Research prototype of tool support of information technology of functional hybrid intelligent systems with a heterogeneous visual field

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Abstract. The use of hybrid intellectual systems integrating of expert knowledge models allows solving heterogeneous problems that only teams of experts under the guidance of the decision-maker previously successfully managed. At the same time, the elements of hybrid intellectual systems exploit only symbol-logical models of knowledge, which significantly limits their capabilities in comparison with teams of experts who successfully argue both logically and figuratively. The article examines the research prototype of the software for tool support of information technology of functional hybrid intelligent systems with a heterogeneous visual field, capable of simultaneously simulating collective verbal symbolic reasoning and activating the visual-figurative reasoning of users.

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1. Introduction

The functional hybrid intelligent systems (FHIS) [1 – 4] have embodied hybrid intelligence [5], i.e. interacting, cooperating and mutually complementary varieties of intelligence [6], by integrating set of computer models solving problems by simulation of intellectual human activity. Practice, on the one hand, demonstrated their effectiveness in solving problems requiring knowledge of expert teams; on the other hand, it revealed a significant drawback – the modelling of cooperation by simulating only logical-mathematical intelligence, language communication, the left-side component of the experts and the decision-maker reasoning. In this regard, it is important to expand the capabilities of the FHIS by modelling in them imaginative, visual, intuitive, reflective and emotional mechanisms of thinking and behavior.

The information visualization methods for decision-making are explored in visual management and control, visual thinking, cognitive psychology and linguistics, image engineering and other scientific fields, summarized and developed in the works of O.S. Anisimov, Yu.R. Valkman, B.A. Kobrinsky, O.P. Kuznetsov, G.S. Osipov, D.A. Pospelov, V.B. Tarasov, I.B. Fominykh, G.P. Schedrovitsky, A.E. Yankovskaya, R. Arnheim, E. de Bono, W.J. Bowman, M. Wertheimer, D. Roam, D. Sibbet. To reduce the complexity of developing visual languages, informal axiomatic theory of role-based visual models on the principles of system theory and system analysis was proposed in [7]. In [8, 9], the metalanguage for the FHIS of the power system management developed in accordance with this theory was considered. In this paper, we describe the research prototype of tool support of the FHIS information technology with a heterogeneous visual field (HVF) for managing the power grid, allowing operational dispatch personnel to receive, understand and speak about holistic pictures of situations and conditions in the power system.

2. Basic shapes of the visual metalanguage for regional power system management

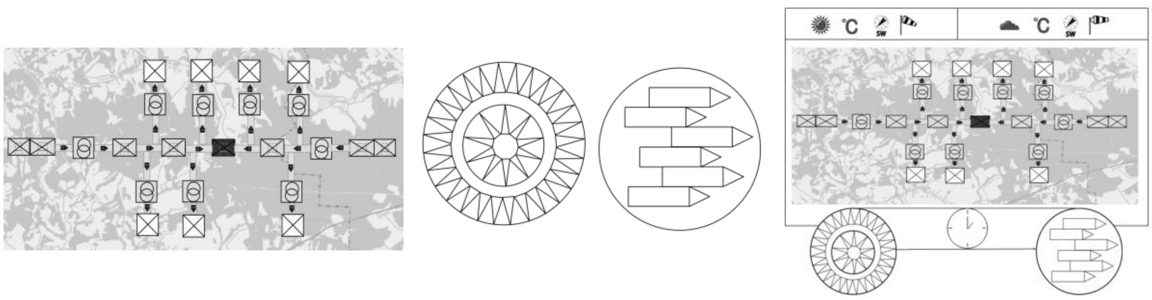
The analysis of papers on visual control, cognitive graphics, information visualization methods [10, 11] made it possible to form the set of the basic shapes underlying the visual metalanguage (Figure 1a) and the set of pictograms [12] for constructing images of resources, properties and actions in the power system management domain, examples of which are shown in Figure 1b.

These shapes and pictograms are visually and formally described on two basic levels of the metalanguage [8]: 1) conceptual and visual basis; 2) schematic images of resources, actions and properties of the control object. A point is the basis of measurements; it generates a line, a movement. A straight line is the component of all geometric figures. The circle is a universal symbol of integrity, continuity and initial perfection. The square symbolizes things (resources) [12], the triangle symbolizes properties, and the arrow symbolizes actions. Based on the shapes presented at Figure 1 visual representations of hierarchies of resources, actions and properties, spatial and operational-technological structures, situations and states were constructed in [9]. Let us consider schematized representations of o-situation, r-situation, and state, since they are crucial for the visual metalanguage for regional power system management.

