Mathematical model of the processes of restoration of power equipment in power systems by criterion of the index of technical condition

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Abstract. The analysis of information about the joint use of reliability indicators and the technical condition index in assessing the state of the main electrical equipment on the example of power distribution schemes to the power system (PDPSP) of modern thermal power plants is given. The authors proposed to enter a new parameter – the index of technical condition for failure (ITCF). Technical assessment carried out by matching the actual values of the parameters of the technical state of the functional nodes with values set normative and technical documentation, as well as manufacturers, and then determine the index of the technical condition, the technical condition index to the failure of functional units and equipment for timely planning of repairs and prevent accidents. The paper presents the results of research of algorithms which allow us to form an improved approach to planning the repair program, taking into account the peculiarities of operation of the equipment.

Comparison the index of technical condition and reliability indicators
Reliability indicators have variable beginning and characterize the probability of a certain event occurring or the fulfillment of specified requirements. They do not reflect the current technical condition, and only take into account statistical data about failures.

The technical condition can be described by using the index of technical condition (ITC), which takes into account the state of each node included in the unit of equipment, and the system in General. The index of technical condition takes values in the range from 0 (the worst value) to 100 (the best value).

But if we take into account the individual characteristics of the failed electrical equipment, the operating conditions and technical parameters of different elements, they are different, so the calculation of reliability indicators using a single technology for the entire set of lines is not possible, since this would have to combine non-identical elements in one group. Thus, the reliability indicators defined for a group of different parameters of the state of the main electrical equipment are a special case and the failure flow parameter (FFP), calculated in this way, is the failure rate in a heterogeneous set of electrical equipment. To eliminate this disadvantage proposed to calculate the reliability of the state of the main electrical equipment by using indicators for a line of unit length.
Evaluation of technical state of main technological equipment is determined by comparing the actual values of the parameters of the technical state of the functional nodes with values set normative and technical documentation, as well as the organizations-manufacturers, and the subsequent definition of the technical condition indices of functional units and equipment in General.

By combining reliability indicators with ITC, you can introduce a new concept, the technical condition index for failure. Imagine the current state as a combination of various factors that take into account the operating conditions (intersecting engineering structures and natural objects, climatic conditions, consumer remoteness, etc.) and the technical condition determined by the ITC.

For each unit of equipment, it is proposed to calculate reliability indicators monthly, as well as the index of technical condition. By analyzing failures, you can deduce a pattern that they occur under a certain combination of influencing factors, certain defects, and environmental conditions. The weather is cyclical, and we can see that failures are repeated in certain periods.

The average failure rate parameter or failure rate calculated statistically using the formula 1 is used as a characteristic of the failure rate.

$$\hat{\omega}(t) = \frac{\sum_{i=1}^{N} m_i(t+\Delta t) - \sum_{i=1}^{N} m_i(t)}{N \Delta t}, \Delta t \ll t$$  \hspace{1cm} (1)

Where $m_i(t)$ – is the number of failures of the object until time $t$; $N$ – is the number of tested objects.

The average time to failure for a restored object is determined similarly to this indicator for a non-restored object, using the formula 2:

$$\hat{T}_{O_{CP}} = \frac{1}{n} \sum_{k=1}^{n} t_{OK},$$  \hspace{1cm} (2)

where $t_{OK}$ – running time to n-th failure, $n$ – number of failures from the start of operation to the end of monitoring.

The calculation of the index of technical condition of functional nodes and the generalized node (ITCFN) is carried out using the formula 3:

$$ITCFN = 100 \times \sum_{i}^{(CW_i \cdot MGP_i)}$$  \hspace{1cm} (3)

Where: $CW_i$-weight coefficient value for the i-th group of technical condition parameters; $MGP_i$-score of the i-th group of technical condition parameters.

Imagine the state of PDSPS as a combination of various factors that take into account the operating conditions (intersecting engineering structures and natural objects, climatic conditions, distance of the consumer, length of the overhead line, etc.) and the technical condition determined by the ITC. Calculation of the index of technical condition of a unit of basic technological equipment ITC is carried out using the formula 4:

$$ITC = \sum(KBY_i \cdot ITCFN_i)$$  \hspace{1cm} (4)

where:

$CW_i$- weight coefficient value for the i-th functional node or generalized node;

$ITCFN_i$ – index of the technical condition of the $i$-th functional node or generalized node.

Considering the reliability index and the ITC calculated according to the method [2] together, we can introduce a new concept, the index of technical condition for failure (ITCF) for this line. ITC is a value that is numerically equal to the maximum value of ITC when FFP is different from zero.
If units of basic technological equipment have several functional units of the same type, the minimum index of technical condition among such functional units is used to calculate the technical condition index of such a unit of basic technological equipment.

If the index of technical condition of the main technological equipment exceeds the value "50" the technical condition index of one of the functional units of such equipment does not exceed the value "25", then the technical condition index of such equipment is assigned the value "50".

