For today one of the first places in its importance and complexity is the problem of ensuring the reliability of electricity supply in power market conditions. The functioning of Ukraine's electric power system (EPS) in recent years is characterized by a significant level of physical and moral depreciation of electrical equipment (more than 70% of the total) and low rates of replacement. This further reduces reliability and leads to an increase in the number of emergencies.

A significant increase of the functional reliability level of electrical equipment and the EPS in general can be achieved by an objective assessment of the technical condition, prediction of lifetime, determination of failure probability and justification of possible terms for its maintenance or replacement.

Firstly, it is necessary to plan the possible time of out of service for equipment, based on technical condition assessment and total estimated technical resource, when its technical condition is characterized by a high level of possible failure. Secondly, the priority sequence of out of service of electrical equipment must also be determined by the level of its significance in the EPS. There are indicators that reflect the failure effect of the analyzed electrical equipment on the security level and operation efficiency of the EPS as importance indicators of electrical equipment for the EPS.

Planned and unscheduled power transformers out of service, sudden failure under the presence of critical damage, resource exploitation and external factors influence is an emergency disturbance for the EPS. This can lead to a further cascade emergency situation with significant losses. In connection with this, the complex simulation problem of technical condition of electrical equipment and EPS states, decision to minimize the exploitation risk of the EPS under electrical equipment out of service today is an urgent task.
Mathematical models of technical condition diagnostics for the power transformer based on a complex of measurements and tests are presented in [1]. Fuzzy models for risk assessment of parametric failure for the power transformer under the presence of damage are considered in [2]. The model system of electrical equipment failures based on statistical data of the general event set adapted to real operating conditions was obtained in [3]. EPS state simulation to determine the quantitative indicators of emergency risk under electrical equipment failures is considered in [4]. But the issue of priority for the power transformer out of service based on the technical condition assessment and EPS state analysis was not sufficiently considered.

In each power system, there are usually several variants of the topology of electrical networks. The task for the operating personnel is to choose such a variant of disconnecting any element that would lead to the least disturbance of the power system, that is, provide the least emergency risk. Thus, there is a problem of selecting the sequence of output of individual units of electrical equipment, in particular power transformer, taking into account the above-mentioned features and factors.

In order to ensure reliable operation of the EPS, the topology is designed so that the disconnection of more than one element in the normal state at maximum load does not result in unacceptable overloads of elements or load constraints [5]. If the N-1 criterion is fulfilled in all calculation states, it is considered that the EPS is reliable. The subset N is the number of EPS power elements, which have a certain degree of influence on the EPS state. Otherwise, appropriate measures should be taken to ensure compliance with the established standards. This approach is deterministic because it does not take into account the probability of emergency situations and therefore does not give quantitative characteristics of EPS reliability, and characterizes the reliability on the basis of compliance with regulatory requirements [6].

Making sound decisions to ensure reliable operation of the EPS requires an integrated approach. It is necessary to take into account the chance of electrical equipment failure, the EPS stochastic state, possible scenario of the development of the emergency situation, economic and environmental consequences, incompleteness and obscurity of information. The risk is an integral indicator of the EPS operation state, which comprehensively takes into account the above-mentioned factors and most completely and sufficiently characterizes the technical condition of electrical equipment and the EPS state [7].

Quantitatively, the risk is defined as the product of the magnitude of the event A by the possibility of event q:

\[ R(t) = A(t) * q(t) \]

The complexity of risk assessment R(t) mainly occurs when determining the possibility of event q(t), which is often used as a probability.

The most appropriate and effective method for estimating the probability risk component for EPS, in particular, which features are a large number of elements, complexity of the structure and a significant wear rate of electrical equipment, is the use of statistical simulation methods [8].

The aim of the present research is to develop the model and algorithm of decision-making on the operation strategy of power transformers on the basis of technical condition assessment of the power transformer and emergency risk under out of service or replacement.