(a) (b)

Figure 1. Basic shapes vocabulary of the language of the FHIS for visual control: (a) basic shapes of visual metalanguage; (b) examples of pictograms for constructing images of resources, properties and actions.

R-situation (resource situation) is a set of spatial relations of the resources of production operations at a given time and in the context of the spatial structure of the control object. Figure 2a shows a schematic representation of the r-situation "normal mode of electric power transmission".



(a) (b) (c) (d)

Figure 2. Schematic images: (a) r-situation "normal mode of electric power transmission" and its location (shown approximately); (b) qualitative, fuzzy characteristics of resources, that are essential for the problem solved at time *t* (role visual relations "property-resource"); (c) role visual relationship "action-action" ("to be at the same time"): the action schemes are not detailed; (d) the state of the visual control object at time *t.*

If in the r-situation the accents are made on the mapping of role-based spatial relations "resource-resource", then in the representation of the parameters and the qualitative fuzzy resource characteristics essential for the problem solved at time *t* (Figure 2b) accents are shifted to role relations "property-resource". This view is related to the inner world of the expert, so the circles were used for the schematization. There are four of them. Schematic images of the properties of static resources of the current p-situation are shown between the central and the outer circles. When solving problems in the control phase, i.e. when standards for the values of the properties are set, the out-of-limits values can be symbolized by the color change of the triangles. In this case, the color of the central circle integrally shows either the norm on properties or the degree of deviation of the properties of static resources from the normal values.

O-situation (operation situation) is the relation "simultaneously" on a set of operations with the control object's resources at a given time in the context of the production structure (process). Since the operation scenario is a plan that forms the current r-situation, the o-situation also determines the r-situation. A graphic representation of the role visual relationship "action-action" ("to be simultaneously") is shown in Figure 2c. Since it is the relation of the objects of the experts' inner world, it is depicted in a circle. Understanding the schematic image "o-situation" assumes a figurative representation of the timeline and vertical line-mark on this scale, which symbolizes the current time and crosses all the actions performed in the control object simultaneously.

The state $S(t)$ of the control object at time t is the set of parameters, qualitative fuzzy characteristics of resources and operations, i.e. o-situations and r-situations [9], essential for the problem being solved at time t. The o-situation is considered in the context of the production structure, and the r-situation is considered in the context of the spatial structure of the control object. In Figure 2d a complex schematic image of the state of the control object at time t is presented, which is composed of schemes of a set of parameters, qualitative fuzzy characteristics of resources and operations, i.e. o-situations and r-situations, essential for the task being solved at time t. It consists of six schematic images. On the top, in two rectangular forms, from the left to the right there are the current meteorological conditions and the predicted ones. In the center there is a graphic representation of the r-situation. In the lower part on the left there is a schematic diagram of the parameters essential for the task being solved at time t, qualitative fuzzy resource characteristics (role visual relations "property-resource"). In the lower right-hand side there is a diagram of the o-situation. An area with a time symbol "clock" links all forms to a single whole: the situation on the resources, the parameters of dynamic and static resources, and the situation on the operations.

3. The architecture of the tool software for synthesizing functional hybrid intelligent systems with heterogeneous visual field

In general, step by step the development of the FHIS with a HVF can be represented as follows: 1) identification of the problem as heterogeneous [1]; 2) reduction of the problem into decomposition; 3) specification of homogeneous servicing tasks (subproblems) and connections between them; 4) construction of method for solving a problem: methods selection for solving tasks, development of heterogeneous model field, FHIS elements and inter-model information interfaces, strategy selection from the table of hybrid strategies; 5) FHIS initialization and configuration; 6) simulation of collective problem solving with FHIS.

For the implementation of the above stages, the architecture of the tool software (TS) "Graphite" for synthesizing of the FHIS (Figure 3) is proposed. The architecture consists of four blocks of subsystems, which are marked with a dashed line: problem modelling, method modelling, visualization and experiment organization.

