Optimal Control of Plant Assets at Electric Companies

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***Abstract*— In this paper the authors formulated and solved the problem of optimal management of production assets of the energy companies. The urgency of the task is due to the need to minimize the financial costs of energy companies to maintain the equipment in good technical condition. The problem of drawing up optimal repair programs in terms of ensuring a given level of reliability is solved. The application of synthesized models and algorithms as a part of the corresponding software is shown.**

Keywords— production assets; optimal management; repair program; power engineering; industry; reliability; neural network

I. Introduction

Today, effective control of plant systems or assets is a key financial performance driver of businesses (efficiency of equipment operation, its repair and maintenance costs, raising profits due to savings on the processes of bringing equipment into proper technical condition) [1]. The power industry is a high-performing and resource-intensive branch of the economy.

The metric of production asset control is a set of engineering and financial performance indicators that describe business operations by various aspects and provide an overall assessment of its performance. Here, there is an explicit link between indicator groups that are contradictory, for example, improving equipment robustness entails extra costs [2].

When managing production assets in order to eliminate the inconsistency of technical and economic indicators, it is necessary to ensure their balance.

Thus, the goal of production assets control is to ensure the balance of performance indicators [3–4], and as a result – the overall improvement of plant assets.

Reaching this goal requires tackling technical tasks (assessment of current technical condition, forecasting of equipment reliability, etc.) with driving the target financial performance. (due to repair and diagnostics of the equipment based on real technical condition).

Ensuring energy companies technological equipment robustness and durability, review of maintainability [5] and production risks [6] helps to ensure equipment functionality and stable production cycle. Here, the financial factor defines opportunities and scope of tackling engineering tasks.References

II. Problem statement

The system analysis shows that the mainstay of production performance the production processes of the energy companies is technical equipment as the most common component of production asset in the power industry.

To maintain technological equipment robustness, companies allocate significant funds, therefore, cost-cutting here is extremely relevant.

The technical effect of tackling this task is ensuring robustness of the power system (due to repair and diagnostics of the equipment based on real technical condition), while the social effect (through automation of the optimal repair program calculation) here is reducing routine work and improving the intelligence of talent (due to the appearance of a powerful analytical toolkit for solving an extremely vital task of managing production assets).

The research focuses on the optimal control of repair programs of electric companies that belong to the grid structure (interregional distribution grid companies).

III. Methods

In terms of applied systems analysis, a company (interregional distribution grid company) is a multilevel hierarchical structure: system – subsystem – component featuring a variable number of sublevels (Fig. 1).

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A piece of equipment is a component (specific fuse, switch, transformer, etc.), subsystems are a complex facility (for example, a power station), systems are a business unit of a grid operator (for example, a power distribution zone or production department).

Here, a system as a whole is a control asset, and the synthesis of solutions is carried out in a bottom-up way: from the component to the system.

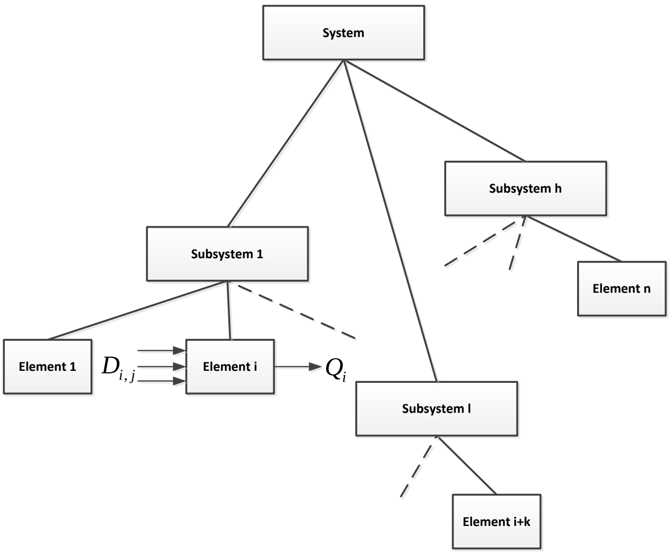

Fig. 1. System structure

Due to the fact that the elements inside the subsystems, as well as the subsystems themselves, are connected in parallel, sequentially or use a mixed connection circuit, then there is a possibility of calculating the reliability of the system in general.

