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Research Article

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Optimization of Complex Parameters of Urban Electrical Distribution Networks

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Abstract The paper introduces with results of optimization analysis of law-governed formation of complex parameters with allowance for all influencing factors, which has determined economic feasibility of application of the limited number of used cross-section of cables. With the help of a method of criterion analysis, the economically reasonable optimizing parameters are determined and recommended for use of the received optimum parameters for electrical distribution networks.

Keywords Optimization, unification, distribution network, cable cross-section, high voltage, transformer

Introduction

Cities' power consumption growth and their power supply systems explains the need of high attention to the principles of optimal design of power distribution grids of cities, the impact of these principles on the general approach to build power supply systems for cities [1]. The most part of the total power supply sistem of the countries are distribution networks (DN). High rates of development of the DN due to the growth of electrical loads and the new power consumers requires the significant financial and material resources for their construction and operation. Thus, at least 2/3 of the DN cost is spent on the DN up to 1000 V and the middle class of voltage. As project design shows, that these costs will remain very high in the future and therefore the problem of the economically feasible building of these networks seems to be very relevant. Under these conditions, an integrated approach to planning optimal development and designing of DN becomes especially important, on the one hand taking into account the requirements of a comprehensive and complete solution of design tasks and the choice of a set of DN parameters, and on the other hand the possibility of typing and unifying the constructed lines. Such approach to the construction of these networks is also necessary because diverse consumers, large number of interconnected elements and objects being simultaneously constructed characterize the modern power supply system (including DNs up to 1000V and medium voltage).

The need for a comprehensive optimization parameters of distribution networks (DN) are determined by the fact that all parameters are functionally, technically and economically interconnected by the transmission and distribution modes of electricity and the technical and economic model should reflect these communications. The analysis of only one DN parameter is one-sided and may be interesting only in special cases [2, 3, 4].

Scientific research, project design institutions and other organizations as well as individual researchers have carried out a number of studies for the optimization and unification of electrical network parameters. Note, that the most of the studies cover optimization and unification of cross-sections of wires (with or without unification of supports) and cables. Meanwhile, modern theoretical issues of optimization solutions in the electricity industry are most fully formulated, which is fully applicable to the problems of optimization and unification of electrical network parameters.

Optimization and unification of cross-sections of cable line of power grids of industrial enterprises was proposed in [5], and optimization and unification of the power flow of transformers 10 (6)/0.38 kV of urban electrical grids are given in [6]. The most complete analysis of the optimization and unification of the cross-sections of wires of the lines of power supply systems of agriculture is cited in [7].

Specific materials used abroad on the high-level optimization and unification of the parameters of urban electrical networks are provided in the references [8-10]. The principles of optimization and unification of power flow of electrical substation (ES)10 (6) / 0.38 kV and cable lines of 10 kV are also used in the practice of designing and construction electrical grids of 0.38-10 (6) kV in some of the largest local cities and industrial enterprises.

It seems that these and similar practical decisions are made based on extensive experience in design and operation, or when the design option of these electrical networks.

At the same time, there is a lack of development and recommendations for optimization and unification of a set of parameters based on a scientific and technical methodology.

The structure of such a technique proposed by the authors is presented below, and the first results of the recommendations thus obtained for urban electrical grids of 0.38-10 kV are given.

Materials and Methods

Optimization of complex parameters of DN and consideration of constraints requires application of mathematical programming method to solve the proposed problem. Such method is the method of criterial analysis and it’s programming [11], which allows solving a set of optimization problems. With this method, the analysis of DN parameters are performed in the form of comprehensive optimization of parameters, based on the global minimum of the technical and economic function. The application of this method makes it possible to identify the optimal network parameters without resorting to variant calculation. In addition, this method allows multi-parameter optimization with a set of constraints, for which the program uses the optimization of nonlinear functions with non-linear constraints using the criterion programming method [11].

At the same time, based on certain assumptions, you can mathematically describe the technical and economic model of the network, which makes it possible to solve the problem in general form based on idealized constructions. In the formation of the technical and economic model, a topological model of the sections of networks fed from electrical substations (ES) and rows of cable sections, constructed with a constant step on the principle of geometric progression, are used. When forming the models, traditional assumptions were made about the constant density of the electrical load over the area of the residential area, the same sections of the head sections of the lines extending from the TS [12].

