Decision-making algorithm for the development of the district of electrical grids

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Abstract. The article presents the stages and operational actions of the formation of a priority alternative for the development of the district of electrical grids. It is proposed to make a priority alternative from the preferred variants for the development of electrical grids objects. The selection and ranking of variants is influenced by the financial constraint, the technical condition of the equipment, the consequences of failure. The article presents two-level block diagram of the decision-making process at the local and global levels. It is proposed at the local level to select the variant for the development of an object of electrical grids by multi-criteria assessment and using neural network technology. At the global level, it is proposed to use the integration of an algorithm for constructing a decision tree and an algorithm for solving an optimization problem.

1. Introduction

The technical condition of electrical grids is one of the most important indicators of the country's power industry. Assessment of alternatives for the development of Russian electrical grids should take into account the following features of the technical condition of equipment:

1) equipment deterioration degree (the worn-out equipment park in some district is more than 50 %);
2) a large amount of equipment with different technical and economic characteristics;
3) growth of socio-economic requirements and financial constraints;
4) many possible alternatives for the development of electrical grids.

Therefore, the development of automated systems for the selection of a priority alternative for the development of power grids is becoming significant [1]. This allows to process large amounts of information; rank alternatives; reduce the time for making a decision; improve the validity of the decision, analyze and evaluate every possible alternative for the development of power grids.

Analysis of scientific in the development of automated systems in the energy sector has identified the following areas:

- optimization of the power supply system under uncertainty [2] using fuzzy logic techniques for the determination of development strategies, multi-criteria optimization and expertise to select the best variant;
- selection of points for placement of deep input substations under load uncertainty [3] by multi-criteria optimization and reducing several criteria to one;

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• selection of the electrical grid configuration by discrete optimization methods according to the
criterion of minimum losses with the possibility of using it in multi-agent systems [4,5];
• calculation, analysis and optimization of electricity losses in the power supply networks of an
industrial enterprise, taking into account multi-criteria assessments of measures [6];
• optimization of the functioning and development of city power supply systems [7,8,9], based
on the method of weighted average normalized assessment;
• assessment of the state of equipment of power supply systems [10,11] using an artificial
neural network.

Abroad, DSSs are being developed in hydropower [12], Smart Grid [13], projects for the repair of
electrical networks [14], reconfiguration of the energy distribution system [5], and energy manage-
ment.

The district of electrical grids have a hierarchical structure, multi-connectivity and nesting of ob-
jects. As noted in [15], the hierarchical structure in any complex system allows to divide the process of
selecting the best alternative into such a number of levels that "the solution of the optimization prob-
lem at each of them was not difficult".

In the paper, the district of electrical grids (DEG) is a set of technologically interconnected objects
located on the same territory and served by one structural unit. An electrical grid object (EGO) is a
collection of a substation and power supply lines.

In connection with the above, the study proposes a two- level decision-making structure. The pre-
ferred variant for the development of the object is selected at the first (local) level. The priority alte-
rnative for the development of the DEG is formed from the preferred variants for the development of
object, taking into account the financial constraints of the investment program. This is the second
(global) level.

Analysis of the literature in the field of decision-making theory revealed the following main stages
of decision-making [15]: formation of alternatives; assessment of alternatives; selection of a priority
alternative. The authors proposed to adapt the classical decision-making process in accordance with
the purpose of the study. Figure 1 depicts the operational steps at each stage of decision making.

![Figure 1. Stages and operational actions of the decision-making process for the development of elec-
trical grids.](image)

Below is the proposed structure of the decision-making process for each highlighted level.

2. Structure of the decision-making process

2.1. Selection the preferred variant at the local level

1. Formation set of variants.

1.1 Database development.

A relational database has been developed for structuring the nomenclature of equipment by their
parameters. As a result, semantic links were established between such basic entities as: «Number of
lines» \( L \{l_1,l_2,\ldots,l_m \} \); «Distance to power source» \( D \{d_1,d_2,\ldots,d_z \} \); «Wire type» \( W \{w_1,w_2,\ldots,w_n \} \); «Num-
ber of chains} \( C\{c_1, c_2, \ldots, c_n\} \); «Pillow» \( P\{p_1, p_2, \ldots, p_n\} \); «Wire section» \( F\{f_1, f_2, \ldots, f_n\} \); «Substation scheme number» \( S\{s_1, s_2, \ldots, s_n\} \); «Breaker type» for the high and low voltage sides of the substation \( BHV\{b_{HV1}, b_{HV2}, \ldots, b_{HVk}\} \in BLV\{b_{LV1}, b_{LV2}, \ldots, b_{LVm}\} \); «Transformer power» \( T\{t_1, t_2, \ldots, t_n\} \) etc. [16].

