Optimization algorithm of thermal power plants repair conditions

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Abstract. The paper presents an algorithm for optimizing the conditions of industrial thermal power plants in terms of repairs to their boiler units and turbine generators, which allows to determine the optimal composition of equipment removed for repair, taking into account the fuel used and the season. The algorithm is based on the dynamic programming method, which allows to set models of turbogenerators and boiler units in tabular form, which, when forming the equivalent characteristics of generators or boilers, allows simultaneous determination of the optimal condition of all equipment for a given electrical and / or thermal load of the power plant. The optimality criterion is the minimum of the total cost of the fresh steam needed to generate heat and power. The optimization algorithm and equipment models are specially adapted to the conditions of industrial power plants.

Keywords: optimization, thermal power plant, power unit, boiler, turbine generator, repair condition, steady state condition.

1. Introduction
The current situation in the market of goods and services sets the task of manufacturers to reduce production costs and thereby increase their competitiveness. Large enterprises with their own sources of power and thermal energy have a significant advantage, due to the constant growth in electricity tariffs from an external supplier.

Sources of distributed generation at an industrial enterprise solve a number of tasks - reduce the cost of electricity transmission, while providing the necessary heat for the process, sell heat, therefore have additional profit, use secondary energy resources, which are a by-product of production, which in turn reduces the cost of heat and electricity and solves environmental problems. The rational management of operating modes of power plants can improve the efficiency of their work.

In the middle of the last century, work appeared on the optimal distribution of loads between turbogenerators [1] and boiler units [2] of thermal power plants, taking into account cross-links [3]. After the collapse of the Soviet Union, a number of articles appeared that focused on the assessment of the efficiency of power plants in the wholesale market [4].

In [5] V.A. Igumenschev and A.V. Malafeev provides an approach to optimize the modes of operation of industrial power supply systems with their own thermal power plants using dynamic programming. However, the complexity of the operation of power plants leads to research in the field of static and dynamic operation of generators together and separately with the system [6–9]. Improving the operation of turbine generators of power plants is also carried out by introducing control systems and assessing their reliability [10]. Problems of distributed generation are engaged in our days [11-12].

The use of mathematical optimization methods for solving problems in the conditions of electric power industry facilities has become widespread. Optimization methods are used to solve power flow control problems of large electric power systems [13-17], using various methods, for example, in [18], the authors proposed to apply the Newton-Raphson method, in [19] the Newton method. The
distribution of active power between the generators of power plants in [20] is solved by applying the guaranteed gain method, and in [21] using a modified sequential equivalent method and dynamic programming.

Research in the field of improving the economic and technological efficiency of industrial power supply systems is relevant, and modern technical tools allow you to simplify the use of complex mathematical apparatus to solve the above problems [26-28].

In this paper, it is proposed to use an algorithm for optimizing the load distribution between boilers and turbogenerators of thermal industrial enterprises, based on the dynamic programming method [21], in order to improve the performance of the power plant as a whole in terms of preventive maintenance.

In addition, the main equipment of industrial thermal power plants was mainly put into operation in the middle of the last century, thus, it is characterized by increased wear and tear and the issue of timely withdrawal for repair is relevant [29,30].

2. Optimization algorithm
Based on the method of calculating the cost of fresh steam [22] and the method of constructing technical and economic models of sources of electrical and thermal power [23-25] and using the optimization algorithm described in [21], a method has been developed that allows forecasting economically viable preventive maintenance regimes block diagram of which is shown in Fig.1.
Begining

\[ D(B;S), P(D;S), C_p, C_{er}, P_{ps}, D_{ps} \]

Load flow calculation

Finding equivalent values of indicators

Formation of equivalent characteristics
\[ D_{ekvi}(B_{ekvi}, S_{ekvi}); P_{ekvi}(D_{ekvi}, S_{ekvi}) \] [21]

Calculation of costs for the production of fresh steam in the normal mode for the winter \( (C_w) \) and summer \( (C_s) \) periods

Alternate shutdown of generators and boilers

Calculation of costs for the production of fresh steam in the winter \( (C_{wi}) \) and summer \( (C_{si}) \) period

\[ d_w=C_w-C_{w_i}; \]
\[ d_s=C_s-C_{s_i}; \]

\[ d_w>d_s \]

For the \( i \)-th element - repair in the summer period

For the \( i \)-th element - repair in the winter period.