To achieve this aim, the following tasks were set:

- to develop the structure of the decision-making model for determining the priority of the power transformer out of service on the basis of complex simulation for the EPS state and technical condition of the power transformer;
- to develop the algorithm of complex simulation for the EPS state and technical condition of the power transformer for emergency risk assessment under the power transformer out of service;
- to carry out the complex simulation for the EPS state and technical condition of the power transformer for making decisions of determining the priority of the power transformer out of service.

4. Materials and methods for model development for making decisions on determining the priority of the power transformer out of service

4.1. Experimental research base

The study was carried out using the statistical information about failures of power and switching electric equipment, which were registered in Ukraine’s power grid.

4.2. Model for making optimal decisions regarding the operation strategy of power transformers using the Pareto ranking method

Determination of the replacement or out of service sequence for the EPS power oil transformers repair belongs to the class of multicriteria problems of selection of alternatives in uncertainty conditions. For today, there are a number of methods for ranking objects by the detection degree of certain properties [9].

For multicriteria problems of alternatives evaluation, commonly accepted approaches is the construction of a permissible solutions set, for which it is impossible to simultaneously improve all partial performance indicators (Pareto region), as well as the use of different aggregate indicators [10]. This decision-making approach involves the construction of a non-dominant alternatives set based on a fuzzy preference relation.

Let a set of decision-making variants (alternatives) be \( A = \{a_1, a_2, ..., a_n\} \). Each alternative is characterized and compared with the other by several features (criteria) \( C = \{c_1, c_2, ..., c_m\} \). As a result of a pairwise comparison of alternatives by each feature, \( n \) preference relations \( c_{ij} \), \( j = \frac{1}{n} \) on the set of alternatives \( a_i \), \( i = \frac{1}{m} \) are formed. It is necessary to choose the alternative \( a' \) from the set \( (A, c_1, c_2, ..., c_m) \) based on this information.

Determination of a Pareto subset of effective solutions is based on the consideration of two types of convolutions: minimization \( Q = C_1 \cap C_2 \cap ... \cap C_n \), which defines a set of non-dominated alternatives \((A, Q)\) in the set; linear

\[ Q = \sum_{j=1}^{n} c_j \cdot \omega_j \]
which uses alternatives according to the degree of non-domination, where \( \omega_0 \) is the weighting coefficient. The solution (alternative), which has the maximum degree of non-domination in both convolutions is considered optimum.

An important issue when solving the problem of making optimum decisions is to determine the weighting factors of the criteria obtained mainly by expert methods. The complexity of obtaining the necessary expert information and the degree of consistency of expert considerations significantly affect the choice of the method for determining the weighting coefficients. The most rational method of weighting coefficients under incomplete and contradictory expert information is the Saati pairwise comparison method [11].

The procedure for solving the selection problem consists of the following steps:

1. Formulation of preference relations \( R_j (j = 1, m) \) on the set of alternatives \( A \) and determination of their membership functions

   \[
   \mu_{kj} (a_i, a_j) = \begin{cases} 
   \frac{1}{2} \mu_k (a_i, a_j) - \mu_k (a_i, a_0), & \text{if } \mu_k (a_i, a_j) > \mu_k (a_i, a_0), \\
   0, & \text{if } \mu_k (a_i, a_j) < \mu_k (a_i, a_0).
   \end{cases}
   \]

2. Construction of the convolution of relations \( R_j \) in the form of the section

   \[ Q_i = \bigcap_{j=1}^{m} R_j \]

   with the membership function

   \[
   \mu_{k} (a_i, a_j) = \min \{ \mu_{kj} (a_i, a_j), k, l = 1, m, \}
   \]

   where \( m \) is the number of alternatives.

3. Determination of a fuzzy subset of non-dominant alternatives \( A \mu_{\omega_0} \)

   \[
   \mu_{\omega_0} (a_i) = 1 - \sup_{a_j \in A} \left( \mu_{\omega_0} (a_i, a_j) - \mu_{\omega_0} (a_j, a_i) \right).
   \]

4. Construction of the fuzzy relation \( Q_2 \) (the second convolution of output relations \( R_j \))

   \[
   \mu_{\omega_0} (a_i, a_j) = \sum_{j=1}^{m} \omega_j \cdot \mu_{\omega_0} (a_i, a_j), \quad \sum_{j=1}^{m} \omega_j = 1, \omega_j > 0, \quad j = 1, n,
   \]

   where \( m \) is the number of criteria; \( \omega_0 \) is the coefficient of the relative importance of the criteria.

