Algorithmic procedures for selection control options for electric power systems

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Algorithmic procedures for selection control options for electric power systems

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Abstract. The paper presents algorithmic procedures for selecting control options for electric power systems. The decision-making algorithm for choosing a strategy for the development of electric power systems for variable boundary conditions is given. The decision-making algorithm in the selection of promising areas of development of electric power systems is shown. The procedure of multi-alternative selection of boundary conditions for the development of the developing electric power system is presented. An example of estimation of characteristics of the distributed electric power distributed system is given.

1. Introduction
Currently, distributed electric power systems are being developed. They are characterized by a large number of parameters. In order to optimize the properties of such systems, the paper proposes a multi-criteria approach.

2. Decision-making algorithm for choosing a strategy for the development of electric power systems for variable boundary conditions
We can introduce a multi-alternative optimization model, which through the connection of alternative variables

$$x_j = \begin{cases} 1, \quad if \;\; j-th\; strategy\; is\; used \;\; for \\ development\; of\;\; the\; electric\;\; power\; systems \\ \qquad\qquad 0, \quad otherwise,\; j=\overline{1,J} \end{cases}$$

with criteria and restrictions on subsystems determines the process of managerial decision-making in the formation of the program of development of the main energy system in the following form

$$\varphi(x_j) \to max,\;\; Z = \sum_{m=1}^{M} \sum_{j=1}^{J} z_{jm}\left(U_n\left(x_j\right)\right) \le Z^{add} \;,\;\; F_i\left(x_i\right) \ge F_i^{pr}, i=\overline{1,I}, \qquad (1)$$

where ‘Z’ are the total costs, $j=\overline{1,J}$ are the numbering indices of perspective components in the system, $z_{jm}(\cdot)$– are the functions that describe the relationship of the cost values for the implementation of the j-th strategy in the m-th subsystem of the main system $\left(m=\overline{1,M}\right)$ with parameter values that define the *j*-th strategy $\left(U_{nj}\right)$, Z^{add} are the eligible costs [1, 2].

Another group of limitations is related to the impact of using of promising components on the dynamics of development indicators and their achievement of the values set by the programs $F_i^{pr}, i=\overline{1,I}$, $F_i = f_i(U_n)$, where $F_i, i=\overline{1,I}$ are the system development indicators, $F(\cdot), i=\overline{1,I}$ are the functions that describe the relationship between the values of the system indicators and the values of the strategy parameters [2].

To construct an algorithm for solving the problem (1), we proceed to the equivalent optimization problem

$$\max_{x} \min_{y>0} \hat{O}(x,y) = \varphi(x_i) + y_0\left(Z^{add} - \sum_{m=1}^{M}\sum_{j=1}^{J} z_{jm}x_j\right) - \sum_{i=1}^{I} y_i\left(F_i^{pr} - F_i(x_j)\right), \tag{2}$$

where $x = (x_1,...,x_j...,x_y)$ – vector of alternative variables, $y = (y_0, y_1,...,y_i...,y_I)$ – the vector of multipliers of the equivalent problems. We use the problem (1) to select the strategy of subsystem development, building on its basis the following procedures of managerial decision-making:

1) balancing the allowable amount of resources allocated for the implementation of the system, with varying boundary conditions of the total cost of the development of all components [3];

2) assessment of reserves to improve development performance through the use of reserves.

In the first situation, when there is a problem of exceeding the total cost of the permissible level, it is expected to reduce the amount of investment in the development of electric power systems. It is necessary to justify the lower limit of decline, beyond which such systems are supported only at the level of functioning without development opportunities. To implement the first module, set a discrete series of values of Z^{add} in the problem (1): $Z_1^{add},...,Z_l^{add},...,Z_L^{add}$, where $L \le 15, Z_l^{add} < Z_{l+1}^{add}$,, and numbers $l=\overline{1,L}$ the binary: $l = 1 + 2v_1 + 4v_2 + 8v_3$, where $v = (v_1, v_2, v_3)$ – vector with coordinates [4] $v_1 = \begin{cases}1,\\0\end{cases}, v_2 = \begin{cases}1,\\0\end{cases}, v_3 = \begin{cases}1,\\0\end{cases}.$

Then the problem (2) is transformed into an optimization problem with a new vector of alternative variables (v):

$$\max_{x} \min_{y>0} \hat{O}(x,v,y) = \varphi(x_j) + y_0\left(Z^{add}(v) - \sum_{m=1}^{M}\sum_{j=1}^{J} z_{jm}x_j\right) - \sum_{i=1}^{I} y_i\left(F_i^{pr} - F_i(x_j)\right), \tag{3}$$

