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Optimization Of Repair Work In Electrical Distribution Networks.

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ABSTRACT

The article discusses possible methodological approaches for multi-criteria evaluation of the effectiveness of complex technical systems. As an example, the problem of choosing the optimal number of repair teams to eliminate damage in electrical networks, depending on the probability of service and their employment rate, was solved.
Keywords: electrical networks, operational activities, repair work, performance evaluation, multi-criteria optimization.

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INTRODUCTION

Grid enterprises perform important and complex functions for the uninterrupted and high-quality power supply to consumers. It is known that the occurrence of emergency situations in electrical networks leads to undesirable interruptions in power supply to consumers.

The negative consequences of interruptions in power supply are well known, they are associated with violation of technological processes, under-production, and spoilage of products, the creation of an unfavorable social situation in the housing sector, etc. As a result, the task arises of quickly eliminating malfunctions and reducing emergency downtime.

The flow of outages in electrical networks is random, and random time intervals between incoming repair requests may be subject to different distribution laws. Studies conducted in relation to the North Caucasus region showed that the recovery time of emergency situations in electric networks of 6–10 kV is subject to an exponential law [1].

The process of the appearance of damages in electrical networks should be considered as a discrete process with continuous time. The stationarity, ordinariness and the absence of an effect of the flow of outages in electrical networks allow the mathematical apparatus of Markov random processes to be used to study the work of repair units.

Among the specific features of the flow of applications for repairs in electrical networks should be noted its unevenness. At some periods of time a large number of applications accumulate; at other times, repair teams may work with underload. In conditions of increased ice-wind load and other natural phenomena, mass disconnections of electric network feeders can occur and in this situation, additional units from other regions of the country are involved in troubleshooting. These events are characteristic of the Moscow region, Stavropol Territory and other regions. In this case, an optimization problem may arise on the rational loading of electricians.

Optimization of repair work, like any other optimization, is in the choice of variable parameters at which the objective function will take the optimal value and satisfy the constraints on the system.

When servicing electrical networks, variable parameters are usually taken as: n - the number of repair crews, λ - the intensity of the flow of outages, $\bar{t}_{obsl}$ - the average repair time. Sometimes, the system structure can be used as a variable parameter or, for example, the maximum allowable number of outages, after which a denial of service occurs.

The mathematical model establishes the relationship between the variable parameters and the criterion of efficiency. If, for example, as the performance criterion we consider the probability of servicing incoming repair requests, then we can write down $P_{obsl} = f(n, \bar{t}_{obsl}, \lambda)$. The operator f can be represented by a system of analytic expressions or specified in an algorithmic form.

If in the task the objective function depends on one variable, then it is enough to determine its maximum or minimum value and the problem will be solved.

The complexity of optimization lies in the possibility of the existence of not one optimality criterion, but several, moreover, contradictory ones. For example, an increase in the number of repair brigades with the elimination of emergencies in electrical networks leads to an increase in the probability of completing the task, but it is associated with a decrease in a load of repair units. In such a situation, you can solve the problem, knowing the comparative value of each indicator or having the opportunity to combine them into one indicator, that is, to obtain the resulting objective quality function. The minimum or maximum value of this function will belong to the optimal solution.

One of the drawbacks of evaluating the effectiveness of complex technical systems is the use of an approach based on using the main characteristic as the objective function when imposing restrictions on all other output parameters.

At the same time, the practice of research and development of electric power facilities requires that a feasibility comparison of alternatives and the search for an optimal solution be carried out using the whole variety of specific quality indicators reflecting various aspects of the system's intended purpose, taking into account its own image of operating conditions such systems [2].

Because of this, the most preferable is the approach consisting of constructing for assessing the quality of a complex system of generalized multi-purpose indicators $x_{m+1} = f_x(x_1, x_2, \ldots, x_m)$, which are a function of local characteristics, that is, a solution to the problem of vector optimization is provided for the class of systems under consideration.

With discrete selection, many possible options for performing repair work form in space E^m discrete finite set D.

Assuming that between a vector of quality indicators $\vec{X}$ or D there is a one-to-one correspondence in spaceE^meach option $Y_\varphi$there will be one point where the vector of quality indicators is $\vec{X}$ (Y_φ) and vice versa.

The discrete choice problem is formulated as follows. Let be $Y_\varphi$solution, the possible variants of which are given on the set D. The quality of the solution is estimated by m scalar indices$x_1, x_2, \ldots, x_m$, forming a vector $\vec{X}$ = < $x_1, x_2, \ldots, x_m$ >. Quality indicator vector $\vec{X}$ connected to the solution $Y_\varphi$functional mapping $Y_\varphi \rightarrow \vec{X}$ = $f_x(Y_\varphi)$, asked to assess the power supply system analytically or statistically.