1.2 Formation of variants consists in generating tuples from variable sets of parameters of electrical grids equipment.

It is proposed to use a cyclic search with matching equipment parameters and checking the level of prospective load. The set of variants is formed by the Cartesian product of the nomenclature data:

\[
A(\theta_1, \theta_2, \ldots, \theta_q) = L \times W \times C \times P \times S \times B_{HV} \times T \times B_{LV} \ A
\]

(1)

Each of the variants is a tuple of length 10:

\[
A(\theta_1, \theta_2, \ldots, \theta_q) = [d_z, w_n, l_m, c_k, f_g, p_j, s_i, b_{HVh}, t_v, b_{LVh}] \in L \land d_z \in D \land w_n \in W \land c_k \in C \land p_j \in P \land f_g \in F \land s_i \in S \land b_{HVh} \in B_{HV} \land t_v \in T \land b_{LVh} \in B_{LV}
\]

(2)

Formation of variants takes into account the technical condition index of each piece of equipment [17] with the subsequent determination of the development scenario: technical re-equipping or reconstruction.

2. Assessment variants.

The second stage of the local level consists of the following operational steps:

2.1 Selection and substantiation of decision-making criteria and development of their mathematical models.

Electrical grids are characterized by a continuous increase in loads due to the appearance of new consumers. Therefore, they are dynamically developing systems. In addition, it is necessary to take into account economic, technical, social, environmental and other requirements.

In this regard, it is proposed to assess the development of an object of electrical grids by multi-criteria assessment model.

As a system of particular criteria for evaluating variants for the development of objects, it is proposed to use the following criteria: economic (total discounted costs); technical (annual loss of electricity); technical and economic (damage from power failure); socio-ecological (area of land withdrawn); technical and operational (unification of equipment, cenology) [2,16].

The development of mathematical models of particular criteria for evaluating variants is proposed to be carried out on the basis of regulatory documents in the field of electric power, as well as taking into account the typification of the nomenclature parameters of equipment. The development of mathematical models of particular criteria is detailed in the works of the authors [2,16].

2.2 Multi-criteria assessment of each variant.

The authors propose to evaluate alternatives for the development of an object of electrical grids by the theory of fuzzy sets or an artificial neural network (ANN). Application of the theory of fuzzy sets is described in detail in the works [2,3]. In this study, we will consider the use of ANN.

To train the ANN, a set of vectors of input and output values was used. The input vector contains the criteria for evaluating the alternative \( X \). The value of the output vector corresponds to them. It contains the preference factor \( T \):

\[
(X^i, T^i)
\]

(3)

where:

\( i \) is the number of the training alternative;
\( X \) is input vector containing the criteria reduced to unit power. These criteria assess the effectiveness of decision making;
\( T \) is a unit output vector that is the preference factor for the alternative. It characterizes the belonging of alternatives to the class of preferable or inexpedient solutions, varies from 0 to 1.
\[ X^i = \left\{ \frac{C^i}{P}, \frac{\Delta W^i}{P}, \frac{D^i}{P}, \frac{S^i}{P}, \frac{N^i}{P} \right\}, \]  

where:

- \( C \) is the total discounted costs for the \( i \)-th alternative of the object;
- \( \Delta W \) is annual loss of electricity;
- \( D \) - damage from power failure;
- \( S \) is area of land withdrawn;
- \( N \) is coefficient unification of equipment;
- \( P \) is level of prospective load.

In the work for training the ANN, the total number of examples was 2180. The number of actually existing substations in the Orenburg region, referred to the set of preferred solutions, was 250. The number of examples from the set of inappropriate solutions was 1930.

3 Selecting the preferred variant

3.1 Ranking variants.

The variants for electrical grids objects are ranked by the value of the preference coefficient, which is determined by the ANN.

3.2 Decision-making.

The preferred variant for the development of an object has the highest preference coefficient.

