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Multiparameter optimization of the parameters of distributed electrical networks taking into account unification

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ABSTRACT: In the article, an optimization analysis of the regularities was carried out to form the number of cable sections used in combination with other parameters, taking into account all the influencing constraints, which revealed the economic feasibility of applying a deeply limited number of cable cross-sections and confirmed the need for multi-criteria evaluation in the optimization problem taking into account unification.

KEYWORDS*:* uncertainty, the criterion, parameter, cable section surface, method, target function, optimization.

I. RELATED WORK

The development of electricity consumption in cities and their power supply systems necessitates increased attention to the principles of optimal construction of distribution electric networks, the influence of these principles on the general approach to the construction of power supply systems [1]. Distribution electric networks (DEN) in cities constitute an essential part of the general electricity supply system of cities. High rates of development of DENs are due to increased electrical loads and the emergence of new electricity consumers, which determine the significant costs of financial and material resources for their construction and operation. At the same time, at least 2/3 of the costs of the DEN are spent on the DEN of 0.38 kV and the middle voltage class. As design developments show, these costs will remain very high in the future, and therefore the problem of the cost-effectiveness of constructing these networks seems to be very relevant. Under these conditions, an integrated approach to planning the optimal development and design of distribution zones becomes especially important, taking into account, on the one hand, the requirements of a comprehensive and complete solution of design problems and selecting a set of distribution parameters, and on the other hand, the possibility of typification and unification of the constructed lines and substations to ensure industrialization construction, installation and operation.Such an approach to the construction of these networks is also necessary because a modern power supply system (including DEN 0.38 kV and medium voltage) is characterized by diverse consumers, a large number of interconnected elements and a large number of simultaneously constructed facilities.

II. INTRODUCTION

The need for comprehensive optimization of DEN parameters is determined by the fact that all parameters are functionally and techno-economically interconnected by transmission and distribution modes of electricity, and the techno-economic model should reflect these communications. Analysis of only one DEN parameter is one-sided and may be of interest only in special cases [2].

Optimization of the unification parameter in combination with other DEN parameters and taking into account the set of constraints requires the use of mathematical programming and computer methods to solve the problem. This

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method is the criterial analysis or programming method [3,4], which allows to solve a set of optimization and unification problems. In this case, the analysis of the parameters (including the unification parameter) of the DEN is carried out in the form of a comprehensive optimization of the parameters, based on the global minimum of the technical and economic function. The use of this analysis method makes it possible to identify the optimal network parameters without resorting to the variant calculation. Another important method's advantage of criterial analysis is that some tasks of quantitative analysis (for example, the stability of a technical and economic function to parameters, the sensitivity of optimal solutions to the source data) are solved without numerical values of the source data. In addition, this method allows for multi-parameter optimization taking into account a set of constraints. For this purpose, we use a program for optimizing nonlinear functions with nonlinear constraints using the criterial programming method [3,4].

The problem in question can be solved by considering various options for the execution of the network at various values of the complex parameters. But this path is very time-consuming and does not provide reliable results. At the same time, based on certain assumptions, it is possible to mathematically describe the technical and economic model of the network, which makes it possible to solve the problem in a general way based on idealized constructions. At the same time, technical and economic models will be formed on the basis of wholesale prices for 0.38kV power cables, unit costs for electrical and construction works. Also used are the topological model of sections of 0.38 kV networks powered by transformer substations (TS), and series of cable sections constructed with a constant step according to the principle of geometric progression. When forming the models, traditional assumptions were made about the constant density of the electric load over the area of the residential area, the same sections of the head sections of the 0.38kV lines extending from the transformer substation.