5. Determination of the fuzzy set of non-dominant alternatives \( A \mu_{\omega_0} \) in the set \( A \mu_{\omega_0} \), ordering of alternatives by the degree of their non-dominance

   \[
   \mu_{\omega_0} (a_i) = 1 - \sup_{a_j \in A} \left( \mu_{\omega_0} (a_i, a_j) - \mu_{\omega_0} (a_j, a_i) \right).
   \]

6. Finding the general set of non-dominant alternatives (the intersection of sets \( Q^n \cap Q^m \) with the membership function)

   \[
   \mu_{ND} (a) = \# \min \left( \mu_{\omega_0} (a), \mu_{\omega_0} (a) \right).
   \]

7. Determination of the best alternative \( a^* \) from the condition

   \[
   \mu_{ND} (a) = \sup_{a \in A} \mu_{ND} (a).
   \]

Consider the fleet of power oil transformers of the power system, which have different operating periods. It is necessary to determine the optimal sequence of scheduled, unscheduled or emergency removal for repair or replacement of power transformers. That is, at a certain time interval, the operational personnel (manager) has the following alternatives \( a_i \) to decision-making: \( a_1^{CT}, a_2^{CT}, ..., a_n^{CT} \) out of service or to replace with the new \( CT_1, CT_2, ..., CT_n \), respectively.

An assessment of alternative solutions should be carried out according to the following criteria: \( C_1 \) is the probability of failure of the power transformer in the interval of observation time; \( C_2 \) is the risk of disturbance of the dynamic stability of the system during the introduction into the repair or replacement of the power transformer; \( C_3 \) is the losses of consumers due to violation of dynamic stability, expenses for repair or full replacement of the power transformer; \( C_4 \) is the term for eliminating the consequences of an emergency situation and restoring the scheme of the normal regime.

Quantitative evaluation of alternatives according to individual criteria requires the power transformer modeling to assess the technical condition and failure probability, as well as analysis of the EPS state and emergency risk determination in case of electrical equipment failure in the conditions of planned or emergency out of service of the power transformer.

**4.3 Power transformer simulation to assess the failure probability**

For today, as stated, there is a sufficient number of mathematical models for the technical condition diagnostics of the power transformer, determination of the type, nature and extent of the defect, as well as, failure probability in the interval of observation time [12]. Depending on the available information about the technical condition of individual units of the power transformer, two types of models to determine the probability of failure were developed.

The dynamics of changes in diagnostic parameters over time can be obtained based on information of complex tests for the power transformer, in particular, the DGA results.

In this case, the use of corresponding mathematical models for predicting changes in technical condition and residual life of units of electrical equipment is the most appropriate. It is possible to determine the term of the diagnostic parameter violation of the permissible limits or the probability of a parametric failure at any moment of time in the observation time interval \( \Delta t \).

Secondly, for the power transformer, there is no information about the technical condition on the basis of which it is possible to reliably identify the possible defect and determine the probability of its parametric failure.

Statistical data on the functioning of the power transformer of the given type, the voltage and power class to form the distribution functions of failure probability are used to estimate the power transformer probability in the corresponding mathematical failure models [13]. The distribution functions of failure probability on the basis of the general set of events are formed and in the general case are not probabilistic characteristics of a separate power transformer. The use of these distribution functions of failure probability allows us to obtain an approximate estimate of failure probability of a particular unit of equipment that
needs to be adjusted taking into account the operation history, the recovery level of the resource after repair and other factors.

For the power transformer and other EPS elements, on the basis of statistical data on failures of the general set of objects at the interval of observation, the types of distribution functions \( F(t) \) were determined. The obtained types of distribution functions \( F(t) \) were checked in accordance with the Pearson \( \chi^2 \)-squared test in all areas of observation. Also, the parameters of the distribution functions \( F(t) \) are determined based on the use of least squares and maximum likelihood methods. Formation of the functions \( F(t) \) of units of electrical equipment of a certain type of EPS, for which there are no retrospective data on failures, was performed on the basis of expert evaluation. Parameters of the function of failure-free operation with the subsequent approximation in the form of functions with fuzzy set parameters are determined [14].