The problem modeling block is designed to develop a description of the domain model of the problem, its tasks (subproblems) and the relationships between them. It includes subsystems of problem identification, its reduction and homogeneous tasks specification. In the problem identification subsystem the scheme of role conceptual models [2] defines the goal, the initial data for the solution, the identifier, and the qualifier. In the problem reduction subsystem the problem analysis continues, but the emphasis is shifted to composition and structure. The original problem is reduced by the developers into the version of the system of homogeneous servicing tasks (decomposition); it is represented in the schematic images language. The task specification subsystem is designed to identify homogeneous tasks according to the scheme of role conceptual models [2]. The goal, the initial data, the classifier, the qualifier are determined, and the methods for solving the problems are pre-selected. According to the specification of tasks, heterogeneity is checked in order to increase the degree of modeler confidence in the fact that the problem is relevant to the "heterogeneous problem" model [2]. This justifies further work on hybridization and synthesis of the method for solving the problem. The result of work of developer team with the subsystems of this block is the domain model, which includes macromodel of the problem, set of its decompositions (maybe even one-element) and the models of homogeneous servicing tasks.

The method modeling block is designed to construct an integrated method for solving problem represented by the signs of FHIS and its elements. The autonomous models design subsystem is intended for modeling FHIS elements and creating their program code for solving homogeneous problems from problem decomposition. Elements are included in the heterogeneous model field (HMF) along with the models created earlier. The works of this stage correspond to the methodologies of autonomous modeling, iterative, and the quality of the HMF depends on the experience of using basic mathematical and heuristic tools. The interfaces of autonomous models overcome differences in the description languages of basic methods and establish the integration relations on the elements of the HMF. The algorithm synthesis design subsystem supports the construction of the FHIS initialization algorithm, the order of choosing the strategy from the knowledge base of the hybrid strategies, which is developed in the experiment organization block, and the direct generation of the FHIS sign according to the selected strategy, the interpretation of which is considered as a method for solving the problem. The result of the work is HMF and integrated method of solving the problem, built over it, relevant to the current problem situation.

