Managing Methods Development for the Production Assets of Thermal Power Plants in Conditions of Insufficient Statistical Data

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Abstract. The paper is devoted to the proposal of a method for making managerial decisions on the replacement of production assets of TPPs in conditions of insufficient statistical data on failures and changes in the technical state of an equipment. It is proposed to use a probabilistic method to predict the period of replacement of production assets, based on the formation of a hypothesis about the law of distribution of equipment failures and its reaching the limit state, which determines the stock of possible operating time of a production asset. As an economic criterion for the period of replacement of a production asset, the use of an indicator of production profitability is considered, the advantage of which is the ability to make a decision to change equipment before the expiration of the life resource in the event of an unsatisfactory economic result of its operation, which is critical in solving the problem of ensuring the economic sustainability of TPPs. In the absence of an investment resource for the replacement of a production asset, it will be possible to recommend the conservation of an ineffective asset, which will minimize economic losses.

1. Introduction

To improve the efficiency of managing the production assets of the energy industry from the standpoint of reducing its energy intensity and emissions of harmful substances into the atmosphere, it is necessary to ensure its transition to an innovative development path that takes into account global trends in scientific and technological development in the world energy.

The radical innovative restructuring of the main generating facilities, which in Russia, in the first place, include thermal power plants (generate more than 61% of electricity and 33% of heat) will be facilitated by technologies that reduce the specific fuel consumption for the production of energy products. These include:

- combined cycle and gas turbine units using high-temperature gas turbines of large, medium and low power,
- coal power units with supercritical (545 °C, 24 MPa) and ultrasupercritical (580-620 °C, 28-32 MPa) steam parameters [1, 2, 3].

In addition to the transition to more advanced technologies for the production of energy products, it is also necessary to solve the problem of maintaining in working order the currently operating TPPs, most of whose production assets are outdated not only morally, but also physically, and require a large amount of current and major repairs [1, 4, 5].
Maintenance of obsolete equipment at TPPs leads to an increase in the cost of operating its production assets, the downtime of the power units of the plant increases, which reduces their annual electricity supply. Also, the equipment operates at the limit parameters, and the predicted service life is not restored even after a major overhaul.

To assess the efficiency of operating TPP assets in market conditions, it is necessary to develop scientifically substantiated methods for calculating the timing of equipment replacement according to the indications of the profitability of its use. The availability of such methods will allow obtaining a reasonable period of its replacement upon reaching the profitability of the value of the alternative investments.

This approach will make it possible to make decisions on the further use of a production asset and its inclusion in investment programs for comprehensive modernization and repairs or its decommissioning based on economic principles. Thus, the decision to change equipment can be made before the expiration of its life resource in the event of an unsatisfactory financial result of its operation, which is important for ensuring the economic sustainability of TPPs. In the absence of funds to replace equipment to minimize financial losses, it will be possible to recommend the conservation of ineffective equipment.

2. Background
Currently, the assessment of the technical condition of production assets is carried out mainly by an expert method, based on the opinion of experienced employees who have worked at TPPs for more than a dozen years. Unfortunately, the change of owners, turnover and lack of adequate reproduction of personnel responsible for the operation of TPPs has led to the fact that the information content of age equipment maps leaves much to be desired. This forces to look for alternative methods for assessing the degree of damage and the reliability of the operation of power equipment [6, 7].

The analysis of scientific works [6, 8, 9, 10] in the field of production assets management demonstrates the possibilities for further development of new methods for assessing the technical condition of TPP equipment, as well as their application into the TPP production assets management system.

Scientific studies [6, 11, 12] show that the assessment of the state of complex equipment should be based on its decomposition into structural elements and their subsequent analysis. For these purposes, the use of the factor analysis method, which involves the construction of aggregate or integral indices, is well suited.

The integral index makes it possible to assess the state of a production asset based on a quantitative assessment of the state of its structural elements and an assessment of the degree of their influence on its performance [13, 14]. In this case, the indices are relative dimensionless units. The sequence of evaluating the integral index of the equipment condition is presented in Table 1.

| Stage | Description |
|-------|-------------|
| 1     | The production asset is decomposed into the main structural elements that determine its performance. The parameters of these elements that determine their state are model factors. |
| 2     | A point scale for assessing the state of the model factors is formed. |
| 3     | The parameters of the state of structural elements are compared with the normative requirements of the documentation for their operation. Based on this comparison, the factors of the model are assessed on a point scale. |
| 4     | Weight coefficients are established, reflecting the influence of the factors of the operability of structural elements on the operability of the production asset. |
| 5     | The calculation of integral indices of the state of structural elements and on their basis of the production asset as a whole is carried out. |
The value of integral index asset status may be interpreted according to Table 2.

