OPTIMAL OPTION FOR AGRICULTURAL ELECTRIC NETWORK BASED ON PYTHON PROGRAMMING RECONSTRUCTION ORDER DETERMINATION

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Abstract. The main criteria for assessing the optimal functioning of agricultural distribution networks 6-10 kV are considered in the article. The criterion of reliability is the integral annual under-supply of electricity, the criterion of the electricity quality is voltage losses in the network, the criterion of economic efficiency is electricity technological losses in the network, and the physical condition is the networks wear and tear coefficient. The parameters of the existing network of 6 kV overhead lines № 10 RP-1 were analyzed, and the sequence of network sections reconstruction was determined according to the multicriteria model, taking into account the uncertainty of electrical loads. A mathematical model of a fuzzy set for determining the functional modal value is considered. A Python program was compiled to determine the modal value of the functional.

1. Introduction
Reconstruction of power supply systems for agricultural purposes is directly related to the reduction of losses and costs of various origins in the power supply system (hereinafter PSS), the determination of which is complicated by the lack of information or incomplete initial information, multi-parameter (multi-criteria) and multi-variant.

Uncertainty of information arises for the following reasons [1]:
1) complex optimization problems do not allow to assess the choice consequences by using one parameter (criterion);
2) the complexity of the power supply system itself and the lack of knowledge does not allow to assess the future state of the system.

It is shown in the work [2] that the problem of uncertainty has a global character. Earlier, attempts were made to build a mathematical model for calculating the main technical and economic indicators of the power supply system efficiency, the application of the multi-criteria optimization method, which depends on the dimension of the alternatives set, the alternatives pairwise comparison method, the method of genetic algorithms. Despite the large existing experience in this area, there are still no generalized methods and recommendations.

2. Materials and methods
Let us consider the problem of determining the optimal variant of the network reconstruction sequence, described by the set of technical and economic parameters and having a multivariate reconstruction. The structural model of the existing 6 kV overhead line network is shown in the Figure 1.
The analysis of the existing 6 kV overhead line network showed that technological losses depend on the transformers load size. The minimum technological losses are observed at the load factor from 0.5 to 0.7. At the substations under consideration, the load factor ranges from 0.08 to 1.43, on average it is close to values of 0.23–0.3. The 6 kV overhead lines lengths range from 0.2 to 3.6 km, the coverage radius of the territory is from 0.4 to 1.3 km.

The networks physical condition, characterized by the wear rate, also leaves much to be desired, since the networks have been in operation without any reconstruction for many years. It is obvious that such a network needs reconstruction. All the network sections have almost equal wear and tear and a discrepancy between the network load and its capacity, therefore, the question arises about these network sections reconstruction sequence.

When considering the task of substation reconstructing, the issues of the transformers choice, their number, the protection devices choice, the conductors’ cross-section, etc. are simultaneously considered. Each possible solution is assessed by several particular or local criteria of efficiency. If we consider only those criteria for which a quantitative assessment is possible, then under certain environmental conditions (resistance of conductors, load powers, parameters of transformers, indicators of equipment failure and restoration of power supply, etc.), it is possible to determine numerical values of all criteria for each of the decisions taken for analysis. The combination of these values constitutes a vector criterion of efficiency [3].

The reliability, quality of power supply and technical and economic indicators of the power supply system efficiency guide the authors to determine the preference between the same solutions for the substations reconstruction.

The calculation of indicators is directly related to the initial data and should take into account their uncertainty. In this case, for the calculation, we will use the deterministic dependencies that are used in the power supply system design.

The electricity integral annual undersupply due to the equipment failure was determined by the formula:

$$W_{ned} = \sum_{i=1}^{n_i} T_i \cdot P_i,$$

where $T_i$ is the total time of consumers disconnection due to the failure of the $i$-th power supply system subsystem; $P_i$ is the total disconnected load due to the failure of the $i$-th power supply system subsystem; $n_i$ is the number of subsystems.

The total time of consumers disconnection due to the failure of the $i$-th power supply system subsystem is:

$$T_i = \sum_{j=1}^{n_{ij}} \omega_{ij} \cdot \tau_{ij} + \lambda_i \cdot t_i + \lambda_{kl} \cdot t_{kl} = \sum_{j=1}^{n_{ij}} \omega_{ij} \cdot \tau_{ij} + k_i,$$

Figure 1. Model of the 6kV overhead line № 10 RP-1 network.
where $\omega_{ij}$ is the failure flow parameter of the $j$-th element of the $i$-th power supply system subsystem; $\tau_{ij}$ is the average recovery time of the $j$-th element of the $i$-th subsystem, h; $\lambda_i$ and $\lambda_{ki}$ are the scheduled and overhaul repairs frequencies of the $i$-th subsystem; $t_i$ and $t_{ki}$ are the scheduled and overhaul repairs duration of the $i$-th subsystem, h; $k_{ni}$ is the time spent on repair work, h; $n_i$ is the number of elements in the $i$-th subsystem.