Need to find the best solution. Y_0, meeting the following conditions:

- the solution must belong to the set of functionally necessary options;
- the solution should be the best, that is, it is necessary to optimize the vector of quality indicators $\vec{X}$:

$$\vec{X}(Y_0) = \max_{\varphi \in D} (\min) \vec{X}(Y_\varphi) . \tag{1}$$

This formulation can be compared with the general form optimization model:

$$Y_o = f^{-1}\left[OP, \vec{X}(Y_\varphi)\right], \tag{2}$$

OP – optimality principle has a meaning course;

f^{-1} – inverse transform $\vec{X}$ to Y.

Mathematically, the model in question is identical to the task of ordering vector sets, and the choice of the optimality principle is the choice of the order relation.

Let us consider the features of vector synthesis in comparison with scalar synthesis. Since in the scalar synthesis each alternative system Y_φ characterized by one single indicator$x = x(Y_\varphi)$ (if restrictions are imposed on the remaining output characteristics), then the solution of the problem of choosing a solution can be brought to an end, that is, the optimal variant must be obtained, or the class of systems having the optimal value of the quality indicator is determined.

In contrast, with vector synthesis two alternatives Y_φ and Y_q (Y_φ, $Y_q \in D$) may be vector comparable or incomparable. Systems Y_φ and Y_q comparable by quality indicator vector $\vec{X}$ = <$x_1, x_2, \ldots, x_m$>, if:

$\vec{X}(Y_\varphi) \leq \vec{X}(Y_q)$ and where in Y_φ definitely better Y_q,

$\vec{X}(Y_{\varphi}) \geq \vec{X}(Y_q)$ and where in Y_q definitely better Y_{φ},

$\vec{X}(Y_{\varphi}) = \vec{X}(Y_q)$ and where in Y_{φ} and Y_q are equivalent.

In the case when none of these conditions is fulfilled, the solutions are incomparable.

Thus, in its pure form, the vector criterion allows one to solve a discrete choice problem if each of the particular quality indicators of one alternativeY_{φ}not worse than the corresponding indicator of another alternative $Y_q x_v(Y_{\varphi}) \geq x_v(Y_q)$.

Since in this case it is possible to speak about the unconditional advantage of one type of power supply over another, this method is called the method of unconditional preference. The application of the Pareto criterion (unconditional preference) allows us to distinguish the area of non-competitive alternatives and exclude them from further consideration. However, in most cases, the requirements of unconditional preference are not met, which leads to the need to use various kinds of generalized optimality indicators, which allow to reduce the multicriterial task to a single criteria criterion task.

In recent years, the opinion that a multi-criteria approach to assessing the quality of complex technical systems is becoming more common.

In this case, in accordance with the principle of unambiguity, the resulting objective function as an optimality criterion should be applied in the form of one generalized indicator, including all considered output characteristics.

A generalized quality indicator of a complex system can be represented by a function of m variables in m + 1 - dimensional space.

$$x_{m+1} = f_x(x_1, x_2, ..., x_m) = f_x(\vec{X}). \quad (3)$$

In so far as $x_{m+1}$is a scalar value, not a vector, the introduction of the indicator $x_{m+1} = f_x(\vec{X})$ essentially means a transition from the vector problem of comparing alternatives to a scalar one. Such scalarization allows not only to simplify the search for the optimal solution, but also to compare the power supply system options among themselves, which by the Pareto criterion turn out to be fundamentally incomparable. Thus, by introducing a generalized quality indicator, the possibility of incomparable solutions is excluded.

The presence of a large number of principles of optimality, known in the technical literature, poses the problem of choosing the approaches that best suit the specifics of finding the optimal system variant. This problem is solved on a conceptual level.

Consider the most commonly used methods for constructing the objective function:

- use of the main characteristic and transfer of all other output parameters to the category of restrictions;
- construction of a generalized system quality indicator;
- multiplicative and additive forms of convolution of particular quality indicators;
- minimax method.

The analysis made it possible to establish the following. The method based on transferring all particular quality indicators, except one, to the category of restrictions, is the simplest. In this formulation, the problem of choosing the optimal solution is formed as a problem of mathematical programming:

$$\max\ (\min)\left[x_i(Y_{\varphi}\right] \text{by } x_E(Y_{\varphi}) \geq x_E^*,\ x_c(Y_{\varphi}) \leq x_c^*. \quad (4)$$

The limitations of the approach under consideration are obvious, since the departure from vector synthesis is actually carried out. In addition, there are no sufficient grounds for choosing, for example, the likelihood of a task being performed by a system by a target function and the transfer into the category of limitations of such characteristics as channel utilization factor, queue length, etc.