Calculation of the technical condition index is carried out in accordance with 4, if the number of functional units of the main electrical equipment with a technical condition index not exceeding the value "50" is less than 15 percent of the total number of such functional units. If the number of functional units of the main electrical equipment with a technical condition index not exceeding the value "50" is equal to or more than 15 percent of the total number of such functional units, the calculation of the technical condition index of such equipment is carried out using the formula 5:

\[ ITC_e = \sum \frac{ITCN_i}{NFN} \]  

where: NFN - the number of functional nodes with a technical condition index that does not exceed the value "50"; ITCN_i - index of technical condition of the i-th functional node with a technical condition not exceeding the value "50" [3].

Based on the received statistical data, the calculation is made the failure flow parameter (FFP) by formula

\[ \omega = \frac{l}{L \cdot T} \]

where \( l \) - the length of the failed PDSPS section for the considered time period; \( L \) - the total length of all PDSPS included in the analysis zone; \( T \) - the considered time period [5].

The failure rate parameter calculated using the PDSPS length allows us to evaluate the reliability depending on the individual characteristics of each line without averaging their parameters [2].

When studying the reliability of electric power systems, an extensive list of additional indicators is used. One of them is the mean of time to failure:

\[ T_H = \frac{8760}{\omega} \]

Additional indicators of reliability considered and the availability factors and forced outage. Since these coefficients are determined by the element's recovery time, which, as indicated earlier, is proposed to be excluded from the calculation, their determination also becomes impractical.

The probability of failure-free operation (PFFO) is often specified as an additional indicator of reliability. If the billing period is one year long, the PFFO is determined using the formula:

\[ P = e^{-\omega} \]

The proposed method for calculating the reliability of the main electrical equipment is based, in contrast to existing methods, not on the use of the number of failures and elements in the group, but on determining the reliability of the main electrical equipment depending on their lengths and individual characteristics.
The algorithm for calculating the index of technical condition for failure is shown on figure 1.

**Figure 1. The algorithm for calculating the index of technical condition for failure**

This algorithm works as follows. Two parameters are required for the calculation, the index of technical condition and the failure flow parameter. We compare the failure rate parameter with zero. If the failure rate parameter is strictly greater than zero, then we consider the current value of the technical condition index to be the technical condition index for failure. At the output of the algorithm, in this case, we get the value of the technical condition index for failure and recommendations about the need for maintenance and repair measures. If the failure rate parameter is zero, we get the current value of the technical condition index at the output. The algorithm for calculating the index of technical condition for failure, it is recommended to implement the current algorithm for finding the index of technical condition.
Assessment of the technical condition of the main technological equipment is the process of determining the integral indicator of technical condition (index of technical condition). Evaluation of technical state of main technological equipment is determined by comparing the actual values of the parameters of the technical state of the functional nodes with values set normative and technical documentation, as well as the organizations-manufacturers, and the subsequent definition of the technical condition indices of functional units and equipment in General.

**Algorithm for finding the index of technical condition, taking into account the failure flow parameter.**

Using the algorithm for finding the index of technical condition for failure, we add the structure of the algorithm for finding the index of technical condition.

Figure 3 presents an algorithm for calculating the index of technical condition, taking into account the index of technical condition for failure. The algorithm is based on the method of calculating the index of technical condition in accordance with the Order of the Ministry of energy of the Russian Federation dated July 26, 2017 No. 676 "on approval of the methodology for assessing the technical condition of the main technological equipment and transmission lines of power stations and electric grids". The algorithm is based on calculating the index of technical condition [2]. In addition to this, the index of technical condition and the failure, index of condition for specific PDSPS equipment are compared as a result of calculations. As a result, the maximum value of the index of technical condition is determined, at which there is a probability of failure of the overhead power line associated with the technical parameters of the PDSPS.

In accordance with Figure 3, when the condition is met, the type of technical condition is determined taking into account the scale of technical condition and a message is issued about reaching the value of the index of technical condition for failure, as well as recommendations on the type and timing of repair (maintenance).

During operation, when the index of technical condition reaches the value of the technical condition index for failure, the probability of an emergency on this overhead power line increases. This means that unscheduled repairs or maintenance must be performed.

For the PDSPS, it is proposed to calculate reliability indicators and determine indicators monthly. Failures can occur due to natural anomalies that occur during certain periods of the year. Thus, it is proposed to split all indicators first by month, then in each month to make a breakdown by reasons for failures:

- failure for an unspecified reason;
- failures caused by staff errors;
- adverse weather conditions;
- overlap the wiring lines of the trees;
- damage to power line elements;
- sketches of foreign objects;
- birds;
- fire;
- failures of the substation equipment.
Figure 2. Algorithm for calculating the ITC based on the predicted ITC for failure

The algorithm works as follows: a unit of equipment is divided into functional nodes, which are divided into groups of technical condition parameters. Each parameter of technical condition is compared with the idealized value specified in the normative technical documentation and (or) instructions of manufacturers. According to the range of values of technical condition parameters, the parameters are evaluated using a score scale. After that, a group of parameters is evaluated, which are assigned a certain "weight" in the node evaluation. Next, the node is evaluated, which is also assigned its "weight" in the evaluation of the hardware unit. After that, the unit of equipment is evaluated (index of technical condition). The resulting index is compared with the index of technical condition for failure. Based on the results of comparison, if the conditions are met, recommendations are made about the need for maintenance and repair activities. Then, based on the received index of technical condition, using the technical condition scale, we get the type of technical condition and a message.
about reaching the value of the index of technical condition for failure, and recommendations on the type and timing of repair (maintenance).