**Table 2. Interpretation of the values of the integral index of the state of the production asset.**

| Integral index | Interpretation of the integral index value |
|----------------|--------------------------------------------|
| 0 – 0.3        | replacement of structural elements of the production asset or its overhaul is required |
| 0.3 – 0.5      | organization of additional control over the condition of the asset between scheduled inspections and planning of the organization of repairs is required |
| 0.5 – 0.8      | development of preventive measures to improve the reliability of the asset is required |
| 0.9 – 1.0      | regular operation of the production asset |

A separate issue is the determination of the period of replacement of the production asset. It represents the period of time remaining before the equipment reaches the limit state, at which it is no longer advisable to operate it for technical or economic reasons. Thus, there are two possible scenarios for reaching the limiting state of an asset:

- technical (the parameters of the state of the equipment or its structural elements regressed and do not correspond to the normative ones, which led to their inoperability),
- economical (the service life of the equipment has ended in accordance with the indicators of the financial result from its use).

The term of the production asset replacement can be estimated using the statistical methods of the theory of reliability [15, 16]. At the same time, they require a large amount of statistical data, which must contain information on failures and parameters of equipment operation.

### 3. Methods

Due to the fact that statistics on failures and operating parameters of production assets are often lacking or insufficient, it is proposed to use probabilistic methods to estimate the equipment replacement period. For their application, a limited number of statistical data are required, allowing the derivation of the laws of distribution of random variables.

Perform forecast replacement period production asset on the basis of the following limited statistics:

- normatively defined asset life,
- data on the state of the asset obtained in accordance with the factor model,
- samples of the operation modes of the asset,
- samples of technological violations.

Probabilistic methods are based on the formation of a hypothesis about the distribution law, in this case, about the probability of equipment failure, which determines the stock of possible operating time of a production asset.

Figure 1 shows a model for assessing the limiting state of an asset and the stock of its possible operating time based on the determination of the probability of equipment failure.

Failures of a production asset during its operation have economic consequences for TPPs that require assessment. This estimate can be obtained by calculating the possible economic damage due to the occurrence of a failure for each selected structural element of the asset and then summing them up [17, 18].

The following components of economic damage can be distinguished:

- costs of restoration work in the event of an asset failure ($D_1$);
- cost of loss of means of production ($D_2$);
- costs associated with the deterioration of the operational parameters of an asset ($D_3$);
- start-up costs ($D_4$);
- costs of compensation for environmental damage ($D_5$);
• costs from partial non-payment of installed capacity \((D_6)\);
• lost profit from underproduction of energy \((D_7)\).

Figure 1. Model for assessing the limiting state of an asset and the stock of its possible operating time.

The cumulative economic damage from the failure of a production asset is determined by the magnitude of the risks and damage caused by the failure of its structural elements. The risks of failure of structural elements are determined by the probabilities of their failure or violations of standard operating conditions. Moreover, in practice, several types of failures of structural elements may occur simultaneously. Thus, to assess the economic damage from the failure of an asset, it is necessary to assess the risks of failure of its structural elements.

Table 3 shows an economic and mathematical model for assessing economic damage, based on the study of the risk of failure of a production asset.

Table 3. Economic and mathematical model for assessing economic damage from the occurrence of a production asset failure.

| 1. Assessment of the risk of failure of a production asset |
|-----------------------------------------------------------|
| \( R(f)_t = P(f)_t \cdot D(f)_t \) | \( P(f)_t \) – the probability of a failure when the asset state parameter takes a critical value in year \( t \); \( D(f)_t \) - economic damage; \( f \) - type of failure |

| 2. Assessment of the risk of failure of a structural element of a production asset |
|-----------------------------------------------------------------------------------|
| \( R(f_e)_t = \sum_{i=1}^{A(n) \cdot 2^{n-1}} P(s(i)) \cdot D(s(i)) \cdot s_i \) | \( s_i \) – combination of the occurrence of several types of failures \( f_e \) of element; \( P(s(i)) \) - probability of occurrence of a combination of element failures in year \( t \); \( D(s(i)) \) – economic damage; \( A(n) \) – number of combinations of element failures (placements with repetitions); \( n \) – number of failure types of element |