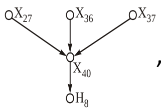
The most rigorous and accurate expression of quality is to obtain a generalized indicator through the physical dependencies of the output characteristics within the system under consideration and the complex technical complex as a large system including the entire power supply system. However, this approach is associated with significant difficulties in establishing such relationships.

In some cases, the objective function is built on the basis of using additive or multiplicative transformations over the selected system of output characteristics. When using additive transformations.

$$x_{m+1} = d_1x_1^* + d_2x_2^* + ... + d_vx_v^* + ... + d_mx_m^*, \quad (5)$$

$x_v^* = x_v / x_v^p$, and x_v^p – some reference value of the indicator selected per unit of measurement;
d_v – weights characterizing the relative importance of each indicator $x_1, x_2, ..., x_m$.

When using multiplicative transformations

x_{m+1} = 

,

(6)

α_v – importance indicator.

The main disadvantage of the considered group of generalized quality indicators is the possibility of mutual compensation of heterogeneous components. In this case, additive convolution has the simplest mathematical structure, which facilitates the solution of the problem, however, the problem of determining the coefficients arises $d_1, d_2, ..., d_m$.

The minimax method is distinguished by more complex computational procedures and is most effective in the absence of sufficient a priori information about the purpose of the system.

A brief analysis of the advantages and disadvantages of various methods for constructing a generalized quality indicator showed that the resulting objective quality function, which takes into account the physical dependencies of the system indicators, has the smallest elements of subjectivity and conventions, but it is rather difficult to perform such a task.

When finding the optimal operation mode of repair crews, in individual cases there is no need to analyze all the performance indicators of the considered queuing system, since they are calculated taking into account the main indicator - the probability of service. At the same time, the probability of servicing is clearly not enough, since this value is contradictory with such an indicator as the load factor of repair crews (with an increase in the number of repair crews, the probability of maintenance increases, but the load factor decreases). In this case, there is an optimization problem in the presence of conflicting indicators.

Consider the following situation. At random points in time under the influence of natural conditions (landslides, ice, strong wind, tornadoes, etc.) there may be an increased failure of overhead transmission lines in one place or another. To eliminate emergency situations, repair units from neighboring regions are usually involved.

There is a problem in this formulation - how to choose the optimal number of invited repair crews in this case? Suppose that local service personnel are involved in troubleshooting current problems, and additional teams are involved only for a certain amount of damage in the electrical networks. Then we have the right to consider a queuing system as a system with a failure. Let us take the average time for eliminating one malfunction typical for the North Caucasus of 3.33 h [1]. Let the shutdown flow intensity vary in the range from 0.1 to 10 (0.1; 0.25; 0.5; 1; 2; ..., 10), and the number of repair teams, depending on the situation, can be attracted from 1 to 40.As performance indicators we will consider: the probability of service (P_{obs}) and staff employment rate (k_z).

Calculation of indicators performed using well-known Erlang formulas for the expressions:

$$P_{obs} = 1 - p_n = p_0 \frac{\rho^n}{n_1}, k_z = \frac{k}{n} = \frac{\rho(1-p^n)}{n} \quad (7)$$

The calculations were carried out on a computer. According to the results of calculations, a graph of the following type was constructed (Figure 1).

