Laboratory Prototype of the Hybrid Intelligent Multi-Agent System of Heterogeneous Thinking

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Abstract
The problems that arise in dynamic problem environments are greatly complicated by time constraints on decision-making. In such circumstances, the decision maker inevitably simplifies the problem situation and the heuristics for its solution, which reduces the quality of the decisions made. In this regard, it is relevant to develop automated intelligent systems that make it possible to develop recommendations for solving a problem without idealizing and significantly simplifying them in dynamic environments. For these purposes, it is proposed to use hybrid intelligent multi-agent systems of heterogeneous thinking, the laboratory prototype of which, intended for the restoration of a regional power grid after large-scale accidents, is presented in this work.

Keywords 1
Heterogeneous thinking, hybrid intelligent multi-agent system, expert team

1. Introduction

The issues of solving problems in dynamic environments have been actively studied since the late 70s of the XX century [1]. In addition to such non-factors [2] of practical problems as heterogeneity, underdetermination, inaccuracy, fuzziness, incompleteness, the following features arise in dynamic environments: the need to make several interdependent decisions to achieve the goal, the variability of the problem environment, decisions are made in real time [3]. Solving problems in a dynamic environment is typical for operational dispatch control of traffic flows, air transportation, and power grids. Researches [4, 5] have shown the negative impact of time constraints on the quality of decision-making, demonstrating a significant simplification of the heuristics used by the decision-maker. In this regard, the development of intelligent systems is relevant to prepare solutions to problems in dynamic environments without their significant simplification. For this, hybrid intelligent multi-agent systems of heterogeneous thinking (HIMSHT) have been proposed in [6]. They integrate the hybrid intelligent approach [7], the multi-agent programming paradigm [8], and the modeling of heterogeneous thinking processes [9]. To assess the effectiveness of the proposed methods, the planning of restoration of power supply in the regional distribution power grid after large-scale accidents is used as a test problem.

2. The problem of restoring power supply after large-scale accidents

The practical problem of restoring power supply (PPRPS) was formulated in [6]. As a result of solving the PPRPS, a plan for power grid restoration should be developed containing the sequence of switching events, and the sequence of mobile teams trips to perform switching and equipment

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repairing. The following plan's optimality criteria have been determined: minimizing the duration of the priority load shutdown, maximizing the total recovered power consumption, maximizing the indicator of the power grid's stability to subsequent accidents. The initial data for solving the PPRPS are represented by the following sets (due to the large number of properties of the elements of these sets, their descriptions are omitted in the paper): elements of the power grid; the incidence relationship between them; locations; driving routes between locations; repair teams; vehicles; resources for power grid restoration; actions to restore the power grid. In addition, the following restrictions are imposed on the feasible solution: radial structure of the network of energized lines; line capacity; compliance of the balances of active and reactive power; permissible limits of voltage and frequency; consumers not affected by the initial shutdown should not be disconnected as a result of switching; the work must be carried out by employees with the appropriate admission, having necessary resources in their vehicle; vehicle capacity; working hours of teams; teams have to return to base at the end of the shift; if it is required to temporarily divide the power grid, the communication lines between the resulting "islands" must have synchronization equipment for subsequent merging.

According to problem-structural methodology of developing hybrid intelligent systems, to solve practical problem, it need to be reduced to a level, where all its tasks correspond to the "homogeneous problem" model [10]. As a result of the PPRPS reduction, the set of the tasks is obtained and corresponding specialties of experts, whose knowledge is necessary for their solution, are determined:

1. identification of an accident, taking into account the incorrect operation of emergency sensors – the engineer for relay protection and automation;
2. forecasting of power consumption – the engineer for analysis and forecasting of power consumption modes;
3. assessment of the requirements for restoration work – the engineer for the repair of power equipment;
4. routing of repair teams – the head of the power grid district;
5. determination of the switching sequence – the engineer for operating modes;
6. drawing up a recovery plan – the dispatcher of the regional operational and technological control.

To solve the PPRPS, it is proposed to simulate the work of a team of the listed experts to solve the problem and its tasks using the HIMSHT methods.

