ARTIFICIAL INTELLIGENCE FOR AUTOMATED ENERGY LOSS SEARCH

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Abstract

Automated search for energy losses is difficult due to the lack of artificial intelligence methods to minimize the risks associated with staff errors. The aim of the work is to develop an artificial intelligence method for automated search for energy losses. Based on the application of the heuristic method of artificial intelligence and digital twin technologies, algorithms for automated energy loss search have been developed. The results of the study were implemented using the complex of technical means (CTM) "Energy" using examples of searching for losses of electricity and energy carriers at energy-intensive enterprises in Russia and Azerbaijan. The application of the research results in automated energy metering systems minimizes the risks associated with personnel errors.

Keywords: search for energy losses, automated accounting tools, personnel errors, digital twins, artificial intelligence.

I. Introduction

The Fourth Industrial Revolution (Industry 4.0) envisions a new approach to production based on the widespread integration of information technologies into industry, large-scale automation of business processes, and the proliferation of artificial intelligence [1]. Information technologies (IT) enhance the efficiency of professional activities and reduce costs, which is why investments in IT continue to grow [2–5]. Despite the expected outcomes, the failure rate of IT projects remains high. Over a quarter of projects fail as they are either abandoned or canceled, and more than half are completed over budget, behind schedule, and/or without the promised functionality [6, 7].

This situation highlights the relevance of risk management in the implementation of information technologies. The solution to this problem for enterprises using computer-aided design (CAD) systems for technological processes (TP) is discussed in studies [8, 9].

The high efficiency of using automated control systems in mass and large-scale production allows productivity to increase by up to 70%, while also raising the rate of metal removal by 30-50%, with simultaneous stabilization of quality and geometric processing parameters. Electric drives used in CNC machines consume a significant amount of energy, so energy consumption must be considered when selecting them. Assessing energy consumption requires studying the operating parameters of the feed and main movement drives and obtaining information on the current values of technological modes under a certain load. It has been established that the higher the efficiency coefficient, the lower the losses and energy consumption of the electric motor, and the higher its energy efficiency; the motor consumes less energy, heats up less, and has a longer operating life, leading to an increased mean time between failures. It is recommended to use IE3 energy efficiency class motors in CNC grinding machines, as they can operate in an open-loop control system without feedback and with positioning devices. This will allow for cost savings on feedback, which is also an undeniable advantage [10].

A pressing issue for energy-intensive enterprises using automated energy metering systems is the detection of unacceptable energy losses.

II. Research Problem Statement

Sources of energy losses may include unacceptable energy leaks due to poor communication infrastructure, unauthorized connections by unscrupulous users, and faulty measuring devices [11]. Losses are considered acceptable if they do not exceed 5% of the incoming energy flow. To conserve energy and improve energy efficiency [12], the operational personnel of enterprises address the issue of detecting unacceptable energy losses by inspecting communication systems for energy flows and diagnosing measuring devices. This professional activity involves significant labor intensity and requires personnel to spend time in hazardous areas with risks of electric shock or exposure to energy carriers.

The use of automated energy metering systems [13] improves measurement accuracy, preserves measured data, and enables the grouping of measurement channels, which helps to pinpoint areas with unacceptable energy losses [14]. However, this also raises the qualification requirements for personnel. On the one hand, they must be familiar with equipment operating modes and the specifics of the technological process. On the other hand, they need to be proficient users of the automated energy metering system.

To minimize risks associated with human errors, it is advisable to apply artificial intelligence (AI) methods [15] and digital twin technologies [16, 17].

The objective of this work is to develop an AI-based method for automated detection of energy losses.

To achieve this objective, the following tasks are addressed:

1. Development of a network model of digital twins for the energy loss balance circuits.
2. Development and implementation of a method for detecting energy losses in energy-intensive enterprises that use automated energy metering systems.

III. Network model of digital twins for energy loss balance circuits

The initial information for creating the network model of digital twins for energy loss balance circuits is the network model of energy flows within the enterprise, which represents a set of interconnected energy flow balance circuits. For example, at the Chelyabinsk CHP-2 (Combined Heat and Power), such circuits include the circuits of the distribution devices (DD): the main (10 kV main distribution), open (110 kV open distribution), and complete (6 kV complete distribution).
Digital twins of the energy flow balance circuits at the Chelyabinsk CHP-2 are presented in Table 1.