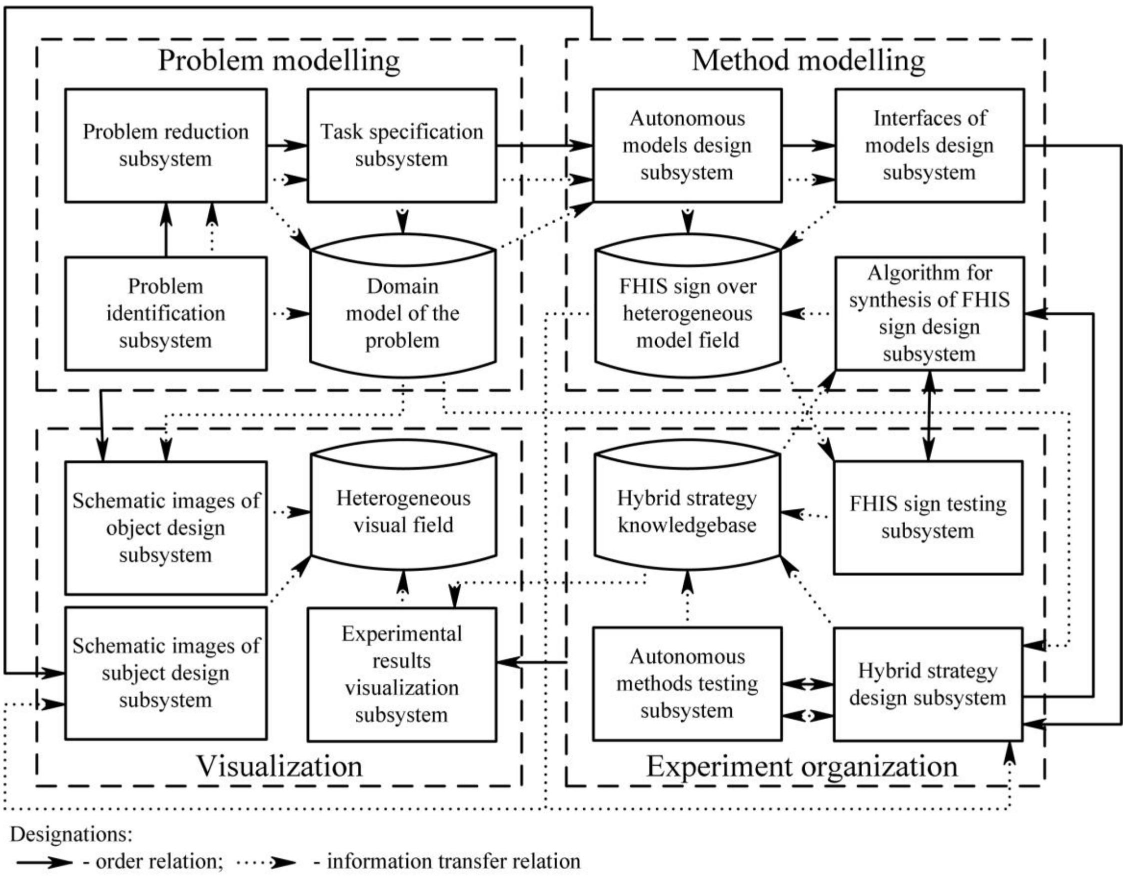


Figure 3. The architecture of the tool software for synthesizing functional hybrid intelligent systems with heterogeneous visual field.

In the experiment organization block, the HMF and the integrated method are tested, their effectiveness is evaluated, after which the results are transferred to the method modelling block. In the hybrid strategy design subsystem, developers replace the decomposition relations between tasks with integration relations. Also they establish relations of correspondence between the initial data, the goals of the problem and the initial data, the goals of homogeneous tasks, respectively. The work ends with the construction of hybrid strategies table that reflects the above links between homogeneous tasks.

Knowledge for the table can be obtained by testing stand-alone methods and their combinations using the autonomous method testing subsystem. Rates of each method and each combination of methods obtained using the autonomous method testing subsystem, along with the hybrid strategies table, are recorded in the hybrid strategies knowledge base, which is then used to synthesize an integrated method for solving the problem. The design of this algorithm is performed in the corresponding subsystem of the method modeling block, after which its evaluation can be obtained in the subsystem for testing FHIS sign. The rate of FHIS sign, together with the sign itself, is included into the hybrid strategies knowledge base. If developer is not satisfied by the FHIS sign rate, an iterative process of adjusting the synthesis algorithm and its evaluation begins, as shown in Figure 3 by bidirectional arrow. The resulting synthesis algorithm is built into the FHIS's element, which model the decision maker, providing it with ability to take into account the dynamic nature of the problems and to synthesize the FHIS sign that would be relevant to the problem at the time of its solution.

The order of using of the subsystems by developers is shown in Figure 3 by solid arrows. If errors or inaccuracies in any of the stages are detected, developers return to the previous ones. The subsystems of the visualization block are launched at the end of the work with the subsystems of the corresponding block, which is shown by solid arrows. The visualization block is intended for visual modeling of the objects of the internal world of the FHIS users with visual control methods. It contains three subsystems: the development of schematic images of the object, the development of schematic images of the subject and the visualization of experimental results. They establish a correspondence between the domain model, the integrated problem-solving method, the results of HMF testing, the integrated method, and their visual representations that the end user understands. The result of visualization is a HVF used to develop the user's imaginative representations of the problem, the methods and results of its solution.

The use of the TS "Graphite" automates all the stages of designing according to the PS-methodology [2]. The subsystems of the TS "Graphite", with the exception of the method modeling module, are visual designers using visual control methods to engage specialists who do not have programming skills in the FHIS design process. Subsystems of the method modeling block, along with visual construction, presuppose the writing of the program code manually.

Let's consider in more detail the main difference of the proposed TS "Graphite" from the means of design of traditional FHIS that is subsystem for the development of visual images on the example of a schematized image of an object.

4. Subsystem for the development of schematized images of the tool software "Graphite"

The schematic images design subsystem is a graphic designer whose main window contains a five-part workspace, a shapes panel, object and property inspectors, a set of standard menus at the top of the window, and a status bar (Figure 4).

The central part of the workspace is designed to construct schematic images of the current r-situation. Above and below it there are sections of the workspace for constructing images of the o-situation and the weather situation. As shown in [13] the operator pays the main attention to the upper left quadrant of the working window, therefore it is recommended to place a schematized image of the current o-situation in the upper left part of the working field. A schematic image of the predicted o-situation should be placed in the upper right part, and schematized images of the current and forecast weather situation should be in the left and right lower parts, respectively (Figure 5).