A distinctive feature of such control assets is a large number of similar small-sized components (few input and output points) and wide range of equipment (combined in appropriate groups of equipment).

The power system as a control asset features large sizes and bulks of information being processed across various hierarchical levels. This means that to process the stated amount of data, highly efficient and productive methods should be used, for example, methods of the artificial neural networks theory.

The purpose of the production assets control system is to ensure robustness and savings. Therefore, the task in hand can be clarified and worded as the minimization of the financial aspect (repair program cost) with the maintained level of system robustness.

One of the key financial indicators that determine the effectiveness of production assets use is the life-cycle cost of ownership, which embraces initial spending and the costs of maintaining functionality with the given robustness during operation.

The second component is ensured by the optimal planning and running of the repair programin the power system. Therefore, a financial indicator can be chosen as an optimality criterion – costs of repair program running, and a robustness metric can be failure probability of a control asset, which is the limit for the task in hand optimal management of production assets.

The minimal optimality criterion at some time intervals of control (the planning period is the period of running the optimal repair program prepared originally) while sticking to the limits is achieved by developing an optimal repair program.

Here, control is the decision to include a defect in the repair program, respectively, the control variables have boolean values.

The decomposed optimal control task for production assets is formalized as follows:

$$\begin{cases} S = \sum_{i=1}^{n} \sum_{j=1}^{m} S_{i,j}\left(D_{i,j}\right) \to \min \\ Q \le Q_{кр} \end{cases} \tag{1}$$

where $D_{i,j}$ is the j-th defect on the i-th system component, $i = \overline{1,n}$, n is the total number of system components, $j = \overline{1,m}$, m is the total number of defects per system component; Q_i is failure probability for the i-th system component; $S_{i,j}\left(D_{i,j}\right)$ is the cost of repairing the j-th defect on the i-th component; S are total costs of repair program; T is a control period (planning the optimal repair program); Q is failure probability for a control asset with the optimal repair program implemented; $Q_{кр}$ is a threshold value of failure probability.

To measure financial indicators operation of production assets and the optimality criterion (cost of implementation of the repair program of production assets), we build a financial-mathematical model based on calculating the costs of correcting a typical defect of an individual system component.

The input data of the mathematical model include details about the type of the defect and the component, the output data embrace the cost of running the current version of the repair programin the entire system. The source of information for these calculations is a checklist with data on labor and material resources required for piece of equipment repair. It also contains details on weighting coefficients that vary depending on external conditions – region, weather, terrain. Weighting factors are needed to take into account the degree of importance (influence) of defects, the elimination of which is planned during the implementation of the optimal repair program for the network company.

To measure the robustness of system components, we build a mathematical model of an artificial neural network, which helps to predict failure probability, depending on the inclusion of the defect in the repair program.

Actually, an artificial neural network is a multi-layer perceptron of direct propagation of a signal with one intermediate layer and sigmoid neuron activation functions.

The number of neurons in the intermediate layer and the form of neuron activation functions are chosen based on the corollaries of the Kolmogorov-Arnold-Hecht-Nielsen theorem [7].

The neural network training was based on the Levenberg–Marquardt algorithm, an activation function is the sigmoid one [8]. To measure system robustness as a whole, we have developed algorithms based on known formulas that help to calculate the robustness of complex systems [9].

Based on failure probability values for each component using the known robustness measurement formulas for non-redundant systems (serial connection) and parallel redundant systems (parallel connection), we determine robustness indicators for each subsystem and the system as a whole (bottom-up).

To find the bottom of the optimality criterion, iterative algorithms are synthesized. They include procedures for measuring the system robustness parameters and determining the economic criterion value using the mathematical financial model. The search procedure is based on the updated sieve method [10].

For each system component, failure probability is measured, provided there is no effect on detected defects (with their complete correction) as well as the cost of the repair programfor each component. Subject to the above procedure of measuring robustness, we identify corresponding values of failure probability for subsystems and the system as a whole, as well as the cost of the repair program, provided there are no defects.

Based on the range of failure probability defined above, the required robustness value of the system and the interval of its accuracy calculation is set.