Table 1: *Digital Twins of Energy Flow Balance Circuits*

Contour Name	Input Channel Groups	Output Channel Groups
ChCHP-2	1, 2, 3, 4	5, 17, 18, 19, 20, 21, 22, 23, 24, 25
MD 10 kV	1, 2	5, 6, 7
OD 110 kV	6, 7, 8, 9	15
CD 6 kV	10, 11, 12, 13, 14, 15, 16	17, 18, 19, 20, 21, 22, 23, 24, 25
Sections 1, 2	10	17, 18
Sections 3	11	19
Sections 4	12	20
Sections 5	13	21
Sections 6	14	22
Sections 7	15	23
Sections 8, 9	16	24, 25

The network model of the energy loss balance circuits at the Chelyabinsk CHP-2 is shown in Figure 1.

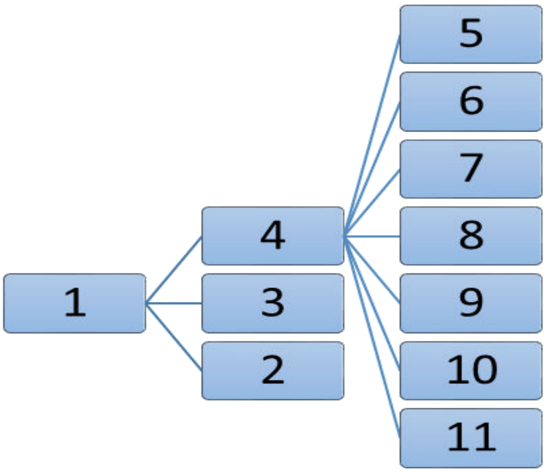

Figure 1: *Network Model of Energy Loss Balance Circuits at Chelyabinsk CHP-2*

IV. Heuristic Artificial Intelligence Method for Detecting Energy Losses

To automate the process of detecting unacceptable energy losses, it is advisable to use artificial intelligence methods to find solutions in the state space. The task is to transition from the initial state to the target state.

The underlying idea of most heuristic algorithms is to evaluate the potential of unexplored vertices in the state space in terms of reaching the goal and to choose the most promising vertex for continuing the search.

The solution to the problem represents a specific sequence of operators that transform the initial state into the target state (Figure 2).

1. Operators gj from the set G are applied to the root of the tree Sn. The resulting vertices form the first level of vertices.

2. Each of the resulting vertices is checked to see if it is the target vertex. If not, the process continues for each of them, forming the second level of vertices. If no operator from G can be applied to a vertex, it becomes terminal (final).

Thus, at each step, two operations are performed: generating a new vertex and checking whether the vertex is the target.

3. When the target vertex is found, the pointers of the arcs are traced in the reverse direction (from the target to the start) to determine the solution path.

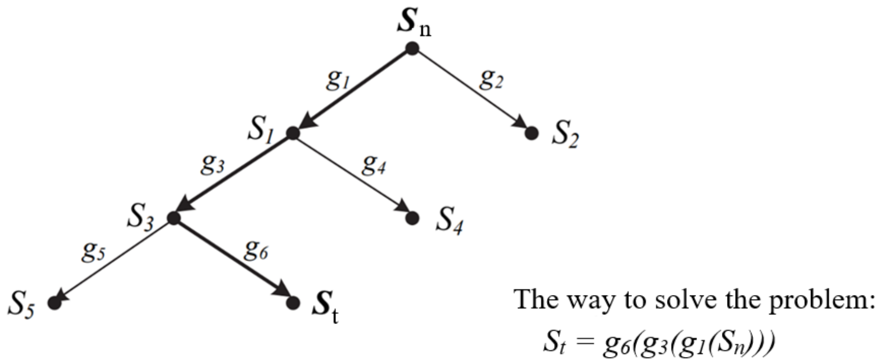

Figure 2: *Solution Tree of the Problem*

Let us consider the method using the network model of energy loss balance circuits at the Chelyabinsk CHP-2 (see Figure 1).

If unacceptable energy losses are detected in Circuit 1 (Chelyabinsk CHP-2), then Circuits 2 (10 kV main distribution), 3 (110 kV open distribution), and 4 (6 kV complete distribution) are checked.

If, for example, unacceptable energy losses are detected in Circuit 6 kV complete distribution, then the sections of the 6 kV complete distribution circuit: 5, 6, 7, 8, 9, 10, and 11 are checked.

As a result, the search area for energy losses is minimized.

V. Implementation of the method for energy carrier loss detection

For Chelyabinsk CHP-2, the network model of energy carrier flows is a set of interconnected balance circuits of energy carrier flows: "Feed Water," "Feed Water for Boilers - Steam," "Fresh Steam," and "Steam 13 kgf/cm²."

The digital twins of the balance circuits of energy carrier flows at Chelyabinsk CHP-2 are shown in Table 2. The network model of the balance circuits for energy carrier losses at Chelyabinsk CHP-2 is presented in Figure 3.

