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Integrated Approach to the Formation of Service Areas for Urban Substations of Different Voltage

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Abstract: UPSS (urban power supply system) is a part of the region or the state power supply system. UPSS development is closely connected with region power supply system development as a whole. The decision of questions of long-term and middle-term planning of UPSS development occurs in the conditions of incompleteness and uncertainty of the initial information. Nevertheless in these conditions the acceptance of development strategy should be based on perspective electric loads of urban TS (transformer substations). There are difficulties with a rational placement of substations in the city with the developed infrastructure. Such problem by theoretically grounded approach to rational formation of UPSS is solved. The hierarchical structure of the organizational construction, voltage levels and load densities is considered. The mathematical and geometrical modeling of service areas for transformer substations of different voltage is fulfilled. The method of graphic placement of transformer substations in the city territory for new substations at existing structure of networks is offered. The aim of the work is to present the new uniform approach which allows finding a rational decision for new substations' placement in cities with developed infrastructure on the beginning design stages in conditions of the information uncertainty. The calculation program Microsoft EXCEL and the graphic program AutoCAD are used for realization of method.

Key words: Power system, load density, voltage level, urban substations.

1. Introduction

The main tasks of UPSS (urban power supply system) are providing the required quantity and quality of electricity to consumers, the high reliability of power supply and the possibility of further network's development without radical reconstruction of existing networks.

Despite the fact that UPSS is objects of continuous development, it is necessary to solve tasks of long term and middle term design for progress strategy's and its realization of measures' choice.

Solving the problems of development on such a prospect is not accurate background information and detailed guidelines projected subjects. It means that challenges of development occur in conditions of incomplete and uncertain information.

To perform the main task and ensure normal functioning, the UPSS of the city and its subsystems must have a rational construction of networks' power supplies. The important role in the rational construction of separate subsystems has the correct placement of high-voltage TS in the territory of the city as power supply sources for networks of different voltage [1-6]. Working out of scientifically well-founded approach to a choice of urban TS powers and places for new substations is necessary.

In this work theoretical and practical approach to solving few problems of 110/10-20 kV network development of Latvian largest city (Riga) for the future 10 years (till 2020) is considered.

2. System Approach to the Formation of UPSS

The UPSS has a hierarchical structure of network's

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voltages and formation. Every UPSS is formed historically with a certain hierarchy of voltages. The hierarchical structures of formation and voltages of the UPSS are presented schematically in Fig. 1 for the largest Latvian cities [2, 4, 7].

This system is stages of hierarchical structure or subsystems: the external supply system of the city with voltage 330 kV and higher, the internal supply system with voltages 110-20-10-0.4 kV and the aggregate of urban consumers.

The formation of UPPS all subsystems must comply with uniform principles of system approach [3]. Then it will ensure the rational development of individual subsystems and the system as a whole.

As united approach for service areas' formation of TS, different voltage is used its geometrical modeling. To realize the approach geometrical models are advised—templates of hexagons. The ideal model of networks' feeding centers' service areas for different voltages, when it is new power of supply system's construction, is presented in Fig. 2.

TS service areas $\Pi_{TS,ij}$ depend on its power and load density in service area. The load density is very important indicator for definition of network's parameters. It is offered to use geometrical templates in the correct hexagon's form for division of city territory or its separate areas into zones service TS of any voltage. Templates' sizes for different voltages' TS submit to strict mathematical correlations and are notable for value for load densities' different levels [7-10].

$$\Pi_{TS,ij} = 2.6 \times R_{ij}^2 = \frac{n_i \times \beta_i \times S_{r,i}}{\sigma_{ij}} \quad (1)$$

$$R_{ij} = 0.62 \times \sqrt{\Pi_{TS,ij}} = 0.62 \times \sqrt{\frac{n_i \times \beta_i \times S_{r,i}}{\sigma_{ij}}} \quad (2)$$

$$A_{ij} = 1.1 \times \sqrt{\Pi_{TS,ij}} = 1.1 \times \sqrt{\frac{n_i \times \beta_i \times S_{r,i}}{\sigma_{ij}}} \quad (3)$$

$$\sigma_{ij} = k_{0j} \times \sigma_{j-1} \quad (4)$$

where n_i is quantity of transformers at i-th TS;

β_i is the load factor of the transformer at i-th substation;

$S_{r,i}$ is the rated power of transformers in the i-th substation, MVA;

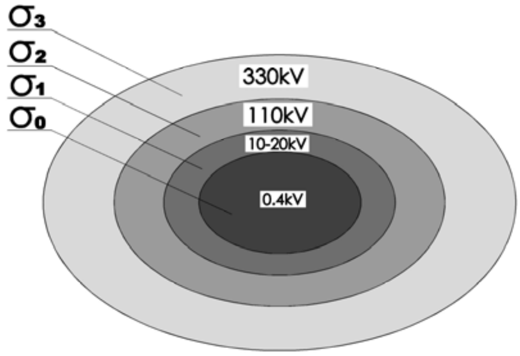

Fig. 1 UPPS hierarchy of voltage levels and load densities.

