoft Excel environment.
5. In the work 110/20 kV TS and 20/0.4 kV TP or 110/10 kV TS and 10/0.4 kV TP optimal power and optimal UPSS technical and economic parameters within the load density range σ = 3-24 MVA/km^2 at the assumed prices are defined (Tables 4.1, 4.2).
6. The feasibility study of the 20 kV voltage introducing into the Riga city power supply system is considered and analyzed as well as the load density ranges at which 110-20-0.4 kV UPSS is substantiated are defined.
7. The proposals for the 110-20-0.4 kV UPSS introducing and the technical measures are developed.
8. The 110/20 kV TS constructive model is substantiated and technical and economic evaluation of it is made, TA and 20-0.4 kV principal schemes are synthesized, the operation regime of the neutral is selected and the opportunities of the voltage regulation are analyzed.
9. Developed 20 kV voltage introducing conception and optimal parameter selection's methods can also be used in other cities, making the necessary adjustments to the circumstances.

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