The basic distribution functions of failure probability for power transformers, which are derived from the general set of events, are shown in Fig. 1.

Ensuring reliable prediction of failure probability of power transformers on the time interval \( \Delta t \) by modifying the failure probability distribution function of the power transformer is performed taking into account the following factors [15]:

- availability of a workable state at the time of observation;
- taking into account the value of the total operational technical resource;
- the level of recovery of the resource after repair at the time of observation.

4.4. Simulation of the EPS state and technical condition of the power transformer for emergency risk assessment

In this article, we considered the influence of accidental changes in the electrical network topology associated with the planned or emergency out of service of the power transformer on the emergency risk under electrical equipment failure, in particular, the technical risk assessment of disturbance of dynamic stability. Fig. 2 represents the algorithm of priority determination of power transformers developed on the basis of risk assessment of an emergency situation in the EPS.
To determine the probabilistic risk component according to a given model of EPS functioning, the developed mathematical and software RISK-ST, RISK-EPS was used. With the help of statistical simulation, the random process of changes in the electric network state, which is determined by the state of elements efficiency and load change at the estimated time interval of observation is simulated. The mathematical model and algorithm for emergency risk assessment under electrical equipment failures (Fig. 3) are described in detail [15].

The considered algorithm for determining the emergency risk of the EPS under electrical equipment failure is presented for the case when the emergency situations set consists of one event: dynamic stability disturbance of the EPS.

5. Test results of decision-making on power transformers operation in the EPS

Fig. 4 shows the test 6-machine scheme of the EPS subsystem which contains five power oil transformers CT1-CT5 with different operation lifetime. The presented test scheme of the EPS model is meshed, has a limited throughput capacity of overhead transmission lines and designed for operation at a centralized electricity supply, which corresponds to the characteristics of Ukraine electric networks.

The state parameters of the test scheme change in the following ranges:
1. The voltage at the node number № 101 varies in the range of [0.95;1.05] Unom.
2. The power of load nodes varies in the following ranges:
   – № 4: P ∈ [860;1,060] MW, Q ∈ [450;550] MVAr;
   – № 6: P ∈ [540;660] MW, Q ∈ [180;220] MVAr;
   – № 100: P ∈ [585;715] MW, Q ∈ [180;220] MVAr;
   – № 202: P ∈ [900;1,100] MW, Q ∈ [580;720] MVAr.

The active power in the generation nodes is accepted unchanged and equal to:
1. № 1: P = 400 MW;
2. № 3: P = 400 MW;
3. № 7: P = 0 MW (synchronous compensator);
4. № 201: P = 1,200 MW;
5. № 203: P = 1,200 MW.

According to the results of power transformers diagnosis using the developed mathematical models in [16, 17], defects with significant development were not identified. At the same time, the high level of the total operating resource of the power transformer with a significant lifetime increases the risk of the power transformer failure. The failure probability of the power transformer at the observation time interval determined using the basic distribution functions of failure probability, which are adapted to the actual operating conditions by the expert estimation of the failure rate λ(Δt), are given in Table 1.

![Algorithm for emergency risk assessment under electrical equipment failures](image-url)
As a result of power transformers ranking at the observation time interval $\Delta t=3$ months, CT$_3$ has the highest failure probability $F(\Delta t)=0.5$ pu.

The forecast dispatch schedule of the EPS maximum load for the I–IV observation time intervals is shown in Fig. 5.

The results of statistical simulation of the operation mode of the EPS test scheme in the initial state for risk assessment of dynamic stability disturbance under electrical equipment failures for different seasonal loads at the I–IV observation time intervals are presented in Table 2.

The algorithm implementations number for statistical simulation of the operating conditions of the EPS test scheme is $n=1,000$.