The second module determines the solution (3) in accordance with the algorithm that determines the set-theoretic model of multi-alternative aggregation. The peculiarity is that in this case a new vector of variable variables is formed

$$x' = (x_1,...,x_j...,x_J, v_1, v_2, v_3) = (x_1,...,x_j...,x_{J+3}),$$

and the variations of the function (3) on the *k*-th iteration are calculated as follows

$$\Delta_j^k \Phi' = \Phi\left(\tilde{x}'^k / x_j = 1; y^k\right) - \Phi\left(\tilde{x}'^k / x'_j = 0; y^k\right),$$

where $\tilde{\mathrm{x}}'^{\mathrm{k}} = \left(\tilde{\mathrm{x}}'_1,...,\tilde{\mathrm{x}}'_{\mathrm{v}},...,\tilde{\mathrm{x}}'_{\mathrm{y+3}}\right), \left(\mathrm{v} \in \overline{1, \mathrm{J}+3}, \mathrm{v} \ne \mathrm{j}\right)$- vector of random implementations of alternative variables x'_{j}. The resulting solutions (3) v_1^*, v_2^*, v_3^* determine the number l^* and the value of $Z_{l^*}^{add}$,, which must be taken in determining the state investment support in the information and communication component of the main system development process [5].

After agreeing on the acceptable level of investment $Z^{add} = Z_{l^*}^{add}$, we return to the results of solving the problem (3) by variables $y_i^* \ge 0, i=\overline{1,I}$). Comparing them with each other, we determine on the basis of expert estimates those of them that have values close to 0 in the vicinity of [0, Δ] and can be used to improve performance [6] and can be used to improve performance indicators applying

Modern Communication Technologies concept (MCT).

As the third module, the following procedure is proposed for expert selection of the neighborhood $[0,\Delta]$ and the corresponding set of indicators $F_{i'}, i' = \overline{1, I'} < \overline{1, I}$, for which there is a reserve in increasing the values of $F_{i'}^{pr}, i' = \overline{1, I'}$. The expert sets the initial interval $\left[0, \Delta^1\right]$ and selects $f_{i'}$, for which $y_i^{*}{}' \le \Delta^1$. Further dialogue with the expert is based on linguistic variables. The linguistic variable γ = <permissible change> is used. The term T_γ ^ 'is chosen as T_γ ^' = <increase>. Then, the term T_γ ^ " has the following meanings:

$T_\gamma^{''}$ = {Strongly, Substantially, Some, Little, Few}.

The expert advisor for each indicator F_i, specifies the values of the term $T_\gamma^{''}$ and its proposed new limit level $F_{i'}^{1\,pr}, i' = \overline{1, I'}$. Then the relative value is calculated [6] $F_{i'}^{0\,pr} = \dfrac{F_{i'}^{1\,pr}}{F_{i'}^{pr}}$ and the value of the membership function

$$\mu(a,b,c) = \begin{cases} 1, \quad if\ F_{i'}^{0\,pr} \le c \\ \dfrac{1}{1 + \left(a \left(F_{i'}^{0\,pr} - c \right)^{b} \right)}, \quad if\ F_{i'}^{0\,pr} > 0, \end{cases} \quad (4)$$

where values of parameters *a*, *b*, *c* are selected according to table 1.

Table 1. Parameters of the membership function.

$T_\gamma^{''}$	a	b	c
Strongly	1	20	3
Substantially	1	30	3
Some	1	40	3
Little	1	60	3
Few	1	100	3

The integral assessment of possibilities of improvement of program indicators of f_i is defined as follows: $\mu^1 = \prod_{i'=1}^{I} \mu_{i'}^1$, where $\mu_{i'}^1$ - membership function values calculated by the formula (4) for the change interval $y_{i'}^{*} \left[0, \Delta^1\right]$.

After that, the expert determines the expediency of the transition to an increase in the interval $\left[0, \Delta^2\right]$, where $\Delta^2 > \Delta^1$. In the case of transition to the interval $\left[0, \Delta^2\right]$, the value of the membership function $\mu_{i'}^2$ is determined similarly to the above. For several variants of the interval $[0, \Delta]$ proposed by the expert, the one for which μ has the maximum value is chosen to improve the program parameters [7, 8].

3. Decision-making algorithm in the selection of promising areas of development of electric power systems

For algorithmization of managerial decision - making of the choice of perspective directions of development of electric power systems it is offered to use multi-alternative optimization model (1).