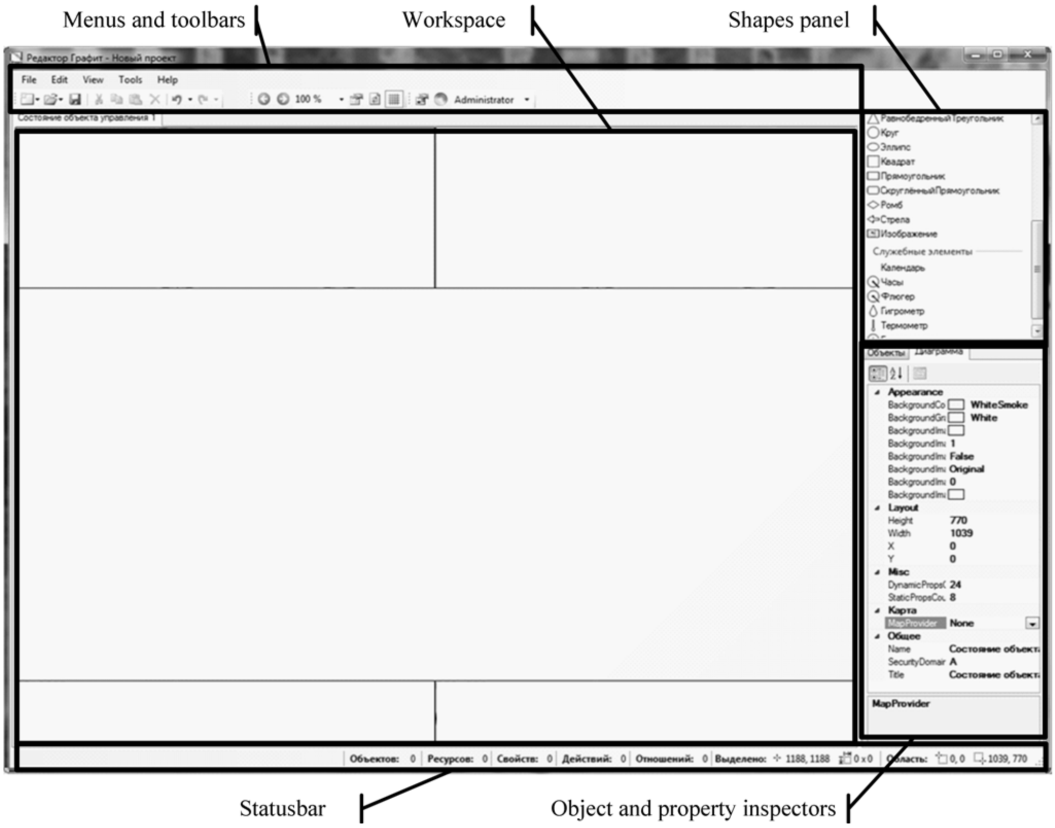


Figure 4. The main window of the schematic images design subsystem.