3. Functional structure of the hybrid intelligent multi-agent system of heterogeneous thinking for restoring power supply

In [6], the HIMSHT model is proposed for solving PPRPS, which formalizes the composition of the system and the relationship of its elements. Based on this model, in [11] the functional structure of the HIMSHT is proposed, presented in Figure 1. It details the composition of the HIMSHT agents, their functionality and the relations between them. The functions of most of the HIMSHT agents are similar to those of the agents of the hybrid intelligent multi-agent system presented in [7]. The interface agent provides user interaction with the system: using the graphical interface presented in the next section, it allows entering the initial data necessary for solving the PPRPS, visualizes the problem solving process and returns solutions. The decision-making agent formulates tasks for the expert agents in accordance with the PPRPS model described in the ontology, providing necessary input data, collects intermediate solutions, makes the final decision at the end of the problem solving process in accordance with the collective thinking method established by the agent-facilitator. The intermediary agent keeps track of the names, models, and capabilities of registered agents, allowing them to find each other. The intelligent technology agents at the top of Figure 1 (logical, analytical, fuzzy, stochastic, and linguistic agents) together with the agent-converter implement heterogeneous methods, models and algorithms for solving problems, dynamically forming a hybrid component of the system. Equipment repair agent, agent of grid area, agent of operational modes, agent-dispatcher, agent of consumption prediction, relay protection agent are the expert agents, which generate solutions by modeling the knowledge and reasoning of experts presented in the PPRPS decomposition, within the framework of collective thinking methods, set by the agent-facilitator. The domain model is a semantic network, the basis for the interaction of agents, is built according to the conceptual model of the PPRPS.