As a rule, the cost of the repair program calculated in such a manner many times exceeds the financial resources available to the network interregional distribution company. Therefore, it needs to be optimized so that the level of reliability of the system is not lower than the preset level for the available amount of financial resources.

This interval is divided into a number of sub-intervals with a fixed step determined by the required accuracy of robustness calculation (for both the system and subsystems). For each value of the system's failure probability, failure options are determined – these include total robustness indicators of the subsystems of the previous hierarchical level.

After all possible options for the given failure probability value are determined, the transition to the lower level of hierarchy (subsystem) is carried out, and the procedure is repeated to measure robustness indicators for each subsystem, with combinations of failure probability values calculated at the component level.

Further, all possible combinations meeting the robustness value of the corresponding subsystem obtained above are calculated. For each combination of robustness indicators, the cost of repair program is calculated.

When the level of components is reached, the reverse "bottom-up" process takes place and the cost of the repair program for each component, subsystem and the system as a whole that meet the requirements of given robustness is calculated.

Among the obtained cost values, we select the minimum one that ensures the given system robustness with minimum repair program.

IV. OPTIMAL MANAGEMENT SYSTEM OF PRODUCTION ASSETS

The task in hand is voluminous and features bulks of data being processed. To deal with it, the computational procedures have been improved and now include parallel computing and the synthesis of multiple control sets per each iteration of the search algorithm.

This makes it possible to significantly reduce the computational costs of intermediate calculations when constructing an optimal repair program.

The structure of the system of optimal management of production assets of a network interregional distribution company is shown in Fig. 2.

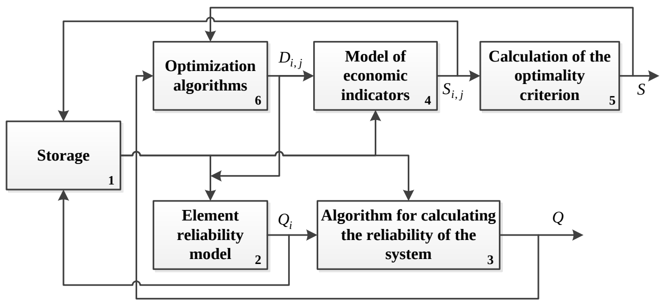

Fig. 2. Structure of the optimal management system for production assets

The storage (Block 1) contains data on the network topology, equipment specifications, statistics (for defects and failures, which is used to form training and test samples in the construction and adaptation of an artificial neural network. In addition, the depository contains information on process flow diagrams and the cost of work, which will be scheduled as a part of the optimal repair program).

Block 6 (it contains synthesized algorithms for calculating the optimality criterion extreme point) synthesizes a set of control actions that serve as the basis for financial metrics (Block 4) and the optimality criterion values (Block 5).

Blocks 2 and 3 determine robustness parameters that correspond to this control set (the probability of failure of a particular system element, as well as subsystems and the system in general, based on the formulas for calculating consecutive, parallel and mixed connections of elements / subsystems).

Block 6 analyses the obtained data for compliance with terms (1), after which a new control set is synthesized. The iterative procedure is repeated until a control set meeting the above conditions (1) is determined.

V. Implementation of the optimal management of production assets within EAM system Optima

Based on the modified methods and techniques offered within the scope of this work, EAM Optima class system developed by «Best Soft» has been used to calculate the optimal repair program for energy companies, including in particular network interregional distribution companies. The information system Optima has web-interfaces and consists of two separate subsystems – user and administrator systems.

Calculation of the probability of failure by groups of equipment, which is used in planning the optimal repair program, is shown in Fig. 3.

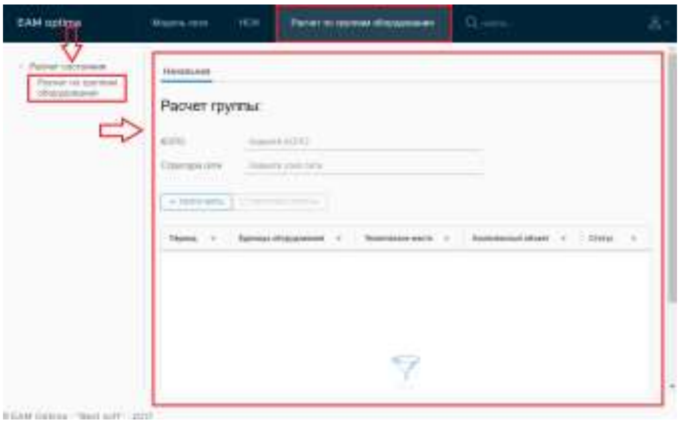

Fig. 3. Calculation of reliability indicators for groups of equipment in EAM Optima

Creation of an optimal repair program (the annual plan of measures for bringing production assets into proper technical condition with a specified reliability level) is shown in Fig. 4.