Taking into account the technical and economic models of total capital costs (cable costs, electrical and construction works), operating costs and electricity losses, a comprehensive technical and economic model of costs for DEN 0.38 kV within one TS [5,6]:

$$\text{З}_{н} = \text{З}'_{H(1)}\sigma_H^{-0,75}S_{ТП(У)}^{0,75}M_H^{0,5} + \text{З}'_{H(2)}\sigma_H^{-0,19}S_{ТП(У)}^{0,19}M_H^{1,06}F_{Г,H} + $$
$$+ \text{З}'_{H(3)}\sigma_H^{-1,38}S_{ТП(У)}^{1,38}M_H^{-0,13}F_{Г,H} * N_{F,H}^{-1} + \text{З}'_{H(3)}\sigma_H^{-1,38}S_{ТП(У)}^{1,38}M_H^{-1,21}F_{Г,H}^{-1}N_{F,H}^{0,3}, \quad (1)$$

where $S_{ТП(У)}$ is the installed capacity of the TS; σ - electric load density;

$\text{З}'_{H(1)}$, $\text{З}'_{H(2)}$, $\text{З}'_{H(3)}$, $\text{З}'_{H(4)}$ - are generalized coefficients that are the initial data in this problem [5].

The number of lines extending from the transformer substation (M_H), the cross section of the head portion of the 0.38 kV lines ($F_{Г,H}$), and the number of cable cross sections 0.38 kV ($N_{F,H}$) used for forming in model (1) are taken as complex optimized parameters. "Competing effects."

Since the obtained model is canonical and the matrix of dimensions of function (1) is of a small order, the solution of the main problems of technical and economic analysis (in particular, unification of cable sections) is carried out using the classical apparatus of the criterial analysis method [3,4].

Using the method of criterial analysis, model (1) was optimized and formulas were obtained that allow one to determine the economic values of the optimized parameters and costs for a 0.38 kV DEN:

$$N_{F,H}^{Э} = \left(\frac{\pi_{1Э}}{\text{З}'_{H(1)}}\right)^{-1,58}\left(\frac{\pi_{2Э}}{\text{З}'_{H(2)}}\right)^{1,553}\left(\frac{\pi_{3Э}}{\text{З}'_{H(3)}}\right)^{-0,763}\left(\frac{\pi_{4Э}}{\text{З}'_{H(4)}}\right)^{0,79};$$

$$F_{Г,H}^{Э} = \left(\frac{\pi_{1Э}}{\text{З}'_{H(1)}}\right)^{-1,743}\left(\frac{\pi_{2Э}}{\text{З}'_{H(2)}}\right)^{1,261}\left(\frac{\pi_{3Э}}{\text{З}'_{H(3)}}\right)^{0,112}\left(\frac{\pi_{4Э}}{\text{З}'_{H(4)}}\right)^{0,372};$$

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$$M_H^{\text{Э}} = \left(\frac{\pi_{1\text{э}}}{\text{З}'_{H(1)}}\right)^{1,327} \left(\frac{\pi_{2\text{э}}}{\text{З}'_{H(2)}}\right)^{-0,455} \left(\frac{\pi_{3\text{э}}}{\text{З}'_{H(3)}}\right)^{0,2} \left(\frac{\pi_{4\text{э}}}{\text{З}'_{H(4)}}\right)^{-0,664};$$

$$\text{З}_H^{\text{Э}} = \left(\frac{\pi_{1\text{э}}}{\text{З}'_{H(1)}}\right)^{-0,336} \left(\frac{\pi_{2\text{э}}}{\text{З}'_{H(2)}}\right)^{-0,232} \left(\frac{\pi_{3\text{э}}}{\text{З}'_{H(3)}}\right)^{-0,1} \left(\frac{\pi_{4\text{э}}}{\text{З}'_{H(4)}}\right)^{-0,332};$$

where $\pi_{1\text{э}}$,$\pi_{2\text{э}}$, $\pi_{3\text{э}}$, $\pi_{4\text{э}}$ - are similarity criteria for economic options.
For model (1), the values of the similarity criteria are:
$\pi_{1\text{э}}$ = 0.336, $\pi_{2\text{э}}$ = 0.232, $\pi_{3\text{э}}$ = 0.1, $\pi_{4\text{э}}$ = 0.332. Taking into account the obtained values of the similarity criteria, the economic values of the optimized parameters and costs of the 0.38 kV DEN after some transformations take the form:

$$N^{\text{Э}}_{F,H} = 1,405 \frac{\text{З}^{1,58}_{H(1)} * \text{З}^{0,763}_{H(3)}}{\text{З}^{1.553}_{H(2)} * \text{З}^{0,79}_{H(4)}} \sigma^{-1,58} \quad (2)$$