| 3. Assessment of economic damage, independent of the number of failures of structural elements |
|--------------------------------------------------------------------------------------|
| \( D(i)_{max}(s(i))_t = \max \left( \frac{D_4(s(i))_t + D_5(s(i))_t}{D_6(s(i))_t + D_7(s(i))_t} \right) \) | \( D_4, D_5, D_7 \) – start-up costs, non-payment of installed capacity, lost profits from underproduction that occurred in the event of a combination of the onset of failures \( s(i) \) in year \( t \) |

| 4. Assessment of economic damage accumulated by a set of failures of structural elements |
|--------------------------------------------------------------------------------------|

| 4 |
| 4 |
Assessment of the cumulative economic damage and the probability of asset failure

\[ D(s) = \frac{R(s)}{P(s)} \]
\[ D(s(i)) = D^{(1)}(s(i)) + D^{(2)}(s(i)) \]
\[ P(s) = 1 - \sum_{i=1}^{n} (1 - P(t)) \]

To determine the economic feasibility of operating a production asset in the condition of energy market, it is required to assess the asset replacement period based on the economic efficiency indicator, in the role of which production profitability can be used.

The profitability of an asset can be represented as the ratio of the profit received from its operation to the cost of maintenance, which will include the cumulative economic damage arising in the event of a violation of the planned operation of the equipment and depending on its condition and service life:

\[ R(t) = \left[ 1 - e^{-\frac{t}{\tau_0}} \right] \]
\[ D(t) = e^{-\alpha \frac{t}{\tau_0}} \]

where \( t = \tau / \tau_0 \), \( \tau, \tau_0 \) – operating time and service life of a production asset; \( \alpha \) – an indicator reflecting the change in the cost of servicing an asset and the specific profit derived from its use over time; \( Pr(t) \) – profit from the use of the asset (from the sale of energy products on the energy market).

The operating cost of a productive asset increases over its service life, while the profit to be derived from its use decreases. Thus, upon reaching the equality of these indicators, it is possible to determine the economically feasible period of replacement of the production asset.

4. Results and discussion

A graphical analysis of determining the period of replacement of a production asset in terms of production profitability is shown in Figure 2.
On the graph, the blue area represents the profit from the operation of the asset, which decreases with an increase in its service life. The red line reflects the increase in the costs of use of the production asset. The point of intersection of the area and the line makes it possible to determine the expedient period for replacement the production asset of the TPP.

The period of replacement of a production asset is determined by the period from the beginning of the operation of the equipment until the moment when the profit becomes equal to the cost of its operation. In this case, the equipment should be replaced.

It should be noted that such an approach to determining the period of replacement of a production asset allows making decisions on its replacement before the expiration of the life resource in the event of an unsatisfactory economic result from its operation, which is critical in solving the problem of ensuring the economic sustainability of TPPs. In the absence of an investment resource for the replacement of a production asset, it will be possible to recommend the conservation of this ineffective asset, which will allow minimizing economic losses.

5. Conclusion

The production assets of TPPs include many units of power equipment interconnected by a single technological process. In market conditions, to ensure reliable and continuous operation of TPPs, it is necessary to organize the planning of the process of replacement power equipment based on the condition of the best ratio of income from its use and the risks of failure during operation. Moreover, the risks of failure are expressed in the form of possible economic damage from disruption of the production asset.

The period of replacement of a production asset can be estimated using the statistical methods of the theory of reliability. At the same time, they require a large amount of statistical data, which must contain information on failures and parameters of equipment operation. Due to the fact that statistical data at TPPs are often absent or insufficient, it is proposed to use a probabilistic method to predict the period of replacement of production assets, based on the formation of a hypothesis about the law of distribution of equipment failures and the achievement of a limiting state by it, which determines the stock of possible operating time of a production asset.

As an economic criterion for the period of replacement of a production asset, the application of the indicator of production profitability, which is the ratio of profit to the operating costs, including economic damage from equipment failures, is considered. In accordance with this criterion, the period of replacement of the production asset will come when the profitability value less than one is achieved.

The advantage of the proposed method is the ability to make a decision to replacement a production asset before the expiration of the equipment's life resource in the event of an unsatisfactory economic result of its operation, which is critical in solving the problem of ensuring the economic sustainability of TPPs. In the absence of an investment resource for the replacement of a production asset, it will be possible to recommend the conservation of this ineffective asset, which will minimize economic losses.

6. References

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