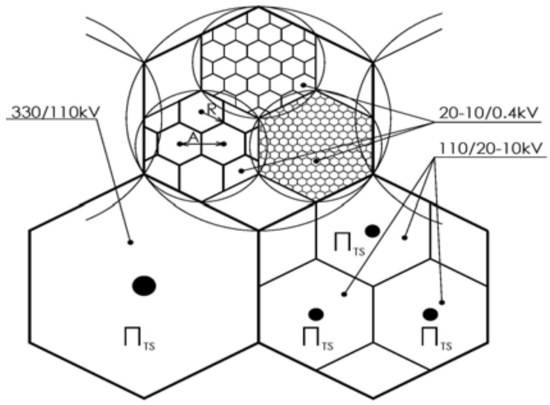

Fig. 2 The ideal model of service areas for TS of different voltage levels.

σ_{ij} is load density in service area of i-th TS at level j of voltage hierarchy, MVA/km^2;

$\Pi_{TS,ij}$ is service area of i-th TS, km^2;

R_{ij} is the radius of service area of i-th TS (also the side of a hexagon and the radius of the circle described around the hexagon), km;

A_{ij} is the theoretically minimum distance between the neighboring substations, km;

k_{0j} is the factor of TS maximum load's simultaneity at j voltage level in the maximum of power system, depending on the TS number in network of j voltage level.

If TS optimum powers for different load densities are determined, then in accordance with Eqs. (1)-(4) the optimum sizes of templates will be calculated. For existing TS the service area's and its radiuses corresponding to established TS powers are defined and have different quantities.

The obtained correlations enable to calculate the TS service areas' radiuses and service areas. Dependences give the chance to compare a range of change of radiuses of service TS of different voltage. For instance, in Figs. 3-5 dependences of admissible service areas' radiuses from load density for TS are resulted with the accepted transformer load factor $\beta = 0.5$.

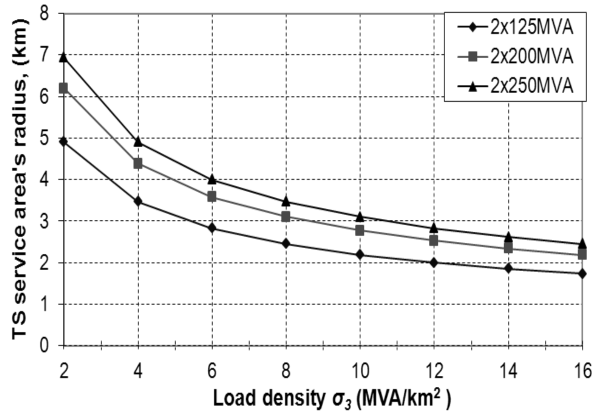

Fig. 3 Admissible TS service area's radius R_i from load density σ_3 for 330/110 kV two-transformer substations.

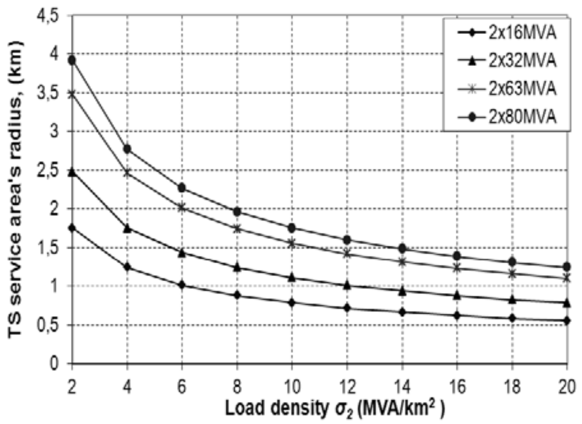

Fig. 4 Admissible TS service area's radius R_i from load density σ_2 for 110/10-20 kV two-transformer substations.

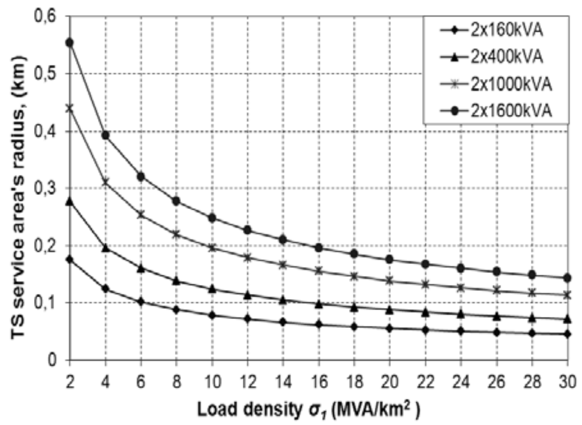

Fig. 5 Admissible TS service area's radius R_i from load density σ_1 for 10-20/0.4 kV two-transformer substations.