Results and Discussion

Considering the above, and taking into account the technical and economic models of total capital costs, operating costs and electric power losses, a comprehensive technical and economic cost model for DNs up to 1000 V within one TS was obtained [12]:

$$C_{LV} = C^{/}_{LV(1)}\delta^{-0,75}_{LV} S^{0,75}_{LV(I)} M^{0,5}_{LV} + C^{/}_{LV(2)}\delta^{-0,19}_{LV} S^{0,19}_{EP(I)} M^{1,06}_{LV} F_{2,LV} +$$
$$+ C^{/}_{LV(3)}\delta^{-1,38}_{LV} S^{1,38}_{EP(I)} M^{-0,13}_{LV} F_{2,LV} * N^{-1}_{F,LV} + C^{/}_{LV(3)}\delta^{-1,38}_{LV} S^{1,38}_{EP(I)} M^{-1,21}_{LV} F^{-1}_{2,LV} N^{0,3}_{F,LV}, \quad (1)$$

where, TS installed capacity; δ - density of electrical load, $C_{LV}{}^{/}{}_{(1)}$, $C_{LV}{}^{/}{}_{(2)}$, $C_{LV}{}^{/}{}_{(3)}$, $C_{LV}{}^{/}{}_{(4)}$ – generalized coefficients, which are determined by the formulas [11]:

$$C^{/}_{LV(1)} = a_{LV} K_{LV1} + I_{LV1}; \qquad C^{/}_{LV(2)} = a_{LV} K_{LV2} + I_{LV2};$$
$$C^{/}_{LV(3)} = a_{LV} K_{LV3} + I_{LV3}; \qquad C^{/}_{LV(4)} = C_0 \Delta Э_{LV1}.$$

Where, a_{LV} -normative ratio of capital expenditure utilization; C_0 - unit costs for the loss of electricity; K_{LVi}, I_{LVi} and $\Delta Э_{LV1}$ - respectively, the components of the total capital costs, operating costs and losses of electricity DN up to 1000V, which are the initial data in this task.

The number of lines extending from the TS (M_{LV}), the cross-section of the head section of lines up to 1000 V ($F_{2,LV}$) and the number of applied cable sections up to 1000 V ($N_{F,LV}$) are taken as complex-optimized parameters, according to which "competing" effects.
Since the obtained model is canonical and the matrix of dimensions of the function (1) has a small order, the solution of the main tasks of the technical and economic analysis (in particular, optimization of cable sections) is carried out using the classical apparatus of criterial analysis [11].
Using the method of criterial analysis, model (1) was optimized and formulas were obtained that allow determining the economic values of optimized parameters and costs for DN up to 1000 V [12]:

$$N^E_{F,LV} = \left(\frac{\pi_{1E}}{C^{/}_{LV(1)}}\right)^{-1,58}\left(\frac{\pi_{2E}}{C^{/}_{LV(2)}}\right)^{1,553}\left(\frac{\pi_{3E}}{C^{/}_{LV(3)}}\right)^{-0,763}\left(\frac{\pi_{4E}}{C^{/}_{LV(4)}}\right)^{0,79}$$

$$F^E_{2,LV} = \left(\frac{\pi_{1E}}{C^{/}_{LV(1)}}\right)^{-1,743}\left(\frac{\pi_{2E}}{C^{/}_{LV(2)}}\right)^{1,261}\left(\frac{\pi_{3E}}{C^{/}_{LV(3)}}\right)^{0,112}\left(\frac{\pi_{4E}}{C^{/}_{LV(4)}}\right)^{0,372}$$

$$M^E_{LV} = \left(\frac{\pi_{1E}}{C^{/}_{LV(1)}}\right)^{1,327}\left(\frac{\pi_{2E}}{C^{/}_{LV(2)}}\right)^{-0,455}\left(\frac{\pi_{3E}}{C^{/}_{LV(3)}}\right)^{0,2}\left(\frac{\pi_{4E}}{C^{/}_{LV(4)}}\right)^{-0,664}$$

$$C^E_{LV} = \left(\frac{\pi_{1E}}{C^{/}_{LV(1)}}\right)^{-0,336}\left(\frac{\pi_{2E}}{C^{/}_{LV(2)}}\right)^{-0,232}\left(\frac{\pi_{3E}}{C^{/}_{LV(3)}}\right)^{-0,1}\left(\frac{\pi_{4E}}{C^{/}_{LV(4)}}\right)^{-0,332}$$

where π_{1E},π_{2E}, π_{3E}, π_{4E} - criteria of similarity of economic options.
For model (1), the values of the similarity criteria are:

π_{1E}=0,336, π_{2E}=0,232, π_{3E}=0,1, π_{4E}=0,332

Taking into account the obtained values of the similarity criteria, the economic values of the optimized parameters and DN costs up to 1000V after some transformations can be expressed by the equations:

$$N^E_{F,LV} = 1,405\frac{C^{1,58}_{LV(1)} * C^{0,763}_{LV(3)}}{C^{1.553}_{LV(2)} * C^{0,79}_{LV(4)}}\delta^{-1,58} \quad , \tag{2}$$

$$F^E_{2,LV} = 0,544\frac{C^{1,743}_{LV(1)}}{C^{1.261}_{LV(2)} * C^{0,112}_{LV(3)} * C^{0,372}_{LV(4)}}\delta^{-0,741} \tag{3}$$

$$M^E_{LV} = 1,529\frac{C^{0,465}_{LV(2)} * C^{0,2}_{LV(3)} * C^{0,664}_{LV(4)}}{C^{1.327}_{LV(1)}} S_{EP(I)}\delta^{0,324} \tag{4}$$

$$C^E_{LV} = 3,676 * C^{0,336}_{LV(1)} * C^{0,232}_{LV(2)} * C^{0,1}_{LV(3)} * C^{0,332}_{LV(4)} * S^{1,25}_{EP(I)}\delta^{-0,587} \tag{5}$$

Expressions (2) - (5) allow, with known source data, to determine the economic values of the basic parameters and costs of the DN up to 1000V.
With the accepted initial data, the economic values of the parameters $N_{F,LV}$, $F_{2,LV}$, and M_{LV}, as determined by (2) - (4), are shown in fig.1 (a), (b), (c), where the dependencies are: "I" - for loopback networks with one transformer ES (Ix630 kVA), "II" - for two-beam circuits of networks with two transformer of ES (2x630 kVA).
The analysis of the results leads to the conclusion that the inclusion of optimized parameters for the number of applied cable sections (N_F) somewhat alters the conclusions about the economic feasibility of building distribution networks up to 1000 V with a single cable cross section when the electrical load density varies over a very wide range.

It turns out that building distribution networks up to 1000V, with large electrical load densities (δ≥10 MW / km²) is really economically feasible with an extremely limited number of cable sections, but for small load densities (δ<10 MW/km²) it is advisable to use 2÷4 cable sections. In this case, DN's up to 1000V are performed with different values of the economically feasible number of outgoing lines M_{LV} (Fig. 1(c)).

The obtained economic parameters of the DN up to 1000V may not satisfy the main technical limitations of the performance of the DN. For DN's up to 1000V, these are limitations on heating and on permissible voltage loss. At high electrical load densities (δ > 12 MW/km²), economic values of the number of applied cable sections up to 1000 V may be less than one, which does not make sense. Therefore, besides technical restrictions, the restriction of $N_{F,LV} \geq 1$ is additionally considered.

To solve the above systems of equations, a special program was used that was developed for solving problems of optimization of a nonlinear objective function with nonlinear constraints using the criterion programming method [5]. The influence of various active restrictions on the economic values of the parameters $N_{F,\ LV}$, $F_{2,\ LV}$ and M_{LV} is shown in Fig.1 (a), (b), (c).

The optimization results showed that in this task the limitation on heating cables DN to 1000V is practically active in all cases considered, and the restriction on allowable voltage loss in DN to 1000V is active at low electrical load densities (δ<10 MW / km²). For loopback circuits of networks, with low load densities, the condition for the admissibility of voltage loss is stronger than the condition for limiting the heating of cables. In this case, the economic values of F_2,n are close to the values allowed by the heating of the cables. An additional limitation is active at high load densities (δ> 10 MW / km²). At the same time, the conditions are not fulfilled due to an increase in F_2,s as is customary in practical design (an increase in the cross section when heating is unacceptable), but due to an increase in the number of lines extending from the TS. In this case, the value of F_2,s is somewhat reduced compared with the value obtained without taking into account the heating limit. This in turn leads to a decrease in the value of $N_{F,\ LV}$ this is especially noticeable at low load densities δ<10 MW / km² (Fig. 1(a), (b), (c)).