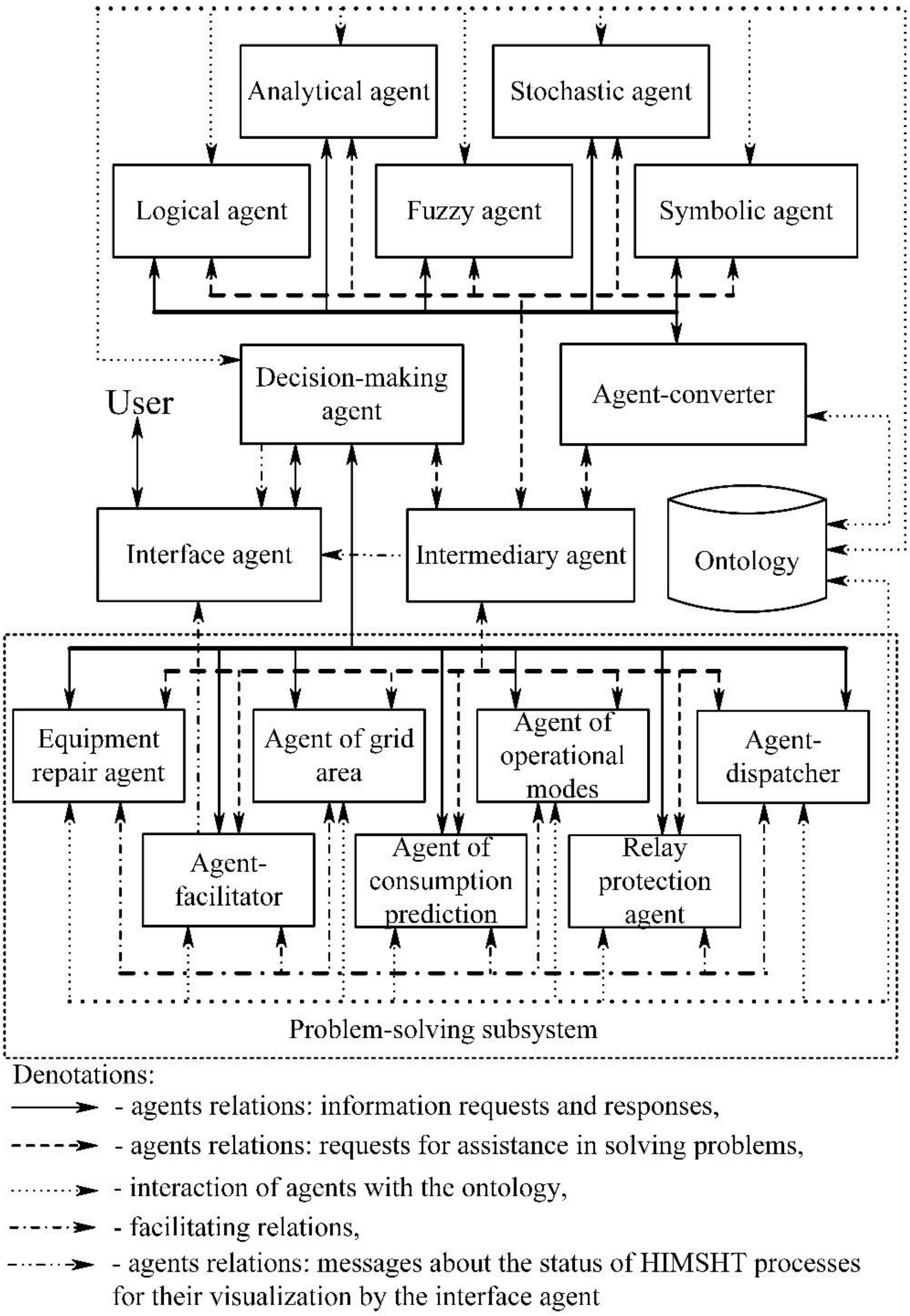

Figure 1: Functional structure of the hybrid intelligent multi-agent system of heterogeneous thinking for restoring power supply

The key difference between the HIMSHT and the hybrid intelligent multi-agent system considered in [7] is the presence of agent-facilitator, which organizes the collective problem-solving process to improve the efficiency of the system, i.e. improving the quality of the proposed solutions and reducing the time for their development. The agent-facilitator identifies the current situation of the problem-solving process in the HIMSHT and activates the relevant "thinking style" of the decision-making agent and the expert agents, using, among others, the "diamond of participatory decision-making" model [9] presented in Figure 2. According to it, problem solving is a three-stage process. At the stage of divergent thinking, agents of the problem-solving subsystem must generate many alternative solutions to the problem posed. The goal of the facilitator agent at this stage is to stimulate by appropriate methods [12] a variety of proposed solutions, which may contradict each other due to the different goals of the agents. If at this stage there are no conflicts and contradictions, despite the use of methods of divergent thinking, it is concluded that the problem has an obvious solution and the process ends. If there are intensive, multiple cognitive conflicts between agents [12], i.e. conflicts about knowledge, beliefs, opinions, the facilitator agent concludes that the problem solving process has moved to the groan stage and it is necessary to take measures to bring the agents' points of view closer together. As the intensity of conflicts decreases, the agent-facilitator makes a decision about the possibility of moving to the stage of convergent thinking. During this stage, the agents of the problem solving subsystem jointly refine the solutions proposed at the previous stages until they receive an agreed collective solution that reflects the diversity of expert knowledge, modeled in the HIMSHT.

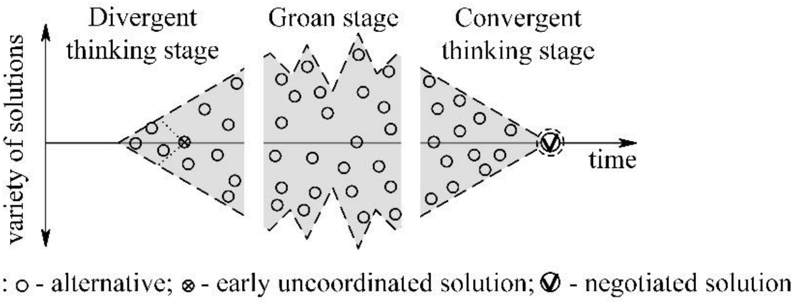

Figure 2: The "diamond of participatory decision-making" model

In [11] the detailed description of agents and their architectures is presented that provide the required functionality. In [13] the heterogeneous thinking protocol was developed that provides the construction of a distributed algorithm for solving the PPRPS and is used in the interaction of the facilitator agent with the decision-making agent and expert agents. Other relationships between agents in Figure 1 are implemented using the standard speech act protocol proposed in [14].