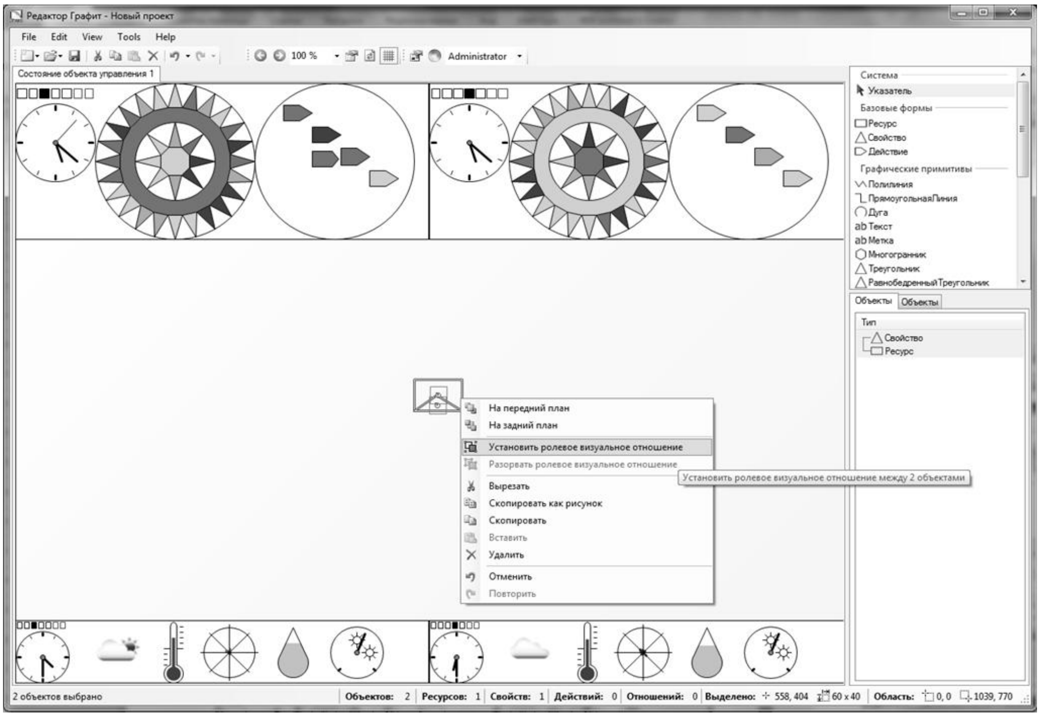


Figure 5. The main window with the developed schematic images of the o-situation and two primitives of the p-situation.

By dragging visual primitives to the workspace from the shapes panel, configuring them using the property inspector and setting the role visual relationships (Figure 5) the developer creates schematized images of r-situation and o-situations (Figure 6).

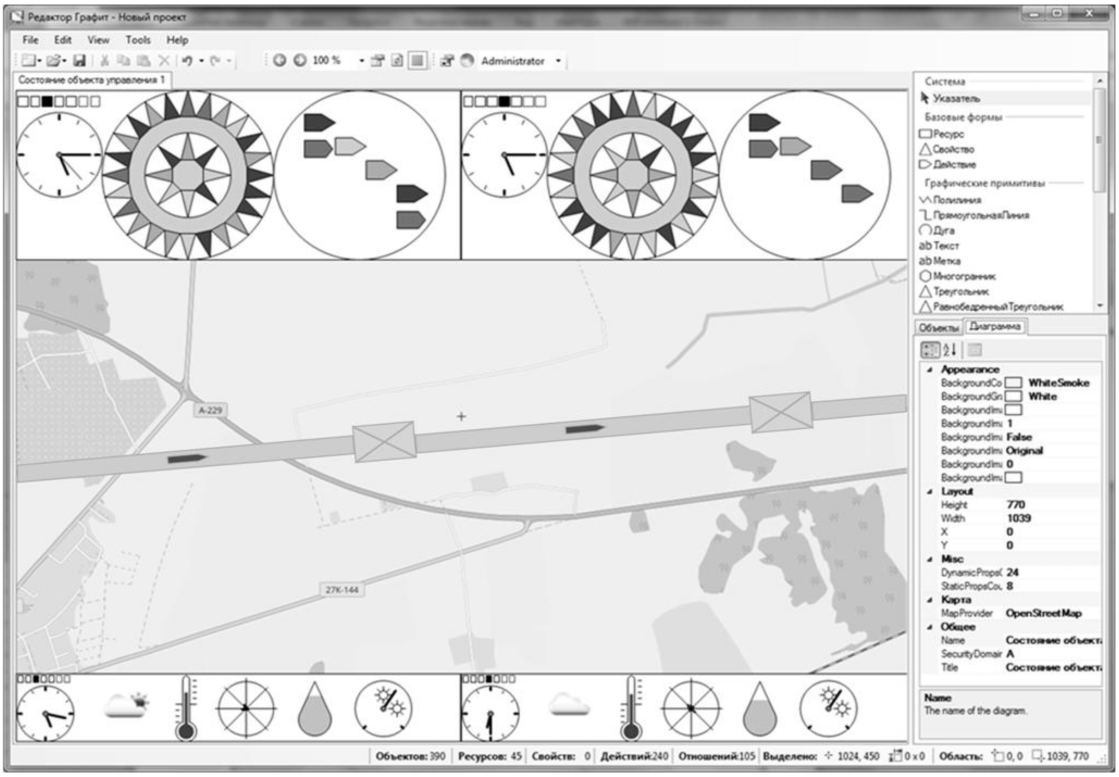


Figure 6. The result of the p-situation and the o-situation schematic images design.

As a result of the compilation, a FHIS with HVF is formed, which user interface is shown in Figure 7. This FHIS is designed to support operational dispatch management of regional power system. It allows user to display current o-situation and r-situation in the regional power system, to model its functioning and build short-term forecasts of these situations evolution. When the r-situation is displayed on a small scale, the visual primitives that represent the power lines "merge" into solid blue (gray in Figure 7) lines, the power flow through which is shown by moving red (dark gray in Figure 7) line segments.