Conclusion

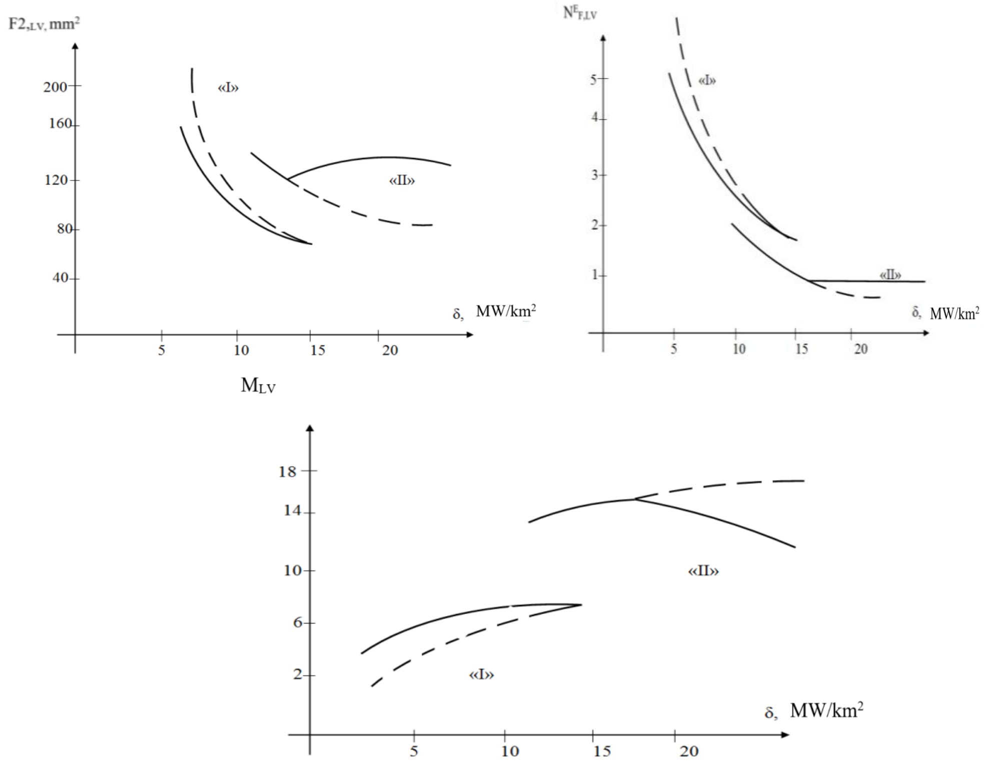

Figure 2: Values of the number of sections (a), the cross section of the head sections (b) and the number of outgoing lines from the ES (c) of the DN up to 1000V (- - - - without restrictions, ___ - with restrictions)

Thus, the construction of the DN at an electrical load density $\delta \geq 10$ MW/km^2 is economically feasible with a single (unified) cable cross-section. It is recommended to use in the DN up to 1000 V section of 120 mm^2. And with load densities $\delta < 10$ MW / km^2, it is optimal to use 2 ÷ 3 cable sections. In this case, it is recommended, depending on the density of the electrical load, to apply a section of the head section of lines up to 1000 V - 185, 150 and 120 mm^2, and sections of subsequent sections - on a scale of standard sections with a ratio of adjacent sections 1.8 ÷ 2.0.

Optimization of parameters shows that building DN up to 1000 V for large load densities is economically feasible with a limited number of sections, and for small load densities with less stringent restrictions on the number of applied sections.

Future Extend

It is necessary to indicate that the obtained results are intermediate, since they are obtained without taking into account stability and the zone is equal to the economic efficiency.

The study of the stability of the technical-economic (cost) model of the DN up to 1000 V in the area of its minimum implies an analysis of the applicability of discrete standard values of economic parameters in the field of economic efficiency of the technical-economic function, the need or the possibility of using additional criteria for a unique choice of parameters (i.e. optimization taking into account unification) and creates prerequisites for further unification of these parameters.

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