Scheduled preventive maintenance

End

Figure 1. Algorithm for the compilation of the optimal scheduled maintenance of the main equipment of power stations
The main initial data for the calculation are:
- process flow diagram of boilers, allowing construction of technical and economic models of boiler units \(D(B;S)\), taking into account their operational capabilities;
- diagrams of turbine generators, allowing the construction of technical and economic models of the generators \(P(D;S)\), taking into account the temperature conditions and the load on the heating and production selections;
- the cost of purchased electricity \((C_p)\) and the cost of energy used \((C_{er})\), accounting for these values allows the analysis of the impact of tariffs on energy resources on the optimal control of operating modes of power plants;
- electric \((P_{ps})\) and thermal \((D_{ps})\) load of power station, allows to calculate the balance of power and heat for given conditions.

The method consists in determining the total cost of fresh steam required for the generation of electricity and heat, which goes to production and district heating, and produced by the power plant in the summer and winter, with alternate shutdown of boilers and turbine generators.

The costs are compared with the reference value calculated for normal operation and the corresponding season (all equipment is included) - \(dw\) and \(ds\). Based on the values \(dw\) and \(ds\), a conclusion is made about the season for putting the equipment into repair - the smaller of the indicators is considered economically viable.

As a result of the calculation, a schedule of preventive maintenance of boilers and turbogenerators of industrial thermal power plants with a mark about the optimal output season is formed.

Using the developed method allows to predict the optimal operating conditions of the power plant and to calculate its main indicators - the cost of fresh steam in total for the power plant and for a separate boiler unit, the cost of fresh steam and electricity, thereby allowing us to estimate the profit of the electrical installation.

3. Practical use in terms of industrial thermal power plant
Experimental calculations were carried out in the conditions of an industrial power supply system with its own thermal power plants. The block diagram of the thermal scheme of an industrial power plant is shown in Fig. 2.

The power plant has 6 turbogenerators and 8 boiler units operating on two steam pipelines, the nominal parameters of the equipment are given in Table. 1. A mixture of blast furnace gas, coke oven gas and natural gas is used as the primary energy carrier in a power plant.
Table 1. The main nominal parameters of thermal power equipment of the power plant

| TG station number | Turbine type | P_{total}, MW | Boiler station number | Boiler type | D_{total}, t / h |
|-------------------|--------------|---------------|-----------------------|-------------|-----------------|
| TG - 1, 2, 3      | PT-12-35/10M | 12            | B - 1, 2, 3           | «GANOMAG »  | 150             |
| TG - 4            | PT-30-2,9    | 40            | B - 4, 5              | TP-200      | 200             |
| TG - 5, 6         | AT-25-1      | 25            | B - 6, 7, 8           | TP-200      | 200             |

For each of the above equipment built technical and economic models according to the method given in [24-25].

Using the optimization method described above and the algorithm implemented in the KATRAN software complex, the cost of fresh steam (in rubles / h) needed to cover the electrical and thermal load of the power plant was calculated.

The calculation results for the normal and repair modes with the alternate withdrawal of the boiler units and turbogenerators of the power plant for repairs, during its operation according to the summer and winter heat schedules, are given respectively in Table. 2 and tab. 3.

Having carried out an assessment of the total cost of steam according to the criterion of their minimum, a plan is drawn up for the repair of boilers and turbogenerators of the power plant, the results are shown in Table. four.