$$F^{\text{Э}}_{\Gamma,H} = 0,544 \frac{\text{З}^{1,743}_{H(1)}}{\text{З}^{1.261}_{H(2)} * \text{З}^{0,112}_{H(3)} * \text{З}^{0,372}_{H(4)}} \sigma^{-0,741} \quad (3)$$

$$M^{\text{Э}}_{H} = 1,529 \frac{\text{З}^{0,465}_{H(2)} * \text{З}^{0,2}_{H(3)} * \text{З}^{0,664}_{H(4)}}{\text{З}^{1.327}_{H(1)}} S_{\text{ТП}(\text{У})} \sigma^{0,324} \quad (4)$$

$$\text{З}^{\text{Э}}_{H} = 3,676 * \text{З}^{0,336}_{H(1)} * \text{З}^{0,232}_{H(2)} * \text{З}^{0,1}_{H(3)} * \text{З}^{0,332}_{H(4)} * S^{1,25}_{\text{ТП}(\text{У})} \sigma^{-0,587} \quad (5)$$

Expressions (2) - (5) make it possible, with known initial data, to determine the economic values of the main parameters and costs of the DEN of 0.38 kV.
With the accepted initial data, the economic values of the parameters $N_{F,H}$, $F_{\Gamma,H}$, M_H determined by (2) - (4), depending on the density of the electric load, are shown in Pic. 1,2,3.

An analysis of the results leads to the conclusion that the inclusion in the composition of optimized parameters of the number of cable cross-sections (N_F) used will slightly change the conclusions about the economic feasibility of constructing 0.38kV distribution networks with a single cable cross-section for varying the electrical load density over a wide range.

It turns out that the construction of distribution networks of 0.38 kV, at high electric load densities ($\sigma \geq 10$ mVA / km^2) is really economically feasible with a very limited number of cable cross sections (one or two), but at low load densities ($\sigma < 10$ mVA / km^2) it is advisable to use 2 ÷ 4 standard cable sections. At the same time, distribution networks of 0.38 kV are performed with different values of the economically feasible number of outgoing M_H lines (from TS) (Pic. 3).

The obtained economic parameters of DEN 0.38 kV may not satisfy the basic technical limitations of the implementation of distribution electric networks. For 0.38 kV DEN, such are the restrictions on current heating after emergency operation and on the allowable voltage loss. At high electric load densities ($\sigma >$ 10 mVA / km^2), the theoretical economic values of the number of cable cross sections 0.38 kV used may be less than unity, which makes no sense. Therefore, in addition to technical restrictions, the restriction $N_{F,H} \geq 1$ is additionally considered. To solve the given systems of equations, a special computer program was used, which was developed for solving optimization problems for a nonlinear objective function with nonlinear constraints using the criterion programming method [7,8]. The influence of various active restrictions on the economic values of the parameters $N_{F,H}$, $F_{\Gamma,H}$ *and* M_H is shown in Pic. 1,2,3.