4. Laboratory prototype of the system

Figures 3 – 7 show the user interface of the laboratory prototype of the HIMSHT, built in accordance with the considered functional structure.

Figure 3 shows the main window of the laboratory prototype of the HIMSHT, containing the main menu and the area, in which the windows of the power grid models are located. Using the elements of the main menu, the system user can create, open, save or import models, customize the appearance of open model windows, initiate the work of the HIMSHT agents to draw up the restoration plan of the power grid, and configure the algorithms they use.

Each PPRPS opens in its own window of the power grid model (Fig. 3 shows the single window representing the power grid model built on the basis of the IEEE 14-Bus System problem from [15]), containing the tabs "Linear power grid diagram" (Figure 3), "Diagram of locations" (Figure 4) and "Directories" (Figure 5). At the "Linear power grid diagram" tab (Figure 3), the user builds a power grid diagram in the workspace using standard elements in the upper left part of the tab, and sets the incidence relationship between them. The values of the properties of the power grid elements and their emergency states are specified using the properties panel in the lower left part of the tab. The "Layout" tab (Figure 4), like the "Linear power grid" tab, is divided into three parts, used in a similar manner to describe the locations of the power grid elements and the routes between them. The "Directories" tab (Figure 5) is intended for filling in and editing data on actions and resources for the restoration of the power grid, repair crews, vehicles. To perform any actions with the directory records, the user needs to select its name in the "Directory" field, after which he can edit its records in the table view in the central part of the tab. Navigation through the directory, adding and deleting its entries is organized using the navigator under the tabular view of the directory.

A prerequisite for drawing up a recovery plan is the current state of the linear power grid diagram, the diagram of locations and the directories. In addition, the user should mark the damaged sections of the power grid at the "Linear power grid diagram" tab. After that, the process of planning the restoration of the power grid by the HIMSHT agents can be started by the main menu "Calculation" item.