The subsystem includes a 6 kV overhead line and a 6/0.4 kV substation.

The failure rate for 6 kV lines depends on its length \[4\] - 0.0787 $\omega_{ij}$ ЛЭП$L = 0.0787$ ЛЭП$/year$, the average recovery time $5ij\tau = 5 h$, the intensity of deliberate outages $0.17 \lambda = 0.17/\text{year}$, the average service time of the scheduled repair and overhaul repair $12t = 12 h$.

The failure rate for 6 kV transformers is $0.016 \omega_{ij} = 0.016$ ЛЭП$/year$, the average recovery time is $50ij\tau = 50 h$, the intensity of deliberate outages is $0.4 \lambda = 0.4/\text{year}$, the average service time of the scheduled repair and overhaul repair is $22t = 22 h$.

Voltage losses were determined taking into account losses in transformers and in lines:

$$\Delta U = \Delta U_{k,T} + \Delta U_a,$$

where $\Delta U_{k,T}$ is the voltage loss in the transformer during a short circuit,\%, taken according to the catalog data of the transformers; $\Delta U_a$ is the voltage losses in the line:

$$\Delta U_a = \frac{100 \cdot I_{pj} \cdot L_j}{\rho_j \cdot s_j \cdot U_j},$$

where $I_{pj}$ is the rated current of the network, A.

The loss of active energy in power lines and transformers for the year was determined by the equation of heat losses:

$$\Delta W = \Delta W_{T,E} + \Delta W_T,$$

$$\Delta W = 3 \beta \cdot \sum_{j=1}^{n} \frac{\rho_j \cdot P_j^2 \cdot L_j \cdot \tau_j}{U_j^2 \cdot s_j},$$

$$\Delta W_T = 3 \beta \sum_{j=1}^{n} \frac{R_j \cdot P_j^2 \cdot \tau_j}{U_j^2},$$

where $\beta$ is the transformer load coefficient; $\rho_j$ is the conductor active resistivity, Ohm mm$^2$/m; $L_j$ is the power line length; $U_j$ is the network voltage; $s_j$ is the wires cross-section; $R_j$ is the transformer phase active resistance; $\tau_j$ is the power supply time per year; $n_i$ and $n_t$ are the number of power lines and transformers, respectively.

If this problem is solved by the classical method, then one of the optimality principles or criteria is preliminarily formulated with the participation of decision-making. The optimality criterion can be the principle of fair compromise. In accordance with this principle, the best solution is the one that provides all the indicators least deterioration. That is, the principle of a fair compromise will correspond to the multiplicative scalar criterion [5]:

$$F = \prod_{g=1}^{n} f_g = \Delta U \cdot \Delta W \cdot W_{neo} \cdot K_{us},$$
where \( f_g \) is the changing parameter of the g-type; \( \Delta U \) is voltage losses; \( \Delta W \) is electricity technological losses; \( W_u \) is energy losses due to undersupply; \( K_w \) is the equipment wear coefficient, depending on the equipment service life.

The criteria and functionality calculation is given in the Table 1.