Fig. 6 shows the histogram of influence distribution of elements failure for the test scheme on the total risk of EPS dynamic stability disturbance on the IV observation time interval.

Analysis of the histogram in Fig. 6 and Table 2 shows that in the normal initial mode, the total risk of EPS dynamic stability disturbance in the IV observation time interval is respectively $R(\Delta t)=0.0078$ pu.

The greatest contribution to the risk of EPS dynamic stability disturbance on the IV observation time interval is made by failures of the overhead transmission lines L1-2, L5-6, L8-200 and power transformer.

### Table 1

| Name | CT$_3$ | CT$_4$ | CT$_5$ | CT$_1$ | CT$_2$ |
|------|--------|--------|--------|--------|--------|
| | ATDCTN-26700/500/220 | ORDC - 533000/500 | ORDC - 533000/500 | ATDCN-500000/500 | AODCTN 333000/500 |
| Operation lifetime $t_1$, year | 47 | 47 | 46 | 29 | 24 |
| $F(t_1)$ | 0.999998 | 0.99926 | 0.99905 | 0.62168 | 0.57136 |
| $F(t_1 + \Delta t)$ | 0.999999 | 0.99942 | 0.99926 | 0.63118 | 0.58181 |
| $F(\Delta t)=\frac{F(t_1 + \Delta t)-F(t_1)}{1-F(t_1)}$ | 0.5 | 0.223 | 0.2195 | 0.0251 | 0.0244 |
The calculation results of quantitative characteristics for the risk of EPS dynamic stability disturbance after out of service of power transformers $\text{CT}_1$–$\text{CT}_5$ in the mode of passing the load schedule of the EPS subsystem are given in Table 3.

Table 3

| Observation time interval | Sample of power transformers in the EPS, which are out of service | $\text{CT}_1$ | $\text{CT}_2$ | $\text{CT}_3$ | $\text{CT}_4$ | $\text{CT}_5$ |
|--------------------------|---------------------------------------------------------------|--------------|--------------|--------------|--------------|--------------|
| I                        | 0.635                                                         | 0.281        | 0.117        | 0.134        | 0.162        |
| II                       | 0.105                                                         | 0.145        | 0.088        | 0.143        | 0.127        |
| III                      | 0.080                                                         | 0.133        | 0.085        | 0.143        | 0.116        |
| IV                       | 0.271                                                         | 0.152        | 0.104        | 0.134        | 0.151        |

Analysis of the results of Table 3, for example, for the power transformer $\text{CT}_1$, shows that out of service at the I time interval is characterized by a high level of total risk of EPS dynamic stability disturbance $R(\Delta t)=0.635$.

The simulation results of ranking of the power transformer out of service according to the evaluation criteria $C_2$–$C_5$ of alternative solutions for the I–IV observation time intervals are presented in Tables 4–6.

Table 2

| No | Element name of the EPS scheme | EPS risk of dynamic stability disturbance $R(\Delta t)$, pu | Observation time intervals $\Delta t=3$ months |
|----|--------------------------------|-------------------------------------------------|---------------------------------------------|
| 1  | $G-1$                         | 0.002                                           | I: 0.001, II: 0.003, III: 0.001, IV: 0.002   |
| 2  | $L1-2$                        | 0.003                                           | I: 0.111, II: 0.005, III: 0.009             |
| 3  | $\text{CT}_1$                 | 0                                               | I: 0, II: 0, III: 0                          |
| 4  | $L3-4$                        | 0                                               | I: 0, II: 0, III: 0                          |
| ... | ...                            | ...                                             | ...                                         |
| 7  | $L2-5$                        | 0.007                                           | I: 0.01, II: 0.009, III: 0.007              |
| ... | ...                            | ...                                             | ...                                         |
| 30 | $G203$                        | 0.005                                           | I: 0.004, II: 0.003, III: 0.003, IV: 0.005  |

As an example, the simulation results of EES modes at the IV observation time interval are presented in order to justify the adoption of optimal decisions regarding the ranking of the power transformer out of service.