The first module defines the transformation (1) into an equivalent optimization problem (2).

In the second module, alternative variables x_j, $j=\overline{1,J}$ replaced by random discrete values $\tilde{x}_j$, $j=\overline{1,J}$, which take their values with probability P_{x_j}. At each iteration $k=\overline{1,K}$ new values are computed $P_{x_j}^{k+1}$ with known values of probabilities at the previous iteration $P_{x_j}^{k}$ and the values of the three implementations of the function variation (2) at the *j*-th variable [2]:

$$\Delta_j^k \Phi = \Phi\left(\left(\tilde{x}^k / x_j = 0\right) y^k\right) - \Phi\left(\left(\tilde{x}^k / x_j = 1\right) y^k\right), \tag{5}$$

where $\tilde{x}^k = \left(\tilde{x}_j, \ldots, \tilde{x}_v, \ldots, \tilde{x}_J\right), \left(v \in \overline{1,J}, v \neq j\right)$ - vector of alternative variables random implementations.

The value of the probabilities $p_i = P\left(\tilde{i}_1 = i_1\right)$ is associated with the interpretation of the factors of the equivalent problem as indicators of the degree of influence of restrictions on the achievement of the extremum of the function $\varphi\left(x_j\right)$. If the values y^k, are defined on the $k-th$ iteration, the change in the probabilities of involving constraints corresponding to the numbers $i_1 = 0,1,\ldots,i,\ldots,I+1$ will be carried out as follows [9].

$$p_0^{k+1} = p^{k+1}\left(i_1 = 0\right) = \left(1 + \sum_{i_1=1}^{l+1} y_{i_1}^k\right)^{-1}, \quad p_{i_1}^{k+1} = p^{k+1}\left(\tilde{i}_1 = i_1\right) = y_{i_1}^k \left(1 + \sum_{i_1=1}^{l+1} y_{i_1}^k\right)^{-1}. \tag{6}$$

In accordance with the distribution (6), the realization of a random variable on the $(k+1)$ iteration is determined. Suppose that this random implementation of $i_1^{k+1} = \Theta \in \left(\Theta = 1,\ldots,I+1\right)$, then

$$y_{i_1}^{k+1} = \begin{cases} max\left\{\varepsilon^{k+1}, y_{i_1}^k - \gamma^{k+1}\left(Z^{add} - \sum\limits_{m=1}^{M}\sum\limits_{j=1}^{j} a_{jm} x_j^k\right)\right\}, if\ \Theta = i_1^k = 1, \\ max\left\{\varepsilon^{k+1}, y_{i_1}^k - \gamma^{k+1}\left(F_i^{pr} - F_i\left(x_k^j\right)\right)\right\}, \quad if\ \Theta = i_1^{k^i} = 1, \\ y_{i_1}^k, \quad if\ \Theta \neq i_1^{k^i}, \end{cases}$$

,where γ^{k+1} - the value of the step of changing the coefficients of the equivalent problem, ε^{k+1}- some small value $(\varepsilon > 0)$, in brackets the values of partial derivatives of the function some little value $(\varepsilon > 0)$ $\dfrac{d\Phi}{dy_{i_1}}$, calculated with the values of alternative variables defined using the distribution $p_{x_j}^k$. The values γ^{k+1}, ε^{k+1} are selected according to the results of computational experiments, the different signs of γ^{k+1} the algorithm points to different types of constraints.

Next, a set of $W_l, l=\overline{1,L}$ variants of the solution of the original multi-alternative optimization problem is formed, and the values of the following parameters are calculated for each l - variant:

$$d_l = \psi\left(x_{jl}\right), \ \Delta z_l = Z^{add} - \sum_{m=1}^{M}\sum_{j=1}^{J} z_{jm} x_j, \ \Delta f_{il} = F_i^{pr} - F_i\left(x_{jl}\right), \quad i = \overline{1,I},$$

where x_{jl} – the value of the alternative variable x_j, corresponding to the solution W_l. The range of indicators $d_l, \Delta Z_l, \Delta f_{il}$ will be used to denote $\psi_{i_1 l}, i_1 = \overline{0,I+1}, l = \overline{1,L}$. The third module allows you to supplement the automated randomized search with a stop at $K_1 \approx 50$ the second cycle with the procedure of group expert evaluation of options $s=\overline{1,S}$ by experts [4].

Dialogue with experts is compatible with adaptive step-by-step $k=1,2,3,...$ adjustment of random variable distributions in a randomized environment [2]. To this end, we introduce $\tilde{l}$ – discrete random variable that takes values $\tilde{l}=\overline{1,L}$ with probabilities $p_l, l=\overline{1,L}, \sum_{l=0}^{L} p_l=1$ and having an initial distribution $p_l^1=\frac{1}{L}$.