| DP  | No of the area  | \( P_t \), kW | \( L_{ef} \), m | \( P_{ct} \), kW | \( s_\mu \), mm\(^2\) | \( K_w \) | \( \Delta U_{el} \), % | \( U_{el} \), kV | \( U_{end} \), kV | \( T_{eb} \), h/year |
|-----|----------------|---------------|----------------|----------------|----------------|---------|---------------------|----------------|----------------|----------------|
| PT 802 | 0-1 | 2x630 | 0.18 | 1406 | 240 | 0.165 | 0.234 | 6.3 | 6.285 | 2.75 |
| PT 203 | 1-2 | 2x400 | 0.701 | 779 | 120 | 0.495 | 0.404 | 6.3 | 6.275 | 4.80 |
| PT 752 | 1-3 | 2x250 | 0.265 | 1144 | 120 | 0.165 | 0.204 | 6.3 | 6.287 | 3.08 |
| PT 753 | 2-4 | 2x160 | 0.35 | 96 | 240 | 0.165 | 0.028 | 6.3 | 6.298 | 3.42 |
| PT 804 | 6-7 | 250 | 0.233 | 75 | 50 | 0.66 | 0.032 | 6.248 | 6.246 | 2.96 |
| PT 801 | 9-11 | 2x400 | 0.045 | 241 | 95 | 0.275 | 0.011 | 6.238 | 6.238 | 2.22 |
| CPT 193 | 12-13 | 250 | 0.01 | 75 | 50 | 0.825 | 0.001 | 6.234 | 6.234 | 2.08 |
| PT 800 | 14-15 | 2x250 | 0.08 | 150 | 95 | 0.33 | 0.022 | 6.222 | 6.221 | 2.35 |
| CPT 12 | 14-16 | 160 | 0.04 | 48 | 70 | 0.275 | 0.045 | 6.222 | 6.219 | 4.20 |
| CPT 58 | 16-17 | 160 | 0.51 | 48 | 50 | 0.275 | 0.045 | 6.222 | 6.219 | 4.20 |
| PT 803 | 18-19 | 160 | 0.96 | 64 | 50 | 0.825 | 0.114 | 6.233 | 6.225 | 5.82 |
| PT 201 | 20-21 | 180+160 | 0.295 | 102 | 70 | 0.495 | 0.015 | 6.212 | 6.211 | 3.52 |
| CPT 193 | 22-23 | 160 | 0.118 | 70 | 70 | 0.495 | 0.025 | 6.214 | 6.212 | 3.25 |
| PT 201 | 23-24 | 160+160 | 0.19 | 1041 | 70 | 0.495 | 0.025 | 6.214 | 6.212 | 3.25 |

As can be seen from the Table 1, first of all, the reconstruction should undergo Packaged Transformer Substation 58, and in the last Packaged Transformer Substation 193. At the same time, large values of the functional may indicate that some of the parameters or several in total do not correspond to the optimal values.

With the logical substantiation of various optimization principles, one use a different approach to obtaining a scalar efficiency criterion based on the fuzzy sets theory use [6]. Here, a fuzzy set is used as a mathematical model of undefined parameters.

Let us represent a fuzzy set as a triangular fuzzy number, that is:

\[
F_\Delta = \left\{ F_{max}, F_m, F_{min} \right\}_\Delta \quad \left( F_{max} \geq F_m \geq F_{min} \right),
\]

where \( F_m \) is the mode, or the triangular fuzzy number crisp value.

The fuzzy set adjective \( F \) to a universal set \( X \) on the interval \((F_{min} ; F_{max})\) is found from the equation:

\[
\mu_{F_{\Delta}}(x) = \begin{cases} 
\frac{x-F_{max}}{F_{max}-F_m}, & x \in [F_{max},F_m] \\
\frac{x-F_{min}}{F_m-F_{min}}, & x \in [F_m,F_{min}] \\
0, & \text{otherwise}
\end{cases}
\]
To obtain the mode (crisp value) of a triangular number, we use the fuzzy averaging method:

\[ p_m = \frac{\sum_{i=1}^{n} \mu_i \cdot p_i}{\sum_{i=1}^{n} \mu_i} \]  

(9)

According to the generalizations adopted by L. Zadeh [7], if the mathematical model (1) - (5) includes parameters that are fuzzy numbers, then \( W_{\text{ned},c} \), \( \Delta U_c \), and \( \Delta W_c \) will also be fuzzy numbers. Thus, the resulting fuzzy number contains both the value with the highest confidence (modal or crisp) and the uncertainty interval (the set carrier).

From 12 functional elements, the triangular number carriers will be: \( F_{\text{max}} = 0.660; \quad F_{\text{min}} = 0.013. \)

For the initial calculation, we set \( F_m = F_{cp} = 0.153. \) Next, we define the membership function and the triangular number mode.

3. Results
The membership function and mode calculation (or the value with the highest confidence) of the functional \( F \) was carried out electronically; for this, the program in Python programming language was compiled (Fig. 2).

![Figure 2. The program for calculating a triangular fuzzy number in Python programming language.](image)

4. Conclusion
The result obtained allows to say that with values of the estimated functional up to 0.177, the transformation and reconstruction of 6 kV overhead lines and transformer substations is not required, since it is not confirmed by the greatest confidence. Thus, for reconstruction consideration, 3 sections of the network are accepted: 1st stage is Packaged Transformer Substation-58, second stage - transforming substation-203, third stage - transforming substation-804.

For values \( F > 0.177 \), it is necessary to analyze further the lines and transformer substations parameters and technical and economic indicators, and identify those that do not correspond to the optimal ones.

The developed program in Python programming language for determining the optimality criterion modal (crisp) value for the network reconstruction, taking into account the uncertainty of the initial information,
will significantly speed up the solution development for the network reconstruction and determine the recon-
struction sequence ranking.

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