In Figs. 6-8 dependences of admissible service areas from load density for TS are resulted with the accepted transformer load factor $\beta = 0.5$.

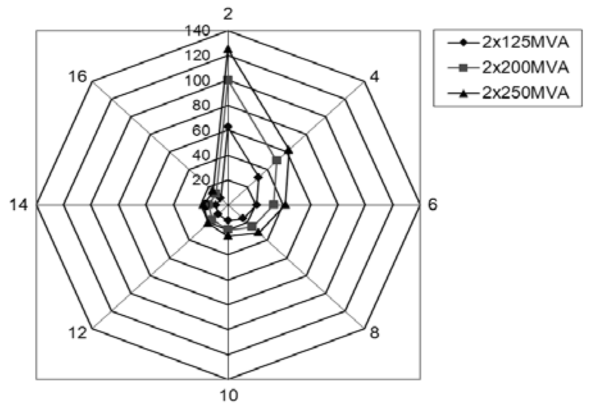

Fig. 6 Admissible TS service area $\Pi_{TS,ij}$, km^2, from load density σ_3, MVA/km^2, for 330/110 kV two-transformer substations in polar coordinates.

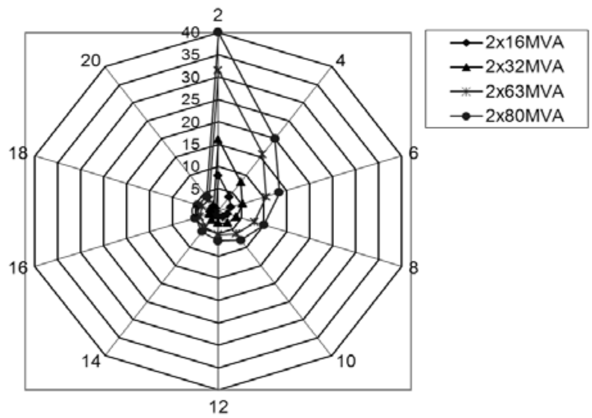

Fig. 7 Admissible TS service area $\Pi T_{S,ij}$, km^2, from load density σ_2, MVA/km^2, for 110/10-20 kV two-transformer substations in polar coordinates.

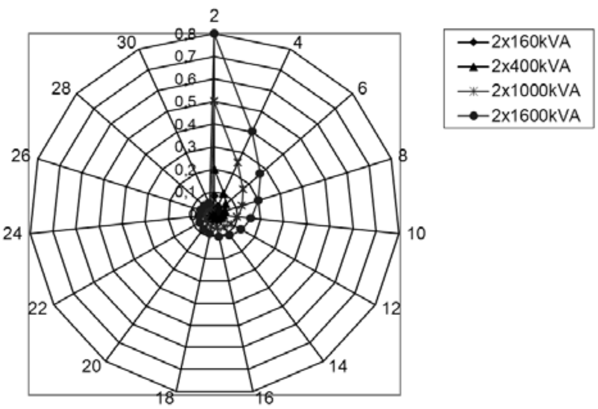

Fig. 8 Admissible TS service area $\Pi_{TS,ij}$, km^2, from load density σ_1, kVA/km^2, for 10-20/0.4 kV two-transformer substations in polar coordinates.

If new consumers appear in TS service areas, then it causes TS load's and load density's increasing in these TS service areas. There are some possible methods for TS additional electrical load's compensation:

(1) Transformer load factor's forced increasing

TS load increasing, due to new consumers, causes transformer load factor's forced increasing. This prolongs till load factor's limited values. If TS electrical load's growth is proportional to load density's growth, then TS service area is constant and is saved in the same boundaries:

$$\Pi_{TS,ij} = \frac{S_{TS,ij} + \Delta S_{TS,ij}}{\sigma_{ij} + \Delta\sigma_{ij}} = \frac{n_i\,(\beta_i + \Delta\beta_i)\cdot S_{r,i}}{\sigma_{ij} + \Delta\sigma_{ij}} = const \tag{5}$$

(2) Transformer's change to greater rated power in one or in several TS

TS electrical load's increasing is possible to compensate with additional transformer power, if change transformers are greater rated power in one or in several TS.