2.2. Selection a priority alternative at the global level

1. Formation set of alternatives.
   1.1 Database development.
   The proposed operational action limits the number of variants for the development of the objects included in the district of electrical grids. The decision-maker fixes the threshold value of the coefficient of preference \( T_{cr} \) for alternatives and the index of the technical condition \( TCI_{cr} \):

\[ \begin{cases} T_i \geq T_{cr} \\ TCI_{EGO_i} \leq TCI_{cr} \end{cases} \]  

where:

- \( TCI_{EGO_i} \) is the index of the technical condition of the \( i \)-th EGO;
- \( T_i \) is the value of the preference coefficient of the \( i \)-th variants, the calculation of this coefficient is performed by the ANN in operational action 2.2.

1.2 Formation alternatives of the district of electrical grids

1.2.1 Formation of preliminary alternatives for the district of electrical grids was implemented by the algorithm for constructing a decision tree (figure 2) and by traversing it in a forward order with a depth-first search [18]. The nodes of the tree are variants of electrical grid objects (the subscript indicates the serial number of the variant, and the upper one - the object number).

The formation of a branch is completed when the amount of costs for the implementation of development measures at the district objects \( \sum C^{EGO_{i+1}} \) exceeds the volume of the investment program \( C_{max} \):

\[ \sum_{i=0}^{n} C^{EGO_{i+1}} > C_{max} \]  

All variants for EGO at the nodes of the branch were added to the preliminary development alternatives for the district of electrical grids.

1.2.2 The final formation of alternatives for the district of electrical grids.

If the decision branch included all EGO, then this is a finally formed alternative for the development of the district of electrical grids \( A^{DEGi} \).
If the decision branch does not include all EGO, then the formation of final alternatives depends on the amount of costs \( \sum C_{E GO_i+1} \) for the implementation of development measures at the district objects:

- if the unspent funds of the investment program \( C_{res} \) are sufficient for the spot replacement of emergency equipment at the object that were not included in the preliminary alternative:

  \[
  C_{\text{max}} - \sum_{i=0}^{n} C_{E GO_i} - C_{res} \geq 0 ,
  \]

  then the preliminary alternatives were complemented by equipment replacement options;

- if the unspent funds of the investment program are not sufficient for the replacement any equipment at any object, then the preliminary alternatives were considered finally formed.

2. Assessment of alternatives.

2.1 Defining criteria.

It was proposed to use the value of repair cost \( C_R \) and damage from equipment accidents \( C_D \) at EGO that were not included in the alternative development of the DEG as an assessment criterion [19].

Making a decision on the selection of a priority alternative for the development of the DEG is an optimization task. Therefore, its mathematical model is proposed on the basis of regulations of electrical grid enterprises of the Orenburg region. It consists:

- Objective function – minimization of repair costs and damage from equipment accidents (formula 8);

- Constraints – Financial volume of the investment program \( C_{\text{max}} \) (inequality 9, where \( C_{E GO_i} \) is the cost of implementing development measures at the \( i \)-th EGO, \( C_{E GO_i}' \) is the cost of spot replacement of equipment at the \( j \)-th EGO);

- Boundary conditions: non-negative values of the determined quantities; belonging to natural numbers of the object serial number (formulas 10-11):

\[
\begin{align*}
\sum_{j=1}^{n} (C_{Rj} + C_{Dj}) & \rightarrow \min \\
\sum_{i=1}^{n} C_{E GO_i} + \sum_{m=1}^{l} C_{E GO_i}' & \leq C_{\text{max}} \\
C_{Rj}, C_{Dj}, C_{E GO_i}, C_{E GO_i}' & \geq 0, \\
i, j & = 1, 2, \ldots, n
\end{align*}
\]
3. Selection the best alternative
3.1 Ranking of alternatives for the development of the district of electrical grids.
3.1.1 The alternatives for the development of the DEG were ranked according to the value of the objective function of the optimization task if they did not contain all objects. When the values of the objective function for several alternatives were equal, they were sorted according to the increase in capital costs.
3.1.2 If all objects were included in the investment program, then the alternatives for the development of the DEG were ranked according to the value of capital costs, because the objective function took a value equal to 0.

3.2 Decision-making.
Automated decision support systems are used to generate a variety of alternatives, to evaluate and rank them. The main purpose of such programs is to provide reasoned information to the head of the department for technical re-equipping and reconstruction of electrical grids to select an adequate and effective option for the development and functioning of electrical grids. Automated decision support systems do not replace the manager, they only provide technical support. The final decision is made by the manager.