To determine the index of technical condition for failure in the Mathcad software environment, the program shown in figure 4 is compiled.

\[
\text{prog}(\text{PPO}, \text{ITS}, n) := \begin{cases} 
\text{ITS}_0 & \rightarrow \text{ITS}_1 \\
\text{for } i \in 1..n & \\
\text{if } \text{PPO}_i > 0 & \rightarrow \text{ITS}_i \\
\text{otherwise} & \rightarrow \text{ITS}_{i-1}
\end{cases}
\]

**Figure 3.** Program code for calculating ITSF

The program code is based on comparing the current technical condition index of electrical equipment with the technical condition index at which a failure was detected, which is determined by comparing the FFP value with a zero value. The technical condition index specifies the index of the technical condition of the waiver.

This innovation in the algorithm for calculating the index of technical condition will allow optimizing the planning of repairs, choosing the most favorable period for the production of work, and also preventing technological violations.

There is a specific dependence between the technical condition index and the failure flow parameter individual for elements of PDSPS. The failure status index for each PDSPS element will allow to planning the repair program taking into account the operating conditions and features of equipment operation.

The presented algorithms allow us to form an approach to planning the repair program taking into account the peculiarities of operation of each element of the main electrical equipment, which in turn will increase the reliability of PDSPS as a whole.

By combining reliability indicators with ITC, you can introduce a new concept, predicted technical condition (PTC). Imagine the current state as a combination of various factors that take into account the operating conditions (intersecting engineering structures and natural objects, climatic conditions, distance to the consumer, the length of PDSPS elements, etc.) and the technical condition determined by the ITC.
We can note that in winter, when ITC is over 90, the probability of failure decreases, regardless of weather conditions. It can be concluded that it is better to repair PDSPS elements in May–June, in order to eliminate the possibility of failures associated with high air temperature in the summer. By performing additional maintenance can reduce the probability of failure in the winter.

It can be concluded that in July, when the ITC approaches a value equal to 60, the probability of failure increases due to damage to PDSPS elements and associated equipment. This is due to aging equipment and lack of timely maintenance. Failure is unlikely with an ITC greater than 70.

If the index of technical condition reaches the ITSF value, the probability of an emergency on the thermal power plant elements increases. Therefore, if the values are equal, the calculation and analytical program, according to [1], makes recommendations about the need for maintenance and / or repair of the equipment.
Figure 6. The number of failures of PDSPS hardware over four years.

Comparative calculation of power equipment for the time period 2016-2019 are shown at table 1.

The considered algorithms allow to form an improved approach to planning the repair program, taking into account the peculiarities of operation of the selected power equipment. When entering the index of technical condition for failure of a specific part of equipment into the calculation algorithm, it is possible to optimize the planning of the repairing program. By analyzing the results of calculations, it is possible to choose the most favorable period for the production of work, and, as a result, prevent technological violations.

Table 1. Comparative calculation of power equipment for the time period 2016-2019.

| № equipments | Average value | FFP x 10^5 | Average ITC | Values | ITCF |
|--------------|---------------|-------------|--------------|--------|------|
| 1            | 32            | 76,91       | 81,46        |        |
| 2            | 538           | 82,61       | 82,4         |        |
| 3            | 134           | 81,04       | 77,51        |        |

The table shows that the ITSF for the studied nodes differs from the one regulated by the regulatory and technical base, which is equal to 60, and is in the range from 77.51 to 82.4, with the failure flow parameter in the range from 32 to 538 x 10^5. For these values, according to the proposed method of assessing the technical condition, it is necessary to include the equipment in the repair program.

To determine the index of technical condition for failure, it is proposed to compare the failure flow parameter monthly, which does not take into account the reasons for failure that are not related to the technical condition of the PDSPS. If this parameter of the failure flow is greater than zero, then the current value of the index of technical condition can be considered the index of technical condition for failure.

When the value of the index of technical condition approaches the value of the failure index, the program issues recommendations about the need for maintenance or repair.

With the accumulation of information about failures and the index of technical condition, we will get more accurate values of the index for failure.

Conclusions.
In this paper the presented algorithms allow us to form an improved approach to planning the repair program, taking into account the peculiarities of operation of the equipment in question. When you enter the ITSF technical condition index calculation algorithm for a specific element of the PDSPS, it is possible to optimize the planning of the repair program. By analyzing the results of calculations, it is possible to choose the most favorable period for the production of work, and as a result, prevent technological violations.
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