Table 2. Calculating the cost of steam generation in the alternate output to repair station boilers

| Season          | Steam generation costs, RUB | B-1  | B-2  | B-3  | B-4  | B-5  | B-6  | B-7  | B-8  |
|-----------------|----------------------------|------|------|------|------|------|------|------|------|
| Total condition |                            |      |      |      |      |      |      |      |      |
| winter          | 35490.15                   | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 13506.75 | 71259.75 | 72694.13 | 6893.1 | 37539.45 | 48624.3 | 13506.75 | 71259.75 | 288019.8 | 295955.4 |
| summer          | 36204.53                   | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 38722.69 | 29726.7 | 38295.08 | 49603.05 | 49888.13 | 38722.69 | 29726.7 |
| Output to repair B-1 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 287926.7 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 293722.3 |
| Output to repair B-2 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 288951.3 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 294767.6 |
| Output to repair B-3 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 283176 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 288876 |
| Output to repair B-4 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 316523.7 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 322895 |
| Output to repair B-5 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 285877.4 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 291631.7 |
| Output to repair B-6 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 274792.5 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 280323.8 |
| Output to repair B-7 |                            |      |      |      |      |      |      |      |      |
| winter          | SMC                        | 34465.5 | 40240.8 | 6893.1 | 37539.45 | 48624.3 | 48903.75 | 71259.75 | 274513.1 |
| summer          | SMC                        | 35159.25 | 41050.8 | 7031.85 | 38295.08 | 49603.05 | 49888.13 | 72694.13 | 280038.7 |

Output to repair B-8
Table 3. Calculating the cost of steam generation with the alternate output to repair station turbine generators

| Output to repair | Season | Reception Costs | Generation Costs | Transmission Costs | Total Costs |
|------------------|--------|----------------|------------------|-------------------|-------------|
| TG-1             | winter | 1110577.6      | 878168.19        | 21799.18          | 2010544.98  |
|                  | summer | 1229267.02     | 887263.89        | 21766.73          | 2138297.64  |
| TG-2             | winter | 1110383.7      | 878164.09        | 21871.23          | 2010419.02  |
|                  | summer | 1229303.5      | 887258.69        | 21803.57          | 2138365.75  |
| TG-3             | winter | 1191626.99     | 850757.87        | 21743.71          | 2064128.58  |
|                  | summer | 1296041.64     | 863739.27        | 21810.34          | 2181591.24  |
| TG-4             | winter | 1157835.5      | 853491.37        | 21808.66          | 2033135.54  |
|                  | summer | 1276580.09     | 863794.64        | 21766.05          | 2162140.77  |
| TG-5             | winter | 1157835.5      | 853491.37        | 21808.66          | 2033135.54  |
|                  | summer | 1276580.09     | 863794.64        | 21766.05          | 2162140.77  |
| TG-6             | winter | 1157495.41     | 853450.27        | 21729.39          | 2032675.08  |
|                  | summer | 1275630.21     | 863764.88        | 21771.42          | 2161166.51  |

Table 4. Planned repairs of the main equipment of the power plant

| Station number | Season | winter | summer |
|----------------|--------|--------|--------|
| B-1            | -      | SMC    |        |
| B-2            | -      | SMC    |        |
| B-3            | -      | SMC    |        |
| B-4            | -      | SMC    |        |
| B-5            | -      | SMC    |        |
| B-6            | -      | SMC    |        |
| B-7            | -      | SMC    |        |
| B-8            | -      | SMC    |        |
| TG-1           | -      | SMC    |        |
| TG-2           | SMC    |        | -      |
| TG-3           | -      | SMC    |        |
| TG-4           | -      | SMC    |        |
| TG-5           | SMC    |        |        |
| TG-6           | -      | SMC    |        |

4. Conclusion
The developed method of optimizing the repair modes of industrial thermal power plants allows you to select the shutdown period of the main equipment, taking into account the electrical and thermal load of the power plant, the heterogeneity of the fuel used, the structure of the thermal circuit, limitations on the equipment operation (technical and economic models built on the basis of regime maps of boilers and diagrams modes of turbine generators).

This approach allows not only to make schedules of repairs, but also to forecast changes in the cost of production of fresh steam due to changes in the cost of purchased and secondary energy resources.

The use of this technique will improve the efficiency of distributed generation sources. The economic effect from the implementation of the results will be 35 thousand rubles. per year per 1 MW of installed capacity of the power plant without additional capital investments.

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