The current o-situation displayed in the upper left corner of the window is interconnected with the p-situation: when user click the circle, triangle, or arrow of the schematic image of the o-situation, the scope of the p-situation changes so the resource associated with the corresponding visual primitive appears in the center of the window. This is especially convenient when the color of the triangle changes to indicate an accident or a pre-emergency state, which allows the operator to instantly assess the current situation and react to it (Figure 8). By default in FHIS with a HVF for operational control of regional power system, the following colors of the o-situation's visual primitives are used (by analogy with the color coding of danger levels): green, yellow, orange and red. The user can set them according to own preferences by changing the interface settings.

Laboratory studies of the developed prototype of the tool software (TS) "Graphite" for synthesizing of the FHIS showed that specialists, who are well versed in the subject area of managing power systems but do not have programming skills, are able to successfully construct control object models, as well as schematized images of its states and situations on it, due to the presence of visual designers. The experience of FHIS development allows talking about a significant reduction of their design duration with the use of TS "Graphite".

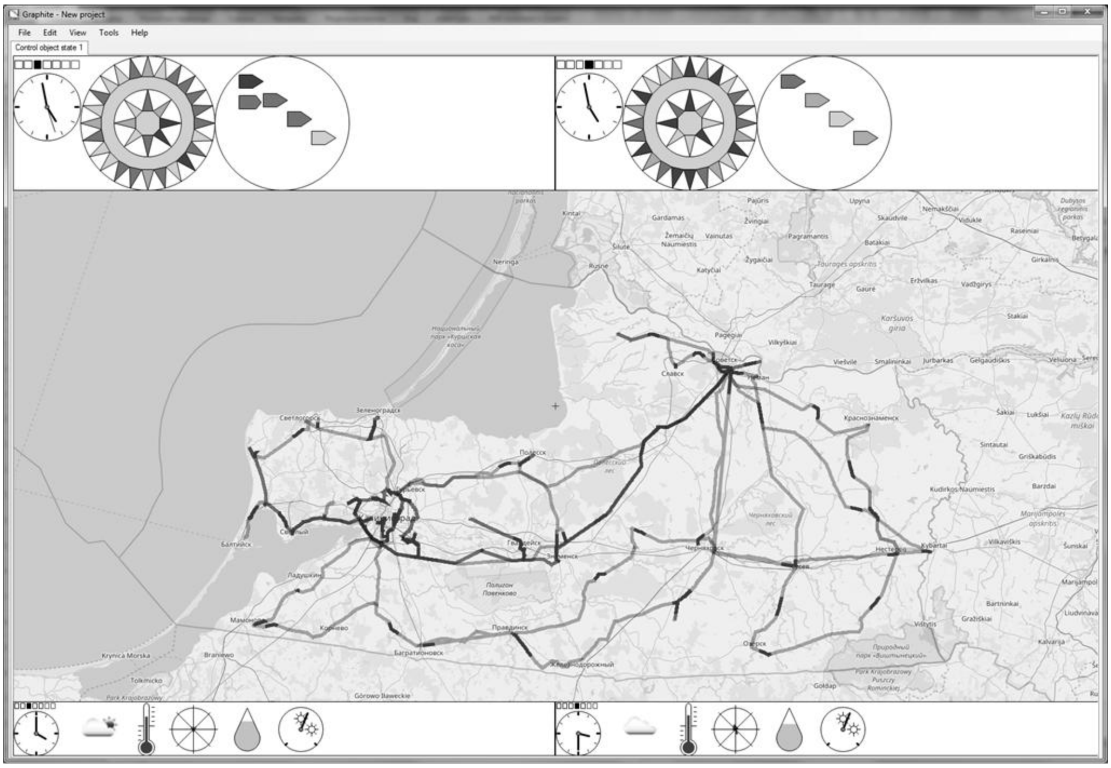


Figure 7. The user interface of functional hybrid intelligent system with heterogeneous visual field for operational dispatch control of regional power system.