Using the Saati method and expert evaluation results of criteria importance, we will determine the weighting factors of the criteria importance based on the following preference system at the IV observation time interval of operation:

$C_2$ dominates $C_1$ with the rate of $b_{21}=5$;
$C_2$ dominates $C_4$ with the rate of $b_{24}=7$;
$C_4$ dominates $C_2$ with the rate of $b_{42}=4$;
$C_5$ dominates $C_1$ with the rate of $b_{51}=9$;
$C_4$ dominates $C_3$ with the rate of $b_{43}=3$;
$C_1$ dominates $C_4$ with the rate of $b_{14}=2$.

According to the formed relations, the paired comparison matrix is obtained and the eigenvalues of the matrix are determined:
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\[
A = \begin{bmatrix}
    b_1 & 1/b_2 & b_3 \\
    b_{21} & b_{22} & b_{23} \\
    1/b_{31} & 1/b_{32} & b_{33}
\end{bmatrix} = \begin{bmatrix}
    1 & 1/2 & 7 \\
    2 & 1 & 1/3 \\
    1/7 & 3 & 1
\end{bmatrix};
\]

\[\lambda_1 = 5.087; \quad \lambda_{23} = -1.044 \pm 3.087.\]

The system of equations for determining the weighting coefficients of importance optimization criteria:

\[
(1-5.087) \cdot \omega_1 + 0.5 \cdot \omega_1 + 7 \cdot \omega_1 = 0;
2 \cdot \omega_1 + (1-5.087) \cdot \omega_2 + 1/3 \cdot \omega_3 = 0;
\omega_1 + \omega_2 + \omega_3 = 0.
\]

The obtained vector of weighting coefficients of optimization criteria has the form

\[
\Omega = \begin{bmatrix}
    \omega_1 \\
    \omega_2 \\
    \omega_3
\end{bmatrix} = \begin{bmatrix}
    0.483 \\
    0.253 \\
    0.264
\end{bmatrix}.
\]

We build convolutions \(\mu_{k_i}(a^T_i, a^T_j)\), \(k, l = 1, 5\), and the elements \(r^i_j\) will be determined in accordance with the rules on the basis of the preferences

\[
r^i_j = \begin{cases}
1, & \text{if } i\text{-th alternative is better } j\text{-th the } k\text{-th criterion;} \\
0, & \text{if the alternatives are the same for the advantage or } j\text{-th alternative the worst } j\text{-th the } k\text{-th criterion.}
\end{cases}
\]

To determine the optimal solution within the limits of the considered lifetime of the power transformer and EPS, we will perform the ranking of alternatives \(A\) according to the criteria \(C\) using indicators \(\succ\) — «better»; \(\prec\) — «worse»; \(\approx\) — «equally».

\[
\mu_{\omega_i}(a^T_i, a^T_j) = \begin{cases}
    a^T_i \begin{bmatrix}
        a^T_{i1} & a^T_{i2} & a^T_{i3} & a^T_{i4} & a^T_{i5}
    \end{bmatrix} \\
    a^T_j \begin{bmatrix}
        1 & 1 & 0 & 0 & 0 \\
        0 & 1 & 0 & 0 & 0 \\
        1 & 1 & 1 & 1 & 1 \\
        1 & 1 & 0 & 1 & 1 \\
        1 & 1 & 0 & 0 & 1
    \end{bmatrix}
\end{cases}
\]

Definition of the first convolution

\[
\mu_{\omega_i}(a^T_i, a^T_j) = \begin{cases}
    a^T_i \begin{bmatrix}
        a^T_{i1} & a^T_{i2} & a^T_{i3} & a^T_{i4} & a^T_{i5}
    \end{bmatrix} \\
    a^T_j \begin{bmatrix}
        1 & 0 & 0 & 0 & 0 \\
        0 & 1 & 0 & 0 & 0 \\
        0 & 0 & 1 & 0 & 0 \\
        0 & 0 & 0 & 1 & 0 \\
        0 & 0 & 0 & 0 & 1
    \end{bmatrix}
\end{cases}
\]

