Optimal Parameters of Load-Center Supply System for Peripheral Districts of Big Cities

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Abstract — This paper is devoted to the analysis of parameters of a city power supply system, which is performed using a high voltage load-center supply system, taking into account modern tendencies of development of big cities. A distinguishing feature of modern society development is a constant growth of a number of big cities and their population, as well as development of power supply for both utilities and industrial area. Such a development of cities and utilities goes along with significant growth of power consumption which requires new power sources. It's essential to foresee the construction of power sources such as high voltage load-center supply systems (LCSS). It was created a unique topology and techno-economical model of the load-center supply system for peripheral districts of big cities. Based on the formed techno-economical model it was carried out a techno-economical analysis of the load-center supply systems feasibility and optimization of its parameters. Results of the research and their analysis are shown in the presented article. The load-center supply system is a compulsory element of the power supply systems of big cities. In addressing the optimal implementation of the power supply system in peripheral areas of large cities it is required examination of the topological characteristics of the districts and the schemas of their power supply. The obtained results allow us to make decisions for the construction of a load-center supply system for peripheral districts of the city, and also to choose the optimum site for the construction of the load-center substation regarding to the power source.

Keywords — Load-centre supply system, techno-economical model, power supply systems, topological characteristics.

I. INTRODUCTION

A distinguishing feature of modern society development is the constant growth in the number of big cities and their populations, as well the development of power supply to both utilities and industrial area. Such development of cities and utilities sees an accompanying significant growth of power consumption. For example, in Moscow from 2000 to 2010 the power consumption increased from 38 to 53 bn. kWh, and according to forecasts by the year of 2025 it can reach 96 bn. kWh. [1]

Such high consumption growth rates require new power sources. It's obvious that it's a significant problem to build new power plants within the city boundaries. It is also not quite possible to transmit the required amount of electric power from the remote sources to consumers through 10-20 kV grid. That's why it's essential to foresee the construction of power sources such as high voltage load-center supply systems (LCSS). This fact leads to the necessity of researching economically the efficient construction of load-center supply systems as well as defining and calculating their parameters.

In the precedent research examples [2-6 etc.] mainly LCSSs involved into city centers were examined. But under the modern conditions of expansion of city territories the construction of LCSSs in new peripheral districts located not far from the external power sources becomes a reality.

II. TOPOLOGICAL CHARACTERISTICS.

In this case it is more reasonable to supply a section of consumers directly from the external power source through the medium voltage grid. That's why a new topology model of the power supply system was designed for big city districts receiving power supply from both an external power source and a radial load-center line (Fig.1). The distribution of electricity from LCSS is produced by magistral cable medium-voltage lines, as each line feeds the same number of transformer substations, which in turn have the same power and is also equally spread throughout the district territory [2]. A low voltage network is also equally spread.

One of the main issues of LCSS planning is the optimal location of the load center substation (LCS). Therefore, in addition to power of $LCSS_{LCS}$ the following parameters as optimum parameters were considered:

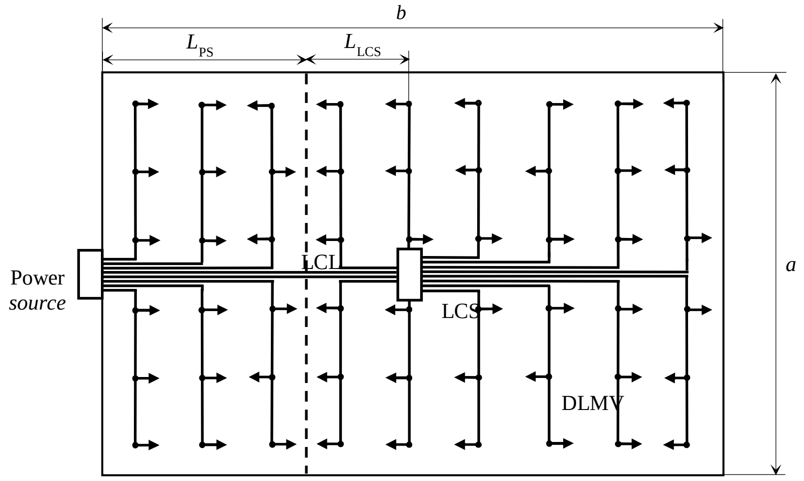


Fig. 1: Topology model of power supply system of peripheral district of a big city from an external power source and a radial load-center system

$L_{PS\%}$ – distance from the power source to the boundary of a part supplied from LCS, expressed as % of district side band, $L_{LCS\%}$ – distance between LCS and the boundary of a part supplied from LCS, expressed as % of the part length.