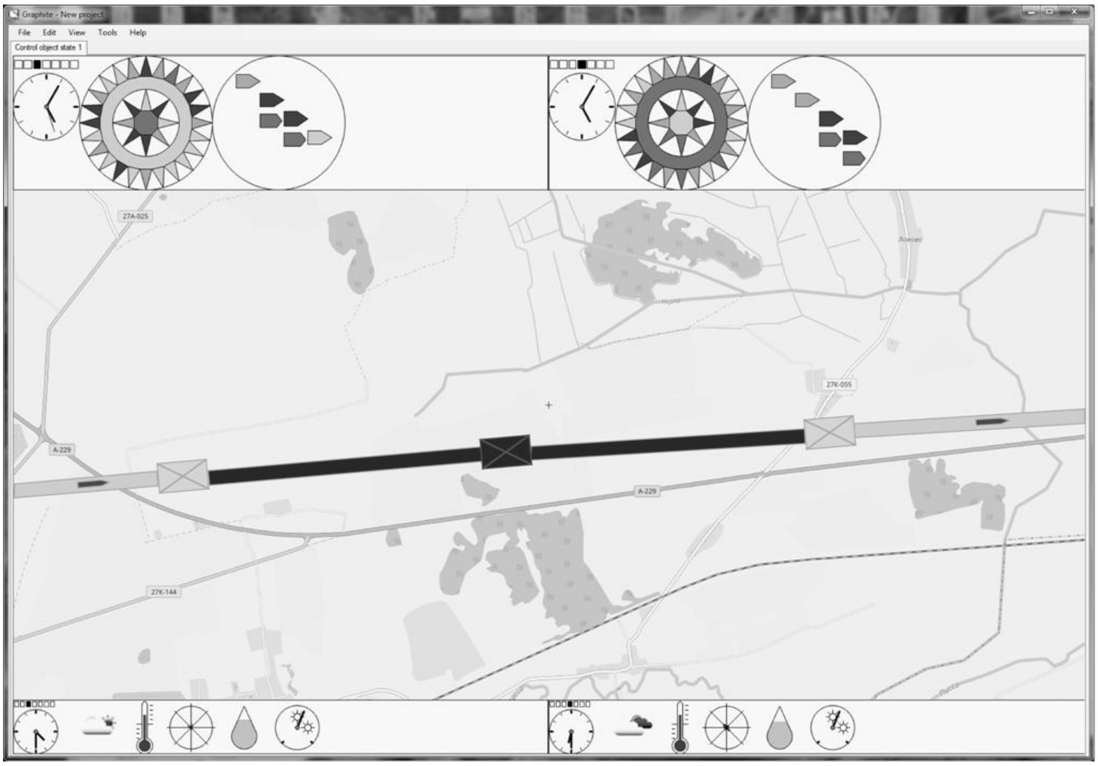


Figure 8. The functional hybrid intelligent system user interface window displaying the emergency situation on the overhead power line.

Developed with TC "Graphite" FHIS will allow to take into account the dynamic nature of complex problems and synthesize the relevant integrated method over the HVF at the time of solving the problem. Using a HVF that establishes the relations between symbolic and visual signs, FHIS can manage the imitation process by connecting the mechanisms of visual-spatial, imaginative thinking, when significant uncertainty arises. These mechanisms allow user to "see" an approximate solution of a complex problem or its subproblems, which can be later justified and refined by methods of logical-mathematical reasoning.

Using the FHIS with a HVF, the operational dispatch personnel have the opportunity to observe current o-situation and p-situation in the power system, to analyze the current mode of their operation, to receive by mouse click the detailed information on events that cause the situation to deviate from normal, and to observe a short-term forecast of situations evolution, developed by FHIS on the basis of modeling of the region's power system. Thus, the operational dispatching personnel move from the event management to the situation management of power system.

5. Conclusion

The elements of the visual meta-language of hybrid intelligent control systems for electrical networks are considered. Symbolization and schematization of resource hierarchies, situational relations and the state of the control object recreates problem situations and is better perceived by a person. FHIS, developed with TS "Graphite" implementing the grammar of visual metalanguage, will significantly reduce the workload for operational and technological personnel, since visual-spatial thinking reflects the surrounding world in the fullness that is intrinsic to a person. This allows one to understand at a glance the conditions for the emergence of a problem situation in the management object and to assess the degree of risk of transition and (or) preservation of non-normative behavior.

The architecture of the TS for design FHIS with HVF is presented. Most TS subsystems are designers using visual control methods to simulate the internal structure of the problem and the method for solving it. The implementation of the proposed architecture of the TS "Graphite" allows automating the design of FHIS with HVF in accordance with the PS-methodology. The process of solving problems in FHIS with HVF has a heterogeneous character: when the domain of phenomena is formalized to search for solutions, the symbolic models of knowledge from the heterogeneous model field are applied, and when there is significant uncertainty not removed by accurate analysis and logical-mathematical reasoning, visually-dimensional, imaginative thinking abilities of experts are activated.

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