Definition of a set of non-dominant alternatives for \(Q\):

\[
\mu_{\omega_i}(a^T_i) = \min_{j=1}^{n} (a^T_i, a^T_j) \quad k, l = 1, 5.
\]

Definition of the second convolution

\[
\mu_{\omega_i}(a^T_i) = (1 1 1 1 1).
\]

Definition of a set of non-dominant alternatives for \(Q\):

\[
\mu_{\omega_i}(a^T_i) = 1 - \sup_{a^{CT}_i} \left(\mu_{\omega_i}(a^{CT}_i) - \mu_{\omega_i}(a^{CT}_i)\right).
\]

\[
\mu_{\omega_i}(a^{CT}_i) = (0 0 0 0 0).
\]

The most effective preventive decision on risk reduction of dynamic stability disturbance is the alternative  \(a^{CT}_i\) with the degree

\[
\mu_{\omega_i}(a^{CT}_i) = 1.0,
\]

that recommends the removal of the power transformer CT for repair.

The simulation results of determination of the optimal solution for the power transformer out of service according
to the $C_1$–$C_4$ estimation criteria of alternative solutions for the I–IV observation time intervals are presented in Table 7.

Table 7

| Observation time intervals | $CT_1$ | $CT_2$ | $CT_3$ | $CT_4$ | $CT_5$ |
|---------------------------|--------|--------|--------|--------|--------|
| I                         | 0      | 0      | 1.0    | 0.50532| 0      |
| II                        | 0      | 0      | 1.0    | 0.50534| 0.50334|
| III                       | 1.0    | 0      | 0.50534| 0      | 0      |
| IV                        | 0      | 0      | 1.0    | 0      | 0      |

The most effective preventive decision on risk reduction of dynamic stability disturbance is the alternative $a^{CT}_1$, with the degree $\mu(a^{CT}_1)=1.0$, that recommends the removal of the power transformer $CT_1$ out of service, and on others the power transformer $CT_5$ out of service dominates.

A comparative calculations analysis of dynamic stability of EPS under out of service of the considered power transformers according to the developed model confirmed the coincidence with the characteristics of emergency situations that arose during the actual operation of power grids of the power company.

6. Discussion of the results of complex simulation of the EPS state and technical condition of the power transformer

The developed approach to select of power transformers ranking is based on the technical condition assessment of the power transformer, risk assessment of emergency situations in the EPS and electrical network state under the power transformer out of service.

The complexity of applying risk assessment at enterprises now consists in the absence of information about real losses in case of electricity supply disruption of consumers and electricity suppliers. With the development of economic and legal aspects of the electricity market, this disadvantage will be less noticeable.

Advantages, in terms of risk assessment of the power transformer failure, are as follows:

- the consequences of failure, both for consumer and electricity supplier are taken into account;
- account is taken of operation lifetime and voltage level;
- the failure probability is determined on the basis of technical condition assessment taking into account the predicted location and defect nature.

The obtained information concerning the possible state of the EPS subsystem is the basis for developing an algorithm for making efficient decisions regarding the operation strategy of the power transformer and the preventive state control of the EPS subsystem.

For further research, it is necessary to accumulate information about models of the technical condition assessment of power transformers with more objects in different regions of the power grid. This obviously requires the mobilization of significant organizational and technical measures with power supply companies. The results can be implemented at power plants and power supply companies.

The application of the proposed methodology at enterprises will increase the efficiency, objectivity in assessing the real situation and, as a consequence, increase the lifetime of power transformers.

7. Conclusions

1. The structure of the decision-making model was developed for priority determining of the power transformer out of service on the basis of using the Pareto method, which has a high degree of consistency of ratings for various experts.

2. The developed algorithm of complex simulation for the EPS state and technical condition of the power transformer for emergency risk assessment under the power transformer out of service can be used for “on-line” forecasting of the accident risk.

3. The complex simulation for the EPS state and technical condition of the power transformer was carried out for making decisions of priority determining of the power transformer out of service, which confirms the acceptable efficiency of the applied approach when drawing up schedules of power transformer maintenance. This approach allows predicting the EPS state both in terms of nodes, and the technical state of electrical equipment.

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