LCS – load-center substation, LCL – load center line, DLMV – medium voltage dual-circuit transmission line, a,b – dimensions of a district, L_{PS} – distance from power source to the boundary of a part supplied from LCS, L_{LCS}– distance between LCS and the boundary of a part supplied from LCS.

III. DEFINING THE OPTIMAL PARAMETERS OF LOAD-CENTER SUPPLY SYSTEMS.

While defining the optimal parameters of load-center supply systems in this research, as an optimum criteria was taken a minimum of discounted costs $C_{d\Sigma}$ for the accounting period T_a:

$$C_{d\Sigma} = \sum_{t=1}^{T_a} \left(I_t + C_t - V_t\right) \cdot (1+E)^{-t} \qquad (1)$$

I_t, C_t – investments for the construction of the object and the total cost of its operation in year t,

V_t – residual value of the object at the end of the accounting period ($t = T_a$),

E – discounting norm.

The following techno-economical models were considered:

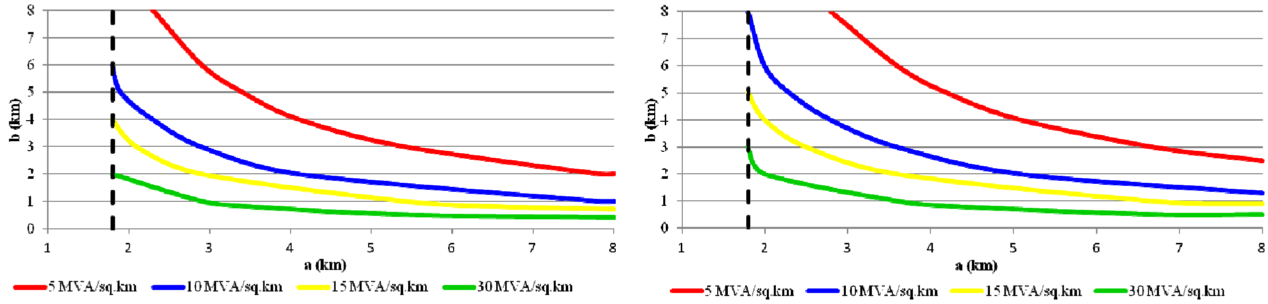
- Discounted costs of LCS - C_{PS};
- Discounted costs on the line LCL - C_{LCL} and substation LCS- C_{LCS};
- Discounted costs of an external source - C_{mvPC} and discounted costs on medium voltage lines - C_{mvLCS}:

$$C_{d\Sigma} = C_{PS} + C_{LCL} + C_{LCS} + C_{mvPC} + C_{mvLCS} \qquad (2)$$

As a result we obtained the expression for the discounted costs depending on the optimized parameters. This expression was the criterion function during LCSS parameters optimization. Alpha

Implementation of the power supply system of the city with the application of LCSS fundamentally changes the structure of the urban power grid and increases the cost of its construction and operation. Therefore it was carried out a techno-economical research of feasibility of LCSS construction in the city, using the resulting model of discounted costs. It assessed the optimization of the parameters of LCSS for districts with a surface density load $\sigma = 5$ MVA/km^2 and more, ranging from 3 to 16 km^2 (district square area in Moscow [8]) with different aspect ratio of the district, while defining the boundary values of σ and geometrical parameters for which the real solution is possible.

By the results of calculations we constructed nomograms of feasibility of LCSS for peripheral districts of cities, which are presented in (Fig.2.) According to the obtained nomograms we can define a particular peripheral district with the corresponding geometric parameters, and



a) rated voltage of LCSS 110 kV

b) 220 kV

Fig. 2: Nomograms of economic feasibility of LCSS

surface density load, for which it is necessary to make a construction of LCSS.

Analyzing the diagram it was concluded:

1) Construction feasibility of LCSS in the peripheral area of the city depends on its geometrical parameters: the values and the ratio of its length b and width a;
2) LCSS is inappropriate to construct at depth (length) of district b (deep into the city) less than 1.8 km;
3) With the increase of the surface density load, the district area is reduced, for which is advisable to make power supply system with application of LCSS.

Based on the formed techno-economical model the optimization of the LCSS parameters has resulted. According to the results of the optimization there was constructed dependence of optimized parameters S_{LCS}, $L_{PS\%}$, $L_{LCS\%}$ on the surface density load σ, the geometric parameters of the district a, b, and their ratio a/b for a district square area ranging from 3 to 16 km^2.

Fig. 3 presents as an example the results of optimal parameters of 110-220 kV LCSS for peripheral district having an area of 10 km^2.