3. Results of the software implementation of the algorithm for selection the priority alternative for the development of the district of electrical grids
In the paper, the developed algorithm is implemented in the C# [20]. Visual Studio was selected as the development environment. The program has been tested and validated on the example of power lines and substations in the Central District of Electrical Grids of the Orenburg Region.

The results of the selection of the preferred variant for the development of the EGO at the local level are shown in table 1.

| Object               | Measure                        | Composition of alternatives and their number |
|----------------------|--------------------------------|---------------------------------------------|
| Substation 35/10 kV  | Technical re-equipping due to increased load |
| "Stepanovskaya"     |                                | Replacement of 2 transformers 6.3 MVA with 10 MVA; replacement of circuit breakers on the 35 and 10 kV side; change of the typical scheme of the substation. 18 pcs |
| Substation 110/35/10 | Replacement of 16 and 10 MVA transformers with 25 MVA transformers; installation of circuit breakers on the 110 kV side, replacement of circuit breakers on the 35 and 10 kV side; change of the typical scheme of the substation. 18 pcs |
| "Selskaya"           |                                |                                             |
| Substation 110/10 kV | Replacement of the 25 MVA power transformer with 40 MVA. 1 pcs |
| "Stepnaya"           |                                |                                             |
| Substation 110/10/6  | Reconstruction due to equipment wear | Replacement of transformers and circuit breakers 18 pcs |
| "Yugo-Vostochnaya"   |                                |                                             |

The results of the selection of the priority alternative for the development of the DEG at the global level are shown in table 2. The investment program was limited to 700 million rubles. The priority alternative includes all considered objects in the Central District of Electrical Grids the Orenburg Region.
The results of the decision support system are consistent with the proposals for substations of the Central District specified in the "Comprehensive program for the development of electrical grids with a voltage of 35 kV and above in the Orenburg region for the period 2018-2022", as well as in the "Scheme and program for the prospective development of the Orenburg region for 2019-2023".

Table 2. Priority alternative for the development of the Central District.

| Object                   | HV circuit breakers | MV and / or LV circuit breakers | Transformers |
|--------------------------|---------------------|---------------------------------|--------------|
| Substation "Yugo-Vostochnaya" | SF6                 | vacuum                          | 40 MVA       |
| Substation "Stepanovskaya"        | vacuum              | vacuum                          | 10 MVA       |
| Substation "Selskaya"           | SF6                 | vacuum                          | 25 MVA       |
| Substation "Stepnaya"          | –                   | –                               | 40 MVA       |

4. Conclusions
1. A two-level block diagram of decision-making on the development of an electric grids region is proposed. It contains the local level of decision-making on the selection of preferred variants for the development of electrical grid object; and the global level of decision-making on the selection of the priority alternative for the development of the district of electrical grids, it is formed from the preferred variants for the development of objects, taking into account the financial constraints. The following stages are highlighted at each level: formation of an alternative; assessment of alternatives; selection the best alternative.

2. It is proposed to use particular criteria to assess variants for the development of objects: economic (total discounted costs); technical (annual loss of electricity); technical and economic (economic losses from power failure); socio-ecological (area of land withdrawn); technical and operational (unification of equipment, cenology).

3. It is proposed to carry out multicriteria estimation and ranking of variants of electrical grids objects by a neural network trained by the error backpropagation algorithm.

4. A mathematical model has been developed for selection a priority alternative for the development of the district of electrical grid. It is represented by a system of equations for conditional optimization, including: objective function - minimization of repair costs and damage in the event of equipment failure that was not included in the investment program; limitation - the financial volume of the investment program.

5. The selection of the priority alternative for the development of the district of electrical grid at the global level is proposed to be implemented by integrating the algorithm for constructing a decision tree and an algorithm for solving the optimization problem. Preliminary and final alternatives for the development of the district of electrical grid are being formed in the context of the limited volume of the investment program. Alternatives are evaluated according to the criterion of repair costs and damage in case of equipment failure. The alternatives of the district of electrical grid are ranked in ascending order of the values of the objective function.

6. The developed automated decision support system was tested and approved. The results obtained are consistent with the schemes and programs for the development of energy for the electric grids of the Orenburg region.

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