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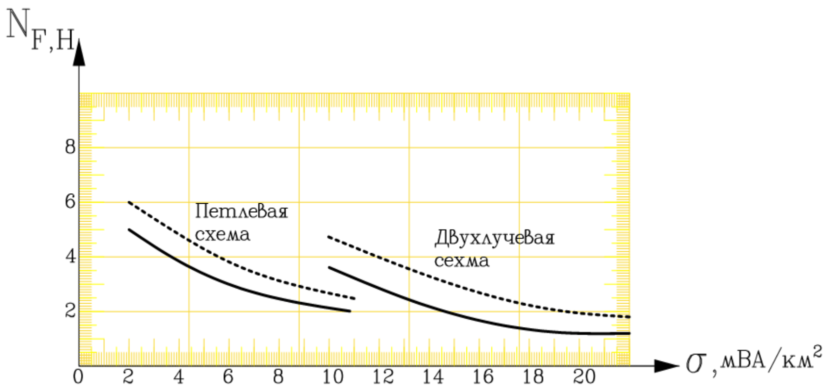
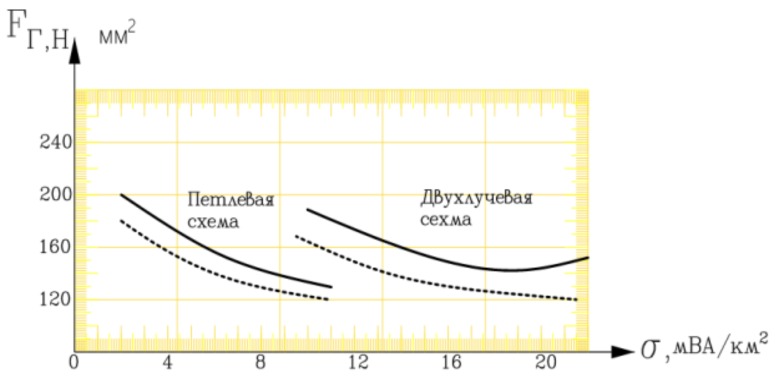
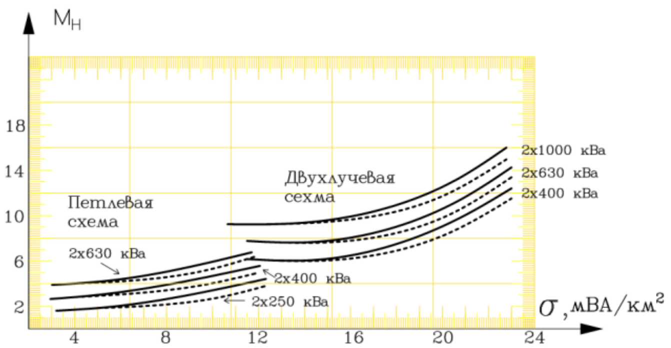
The optimization results show that in this problem, the restriction on heating cables of DEN 0.38 kV in almost all cases is active, and the restriction on permissible voltage loss in DEN 0.38 kV is active at low electric load densities (σ <10 mVA / km^2). For loop networks, at low load densities, the condition for admissibility of voltage loss is stronger than the condition for limiting the heating of cable conductors. At the same time, the economic values of $F_{Г,Н}$ are close to the values acceptable for heating cables of 0.38 kV in the post-emergency mode. An additional limitation is active at high load densities (σ> 12 mVA / km^2). Moreover, the conditions are met not by increasing $F_{Г,Н}$, as is customary in practical design (increasing the cross section if heating is unacceptable), but by increasing the number of lines departing from the TS. At the same time, the value of $F_{Г,Н}$ decreases slightly compared to the value obtained without taking into account the heating limit. This, in turn, leads to a decrease in $N_{F,H}$ this is especially noticeable at low load densities σ <10 mVA / km^2 (Pic. 1).



Pic. 1. The number of used cable cross-sections DEN 0.38kV:
- - - - - - – without restrictions, -------- – with restrictions



Pic. 2. The number of used cable cross-sections of DEN 0.38kV:
- - - - - - – without restrictions, -------- – with restrictions



Pic. 3. Number of lines extending from TS 10 / 0.38kV:
- - - - - - – without restrictions, -------- – with restrictions

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III.CONCLUSION

Thus, the optimization results lead to the conclusions:

- construction of RES 0.38 kV at an electric load density σ≥10mVA / km^2 is economically feasible with a single (unified) cable cross-section. At the same time, it is recommended to use a cross-section of 120 mm^2 in a DEN 0.38 kV.

- at load densities σ <10 mVA / km^2, the use of 2–3 cable cross-sections is optimal. In this case, it is recommended, depending on the density of the electric load, to use the cross section of the head section of the 0.38 kV lines - 185, 150 and 120 mm^2, and the sections of the subsequent sections - on the standard section scale with a ratio of adjacent sections of 1.8 ÷ 2.0.

It is necessary to indicate that the results obtained are intermediate, since they are obtained without taking into account the stability and the zone of equi-economic feasibility. The study of the stability of the technical and economic (cost) of the 0.38 kV DEN model in the region of its minimum involves an analysis of the applicability of discrete standard values of economic parameters in the field of equi-economical technical and economic functions, the need or the possibility of applying additional criteria for an unambiguous choice of parameters (i.e., multi-criteria assessment optimization tasks taking into account unification) and creates the prerequisites for further unification of these parameters.

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