At each k-th step, we will generate the value of a discrete random variable $\tilde{l}$ [3] and present a variant W_l^k with the values of the indicators $s=\overline{1,S}$ to the experts for evaluation ψ_{il^k}, $i=\overline{0,I+1}$. At the same time, we will adjust the weights of the indicators [5]:

$$0 \le \alpha_{i_1}^k \le 1, i=\overline{0,I+1}, \sum_{i_1}^{I+1} \alpha_{i_1}^k=1, \alpha_{i_1}^1=\frac{1}{I+2}.$$

To this end, each *s*-th expert ($s=\overline{1,S}$) is asked: "The value of which indicator ψ_{il^k} does not satisfy him to the greatest extent?". Let him answer: "the indicator i_s^k". His answer is formalized as [6]:

$$A_{i^k}^s=\begin{cases}1, \textit{if the value of the j-th index} \\ \textit{does not suit the s-th expert} \\ 0, \textit{otherwise}.\end{cases}, \tag{7}$$

Estimates (7) are used to adjust the weights and the distribution of the discrete random variable $\tilde{l}$. The number of β the indicator, which is important $A_{i^k}^l=1$ for the majority of experts, is determined.

$\alpha_\beta^{k+1}=\frac{\alpha_\beta^k+\Theta^k}{1+\Theta^k}, \alpha_i^{k+1}=\frac{\alpha_i^k}{1+\Theta^k}, i=\overline{0,I+1}, i\ne\beta$, where Θ^k - the value of the step in the calculation of the new values of the weight coefficients.

Then we determine:

$$\beta_{i^k}=\begin{cases}1,\text{if at least one value } A_{i^k}^s=1, \\ 0, \textit{otherwise}\end{cases}, i^k=\overline{0,I+1}, \ \beta_{i^k}=\sum_{i^k=1}^{I+2}\beta_{i^k}$$

And the probability values are calculated

$$P_{l^k}^{k+1}=\frac{P_{l^k}^k+B_{l^k}}{1+B_{l^k}}, P_{l^k}^{k+1}=\frac{P_l^k}{1+B_{l^k}}, l=\overline{1,L}, l\ne l^k.$$

Through the $k=k_2\approx L$ steps as a rational solution of the problem of multi-alternative optimization W^*, for which the condition is satisfied $P_l^*=\max_{l=\overline{1,L}} P_l^{k_2}$.

4. Results

The results of comparative numerical analysis of indicators with optimization and without optimization in figure 1. Here N - number of thousands electric devices in the region, 1 - without optimization, 2 - with optimization.

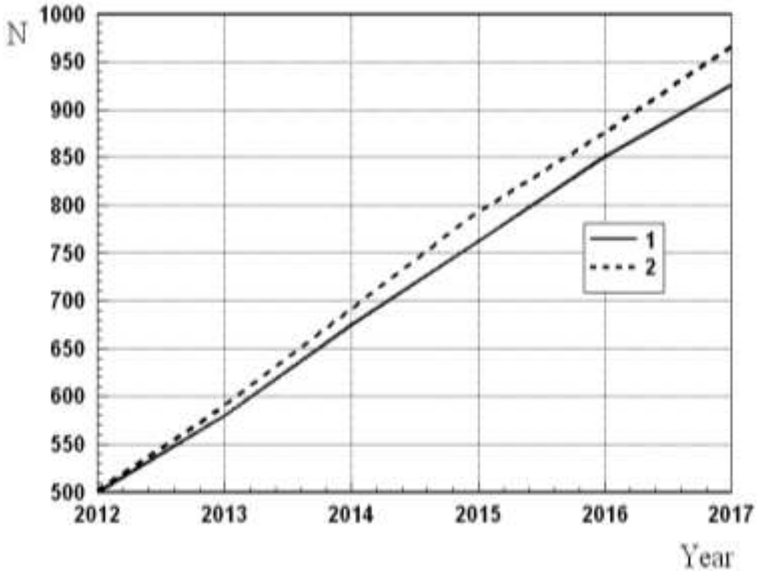

Figure 1. Growing number of electric devices in the region.

5. Conclusion

In the field of electric power, the increase in updates of technological platforms occurs with some frequency, as the main sign characteristics of the network can be considered an increase in the density of consumption. The paper proposes a mathematical model which considers the development of distributed electrical systems and optimization of their performance.

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