By analyzing these relationships the following results were obtained:

1) Optimal power values of LCS for peripheral district of the city is 80 MVA and more, for rated voltage

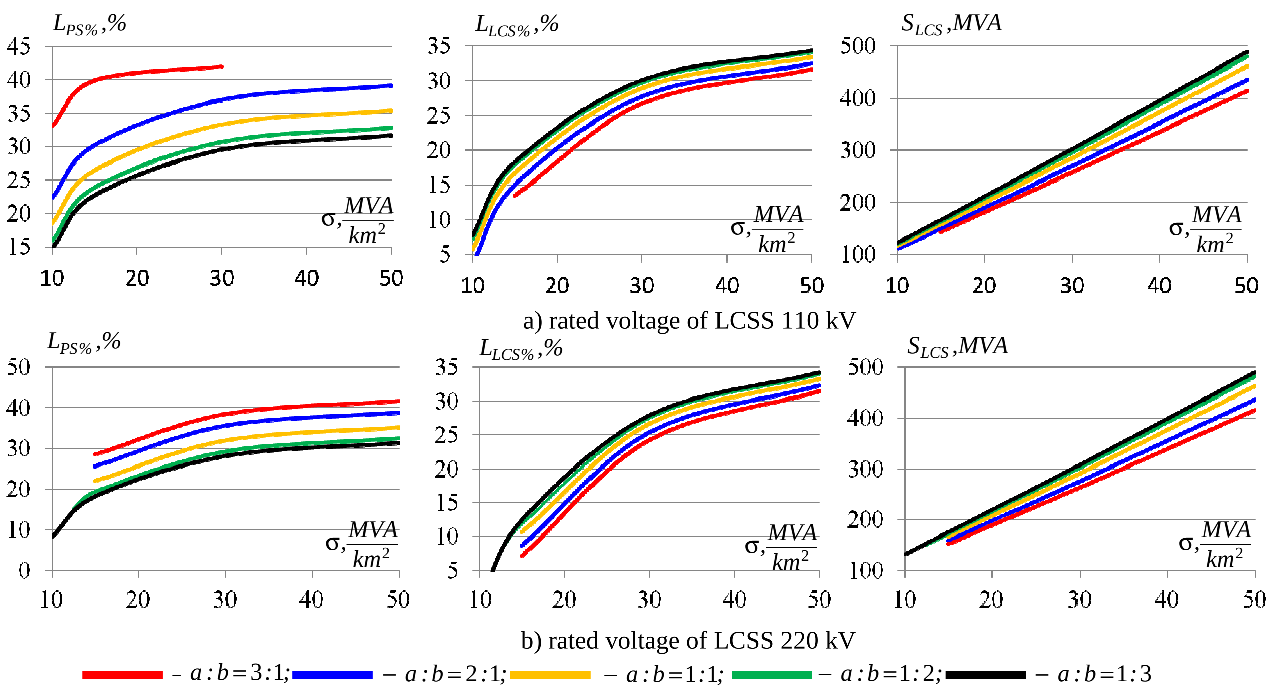


Fig.3: Results of optimal parameters of 110-220 kV LCSS for the peripheral district in an area of 10 km^2

of LCSS 110 kV and 126 MVA and more, for voltage 220 kV depending on the value of the surface density load. The maximum power value of LCSs that are constructed in large cities of Russia is 400 MVA. Due to the results that we obtained, S_{LCS} reaches values of 600-700 MW. Consequently, for the peripheral districts of big cities it is appropriate to include the magistral LCSS. This statement makes an interest for the further research.

2) For the districts of 3 to 16 km^2 and load density 20 to 50 MVA/km^2 it is reasonable to locate LCS at a distance of 20-45 % of district side b;

This fact is explained by the interaction of two competitive effects. When the distance between PS and LCS grows the part of the district supplied directly from PS increases as well, and the part supplied from LCS decreases. As a consequence, on the one hand, LCS construction, operation and losses coverage costs decrease and also the costs of medium voltage grid of LCS decrease as well. On the other hand construction costs of medium voltage grid supplied directly from the power source grow. Length of the load-center line grows, and, correspondingly, its costs grow as well.

3) The optimal location of LCS from the supplied part is 5 to 40% of part length;

The increasing importance $L_{LCS\%}$ with increasing of the surface density load and the size of the district area is because of the increasing costs of construction, operation and compensation for energy losses in medium-voltage network. The total length of medium voltage lines has a minimum value in the location of LCS in the center of the loads feeding by the part of this district. But it must be kept in mind that the closer the location of LCS to the center of the loads, the greater the length of the load center line.

IV. Conclusion

The load-center supply system is a compulsory element of the power supply systems of big cities. Consequently, we need to research their optimal parameters.

In addressing the optimal implementation of the power supply system in peripheral areas of large cities it is required examination of the topological characteristics of the districts and schemas of their power supply. The obtained results allow us to make decisions for the construction of a load-center supply system for peripheral districts of the city, and also to choose the optimum site for the construction of load center substation regarding to the power source.

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