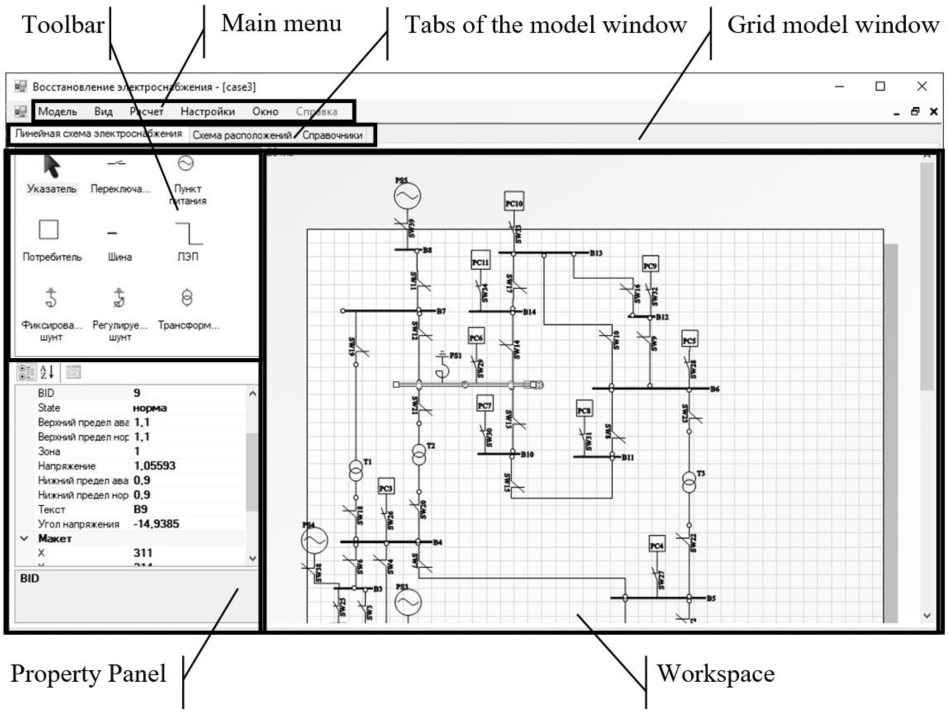

Figure 3: The laboratory prototype of system. "Linear power grid diagram" tab

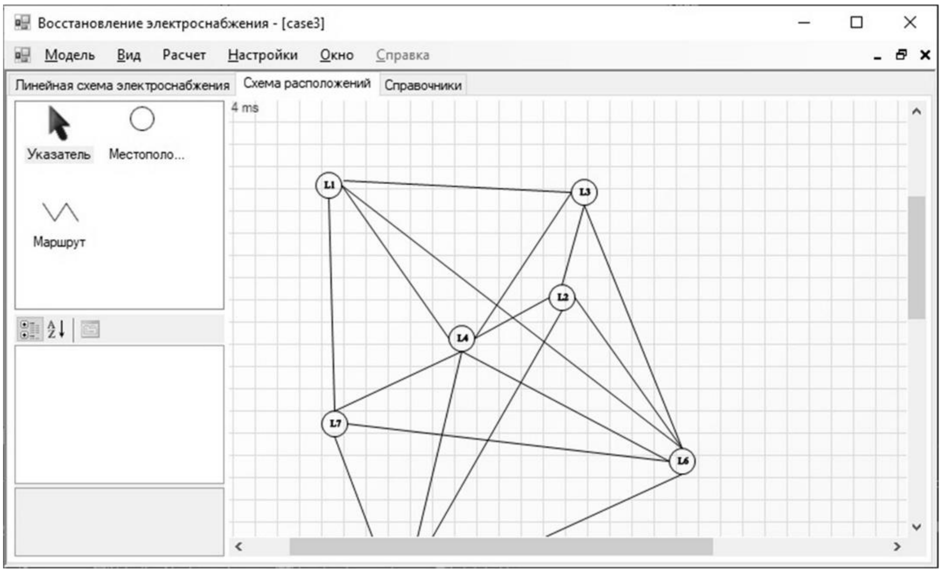

Figure 4: "Diagram of locations" tab

While the HIMSHT draws up a plan, the user can observe the process of heterogeneous collective thinking of agents (Figure 6). The visual representation of the problem-solving process is based on the diagram of the "diamond of participatory decision-making" (Figure 2). The diagram has two axes: "solution number" and "conflict magnitude". Solutions received by agents are represented by circles, inside which there is an abbreviation denoting the name of the agent that generated the solution. Decisions are placed alternately above and below the horizontal axis "conflict magnitude". The ordinal number of the solution corresponds to the coordinate on the axis "solution number", and the coordinate on the axis "conflict magnitude" is determined by the value of the intensity of the conflict of agents [16] after receiving this solution. Dashed lines that limit the obtained solutions from above and below indicate the stage of collective heterogeneous thinking. Straight lines diverging from the horizontal axis indicate the stage of divergent thinking, broken lines indicate the groan stage, and straight lines converging towards the horizontal axis indicate the stage of convergent thinking. If necessary, the user can stop the PPRPS solution process by pressing “Cancel” button.