The planning can be carried out both for the entire system of a company, and for its individual subsystems, organizational and technical locations.

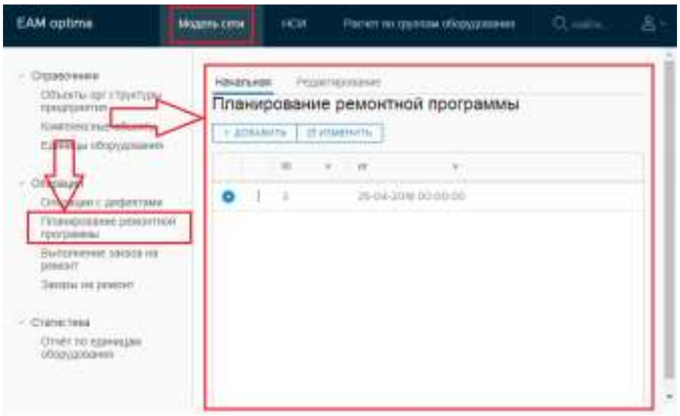

Fig. 4. Planning an optimal repair program in EAM Optima

Fig. 5 shows the example of the fragment of an optimal repair program for production assets of an energy company calculated in EAM Optima.

Fig. 5. The example of optimal repair program in EAM Optima

The proposed concept optimal management of production assets of energy enterprises was adopted by hierarchical distribution power systems, and can be customized for companies generating electric and thermal energy.

Artificial neural networks are used to calculate the probability of equipment failure. The implemented methods and approaches were tested in the Optima EAM-system developed by «Best Soft» and showed their high efficiency in planning repair programs that are optimal in terms of financial costs and ensuring the maintenance of production assets in the proper technical condition at a given level of reliability of elements, subsystems and the system in general.

References

[1] Protalinski O.M., Protalinski I.O., Hoards O.N. Optimal control system of the energy enterprises production assets. Automation and IT in energy. 2017. No. 4 (93). Pp.5-8. (in Russian)

[2] GOST R 55235.1-2012. Practical aspects of business continuity management. Asset management. Requirements for optimal management of production assets. (in Russian)

[3] Bauer K. KPIs-The metrics that drive performance management. Information Management. 2004. Vol. 14, No. 9, pp. 63-64.

[4] Bhatti M.I., Awan H.M., Razaq Z. The key performance indicators (KPIs) and their impact on overall organizational performance. Journal of Quality & Quantity. 2014. Vol. 48, No. 6, pp. 3127-3143.

[5] Yashchura A.I. System of maintenance and repair of power equipment. Handbook. Moscow. Publ. of the NTS ENAS. 2006. 504 p. (in Russian)

[6] Chernova G.V. Risk management Practice at the enterprise level. Saint Petersburg. Peter. 2000. 176 p. (in Russian)

[7] Yecht-Nielsen R. Kolmogorov's mapping neural network existence theorem. IEEE First Annual International Conference On Neural Networks. 1987. Vol. 3. Pp. 11-13.

[8] Stepanov P.V., Protalinsky O.M., Shcherbatov I.A. Neural network model of forecasting the state of equipment of energy enterprises. Mathematical Methods in Engineering and Technology - MMTT. 2017. Vol. 12. No. 2. Pp. 42-44.

[9] Balakirev V.S., Bolshakov A.A. Reliability and diagnostics of automated systems. Saint Petersburg. Publishing house of Polytechnical Institute. UN-TA. 2018. 144 p. (in Russian)

Ravindran A. Ravindran R. K. Optimization techniques. Moscow. World. 1986. Vol. 1, 2. 320 p. (in Russian)