$$\Pi_{TS,ij} = \frac{S_{TS,ij} + \Delta S_{TS,ij}}{\sigma_{ij} + \Delta\sigma_{ij}} = \frac{n_i \cdot \beta_{kor,i} \cdot (S_{r,i} + \Delta S_{r,i})}{\sigma_{ij} + \Delta\sigma_{ij}} \tag{6}$$

(3) Transformers' increasing number

TS electrical load's increasing is possible to compensate with transformers' number growth in one or in several TS.

$$\Pi_{TS,ij} = \frac{S_{TS,ij} + \Delta S_{TS,ij}}{\sigma_{ij} + \Delta\sigma_{ij}} = \frac{(n_i + \Delta n_i)\cdot\beta_i \cdot S_{r,i}}{\sigma_{ij} + \Delta\sigma_{ij}} = const \tag{7}$$

(4) New TS building

If all methods of additional electrical load's covering are used, however, it can not be compensated, then it is necessary to increase quantity of substations, i.e. building of one or several new substations that new TS afresh divide neighboring TS loads. If city covered area does not change, then its territory is:

$$\Pi_{city} = \sum_{i=1}^{n_{TS}+\Delta n_{TS}} \Pi_{TS,ij} = const \tag{8}$$

According to the accepted geometrical model (Fig. 2), the service areas of future TS in the hexagon's form are replaced in the masterplan of city (dashed hexagons in Fig. 9). The service areas of the existing substations are replaced by equivalent of service areas in the hexagon's form (continuous lines in Fig. 9). It is necessary to execute because real service areas are unequal complex geometries even for service areas with the same load density. Such complex geometric shapes are not amenable to analyze changing of service areas with load density's increasing or decreasing. It leads to a lack of united approach to the network's formation and complicates the analysis of TS service areas' change with load growth. When the load density varies, TS service areas and radiuses also automatically change. For example, if load density increases, the service area shrinks (Figs. 6-8).

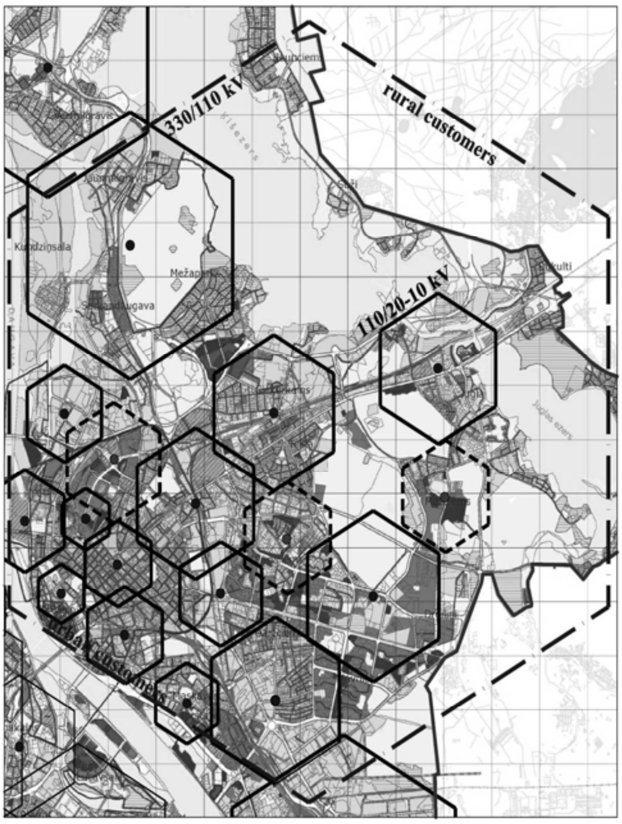

Fig. 9 Existing and possible new TS location in the masterplan of city considering a task of middle-term planning of the city's development.

In consequence of this service area for future TS appears. Therefore, load redistribution should be carried between the existing and perspective substations. For automation of calculations and placing of templates in the masterplan of city (Fig. 9) the computer program Microsoft EXCEL and graphical program AutoCAD are used [7, 11].

3. Conclusions

(1) The scientifically well-founded approach to the formation of TS urban power supply system in solving of development problems is offered;

(2) The geometrical modeling of transformer substations service areas in view of correct hexagons is fulfilled for TS of different voltage;

(3) The templates for placement of TS by any voltages in the city territory are developed and theoretical expressions for templates' sizes for 110/10 kV TS are created;

(4) TS service area's common approach makes it possible to solve network's development task on early project stage: to define power's TS service areas and soundly it divide in covered area of city;

(5) The computer programs Microsoft EXCEL and AutoCAD to automate the process of calculations and arranging the service area at the masterplan of the city are used;

(6) If new information appears in development's calculation period, then it is possible to correct TS service area and its' division in the plan of city.

Acknowledgments

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