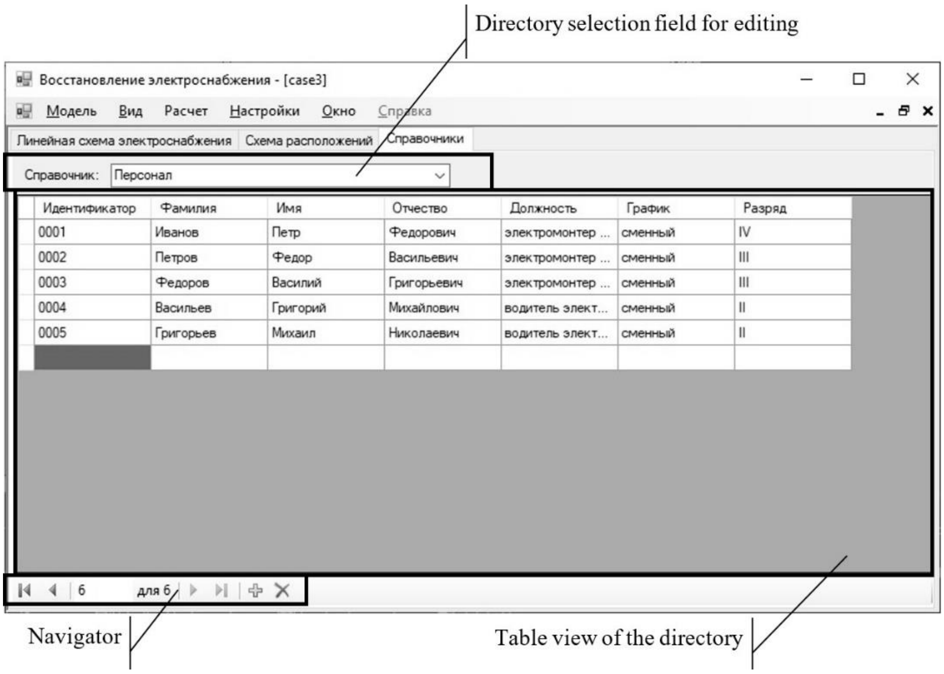

Figure 5: “Directories” tab

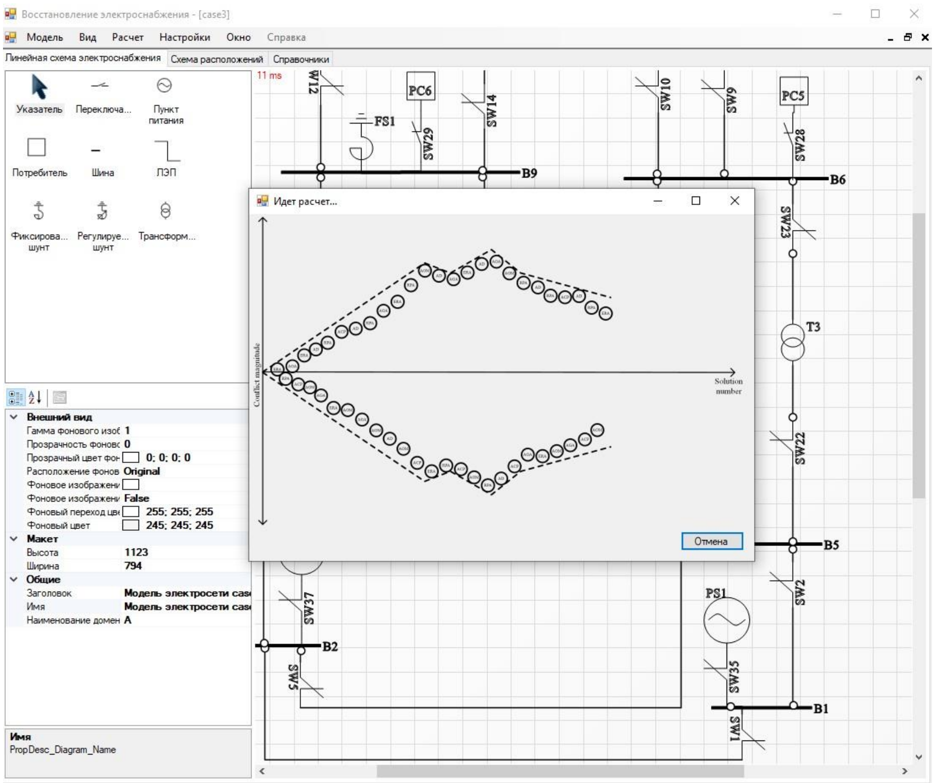

Figure 6: Problem-solving process visualization

At the end of the HIMSHT reasoning, the set of plans for power grid restoration are formed, which are evaluated according to the optimality criteria of the PPRPS. If the user interrupts the system’s computations, this set includes all solutions generated by the agents. If the HIMSHT has normally completed reasoning, only the solutions of the convergent stage are included in the set. A list of

Pareto optimal solutions is formed from this set. This list, sorted in descending order of the summary criterion of the plan’s effectiveness, is presented to the user (Figure 7) in the “Planning Results” window. To view any of the proposed restoration plans, the user have to double-click the corresponding row in the planning results. The selected plan opens in the separate window, the title of which indicates its name. The plan is a list of operations to turn on and off the switches, send repair teams to the power grid facilities and restore them (Figure 7). The processes in the power grid during the execution of the plan can be visualized step by step at the “Linear power grid diagram” tab.