Table 2: *Digital twins of the balance circuits of energy carrier flows*

No	Contour Name	Input Channel Groups	Output Channel Groups
1	ChCHP-2	1, 2	6, 7, 11, 12, 13, 14, 15, 16
2	Feed Water	1, 2	3, 4
3	Feed Water for Boilers - Steam	3, 4	5, 6, 7
4	Fresh Steam	5	8, 9, 10, 11, 12
5	Steam 13 кгс/см2	8, 9, 10	13, 14, 15, 16
6	Feed Water - Steam for Boiler №1	31, 41	51, 61, 71
7	Feed Water	32, 42	52, 62, 72

	- Steam for Boiler №2		
8	Feed Water - Steam for Boiler №3	33, 43	53, 63, 73
9	Feed Water - Steam for Boiler №4	34, 44	54, 64, 74
10	Feed Water - Steam for Boiler №5	35, 45	55, 65, 75
11	Feed Water - Steam for Boiler №6	36, 46	56, 66, 76
12	Feed Water - Steam for Boiler №7	37, 47	57, 67, 77
13	Feed Water - Steam for Boiler №8	38, 48	58, 68, 78
14	Feed Water - Steam for Boiler №9	39, 49	59, 69, 79

The method for detecting unacceptable energy carrier losses is based on the system of measurement channels in the CTM "Energy" system. In this approach, the mathematical model of each balance circuit represents a group consisting of the relative difference between groups of input and output channels. For example, the group of balance circuit No. 3 (Feed Water for Boilers – Steam) will have the following composition: (3+4-5-6-7) / (3+4), meaning its value will represent the relative difference between the input and output flow of energy carriers.

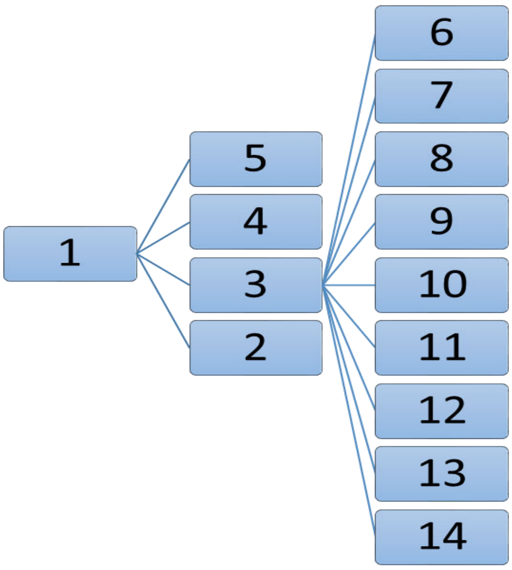

Figure 3: *The network model of the balance circuits for energy carrier losses at Chelyabinsk CHP-2*

If the value of the balance circuit group does not exceed 5%, then the energy carrier losses are considered acceptable. Otherwise, it is necessary to investigate the energy carrier losses in the circuits included in that group.

The method for detection uses the network model of the balance circuits for energy carrier losses (see Figure 2).

If unacceptable energy losses are identified in circuit 1 (Chelyabinsk CHP-2), then circuits 2 (Feed Water), 3 (Feed Water for Boilers - Steam), 4 (Fresh Steam), and 5 (Steam 13 kgf/cm²) are checked.

If, for example, unacceptable energy losses are identified in circuit 3 (Feed Water for Boilers -

Steam), then circuits 6-14 (Feed Water - Steam for Boilers No. 1-9) are checked.

If, for example, unacceptable energy losses are identified in circuit 10 (Feed Water - Steam for Boiler No. 5), the area for loss detection is reduced by approximately 12 times.

For Chelyabinsk CHP-2, as a result of applying the method for detecting energy carrier losses using the CTM "Energy" system, the area for loss detection is reduced by 4 to 12 times.

Thus, mathematical software has been developed that enables the management of the energy loss detection process using artificial intelligence methods and digital twin technologies. The foundation of the developed mathematical software consists of a network model of digital twins for energy loss balance circuits and a heuristic artificial intelligence method that allows for the localization of areas with unacceptable energy losses. Implementing the research results through automated energy metering systems minimizes the labor intensity and time of professional activities in areas where harmful factors may be present.

VI. Conclusions

Based on the application of heuristic artificial intelligence methods and digital twin technologies, algorithms for automated energy loss detection have been developed.

The research results have been implemented using the "Energy" complex of technical means (CTM) with examples of detecting energy and energy carrier losses at energy-intensive enterprises in Russia and Azerbaijan.

The application of the research results in automated energy metering systems allows for the minimization of risks associated with human errors.

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