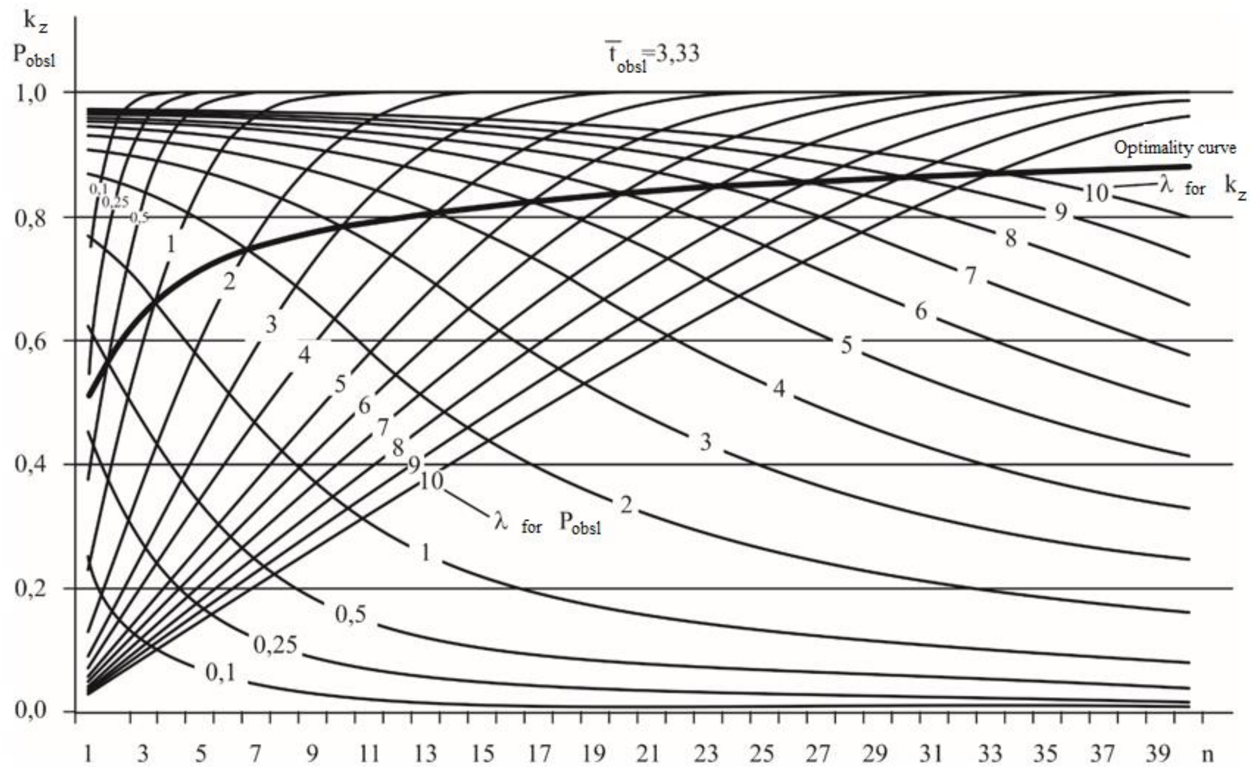


Figure 1: Dependence the service probability and employment rate the number of repair teams

Perform an analysis of the resulting graph [3]. Given a certain value of λ, you can get the maximum allowable value of the service probabilityP_{obs}. For example, when$\overline{t}_{obs}$= 3,33 handλ = 1, P_{obs}= 1 byn = 9. However, it cannot be argued that the obtained number of repair crews is optimal, since it did not take into account the size of the employment of crews. From the graph of figure 1 it is clear that in this situation k_z = 0,35, that is, the mode chosen for using repair crews is not satisfactory, since they are idle for 65% of the time. At the same time, as follows from the schedule, a further increase in the number of repair crews will not lead to a significant increase in the probability of maintenance, since it is already close to one, and simple repair crews will increase. Therefore, such a solution cannot be optimal.

To determine the optimal number of repair teams should use the method of comparison. For SMO with failures, it is convenient to compare two indicatorsP_{obsl} and k_z. At the same time, such initial indicators as the average recovery time and the intensity of the power outage flow should be taken as constant. The value that is optimized in our case is the number of repair teams. The queuing system will function optimally ifP_{obs} and k_z will be quite important. In this simple repair teams will be insignificant.

Consider the dynamics of changes in these indicators when varying the number of repair teams. With the number of repair teams n = 1 P_{obs} = 0,23 and k_z = 0,77. As you can see, the probability of maintenance is low, and the employment rate of repair teams is high. Difference between P_{obs} and k_z makes up 0,54. Conclusion - there is a significant discrepancy in performance, the probability of service is small, the option is not optimal.

Increase the number of repair teams to 2, thenP_{obs}= 0,5 and k_z = 0,7. The difference between the indicators has decreased dramatically. WhereinP_{obs} increased almost 2 times, and k_z changed slightly. Increase the number of repair teams to 4, we get P_{obs}= k_z = 0,67. Note that by increasing the number of brigades by one P_{obs} continues to grow dramatically and k_z changes slightly. Take n = 5. With this value of the number of repair teams P_{obs} = 0,9, i.e. the probability of service increases steadily, and k_z = 0,57, i.e. began to decrease. The difference between the indicators increased and reached a value of 0.33. With a further increase in n to 6 P_{obs} = 0,96andk_z = 0,48. The probability of maintenance continues to increase, and the employment rate declines, the difference between the indicators is steadily increasing.

Tracing the dynamics of indicatorsP_{obs} and k_z it can be concluded that the optimal number of repair teams will be in the case when the probability of service and the employment rate will be equal at constant values λ = const and $\bar{t}_{obs}$= const. Thus, the optimality condition for the problem under consideration is n_{opt} = 4 and P_{obs} = k_z = 0,67.

The graph in figure 1 shows the curve of the optimal values of the number of service channels at constant values λ = const, $\bar{t}_{obs}$= const and P_{obs} = k_z.

CONCLUSION

Thus, when evaluating the effectiveness of a complex system using two indicators in the event of inconsistency, the proposed comparison method allows finding the optimal solution with sufficient accuracy for practice.

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