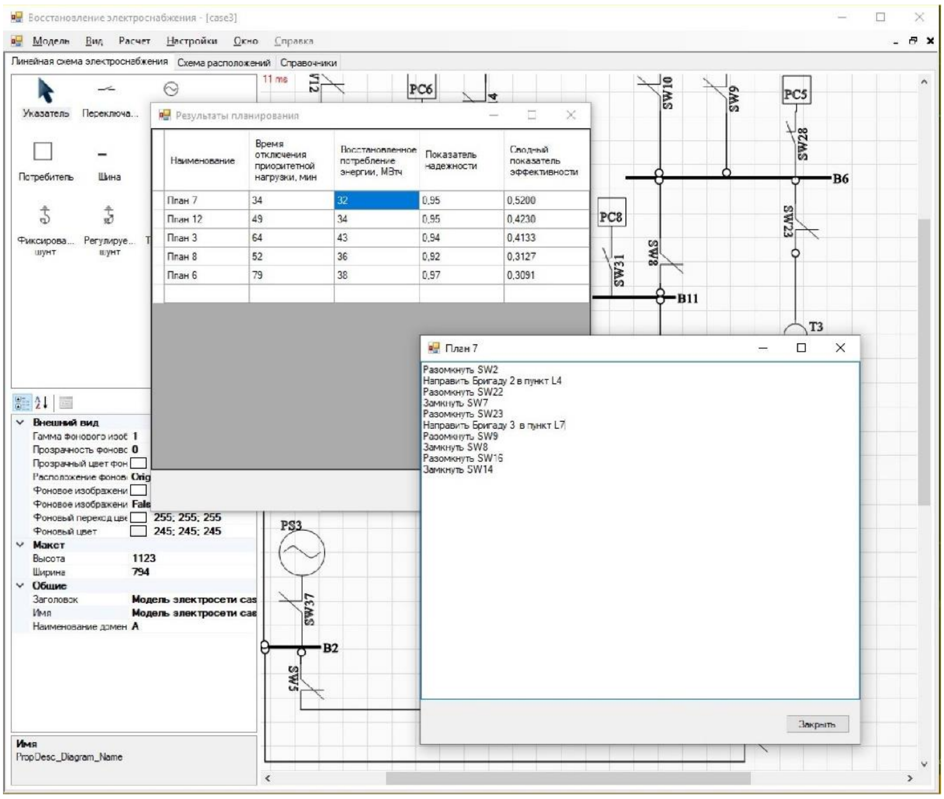

Figure 7: Planning results

Testing the HIMSHT prototype on tasks from datasets [17] demonstrated the ability to build power grid models close to real ones, simulate failures of their elements and draw up recovery plans. Thanks to the integration of methods of synergistic artificial intelligence and heterogeneous thinking, the industrial design of the HIMSHT will make it possible to develop recommendations for power supply restoration in conditions of shortage of time, comparable in quality with the solutions developed by expert teams without time constraints. Promising lines of research in this area are the development of new algorithms for heterogeneous thinking and the study of their effectiveness, as well as the use of the HIMSHT to solve other problems in dynamic environments.

5. Conclusion

The features of solving problems in dynamic environments are considered, in particular, the simplification of the situation and heuristics by the decision-maker is noted. The relevance of the development of intelligent systems capable of solving problems without their significant simplification in conditions of time pressure is shown. As an example of a problem solved in a dynamic environment, the PPRPS is proposed, its informal formulation is presented. The functional structure of the HIMSHT for solving PPRPS and the results of the development of the laboratory prototype of this system are considered. Laboratory testing of the prototype showed the relevance of the proposed models to processes in small teams of experts solving problems under the guidance of a decision maker, with the mediation of a facilitator.

6. Acknowledgements

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