Intelligent Technologies and Tools to Support Hierarchical Research for Justification of Strategic Decisions on Energy Development

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***Abstract* — The paper is concerned with a general scheme of hierarchical studies aimed at substantiating the energy development. It also considers an approach to integrating the software, information support and intelligent information technologies required for research. The concept of knowledge management is proposed for the semantic integration of data, knowledge and software components. It can also be used as a methodological, fractal approach to knowledge structuring. In addition to a two-level research technology, which integrates semantic and mathematical modeling, and intelligent IT-environment supporting them, including semantic modeling tools and the ability to integrate with traditional software systems, we consider the concepts and content of semantic modeling.**

The architecture of a multi-agent intelligent environment (MAIE) is proposed as the development of the IT-environment. It integrates the levels of information analysis (semantic modeling), development and substantiation of decisions (using mathematical modeling), and representation of the proposed decisions. We demonstrate the proposed methodological multi-agent approach to MAIE development; the main components (agents) of MAIE and their scientific prototypes developed under the guidance of the authors are defined.

***Index Terms* — Hierarchical studies of the energy sector, intelligent information technologies, mathematical and semantic modeling, knowledge management, fractal stratified model, intelligent IT-environment, multi-agent systems.**

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I. Introduction

The spread of the concepts of Smart Grid [1-2] and Digital Energy [3-5] in Russia generates the need to take into account the fact that their adoption distinguishes two interrelated areas – technological infrastructure, and information and telecommunication infrastructure. The success of the digital transformation of the energy sector largely depends on the successful application of modern information technologies. In turn, the application of the latter makes sense if there is a developed modern technological infrastructure. Solutions for the development of technological infrastructure, of course, belong to the class of strategic decisions. Melentiev Energy Systems Institute of SB RAS (MESI SB RAS) has traditionally conducted hierarchical energy studies, the results of which can be used to justify strategic decisions on energy development.

To justify and support such decisions, it is advisable to use intelligent information technologies. These are primarily the technologies of semantic modeling and knowledge management, which are developed by the team under the guidance of the authors and used to create intelligent systems to support the strategic decision-making in the energy sector. An approach to the construction of such an intelligent system (multi-agent tool environment) is proposed. It integrates mathematical and semantic methods and models, and software tools for their support developed at the MESI SB RAS.

II. Hierarchical systems studies of the energy sector

The MESI SB RAS is one of the leaders in the field of systems research in the energy sector of Russia [6]. The main scientific areas of the Institute include the theory of the creation of energy systems, complexes and plants, and their control; scientific foundations and mechanisms for implementing the energy policy of Russia and its regions. The studies within the framework of these areas focus on the energy systems (electricity, gas, oil, oil products, heat), Russia's energy security; regional energy issues; the interactions between energy and economy; promising energy sources and systems; and studies in the applied mathematics and computer science [6].

Until recently, the main tool for the studies has been mathematical modeling and computational experiment. In the context of the new development trends in the Russian energy sector (Smart Grid and Digital Energy), much attention is paid to the development and application of intelligent information technologies. The Digital Economy Program implemented in Russia is now actively developed. The federal project "Digital Energy Sector" is a part of this Program. The authors think that the federal project «Digital Energy Sector» does not pay enough attention to such areas as intelligent support of strategic decision-making on the development of the technological infrastructure of the energy sector and cybersecurity of critical energy facilities. Below we consider the first area in more detail. A major role in making the strategic decision- should be played by their scientific justification, which can employ the scientific achievements of the institute.

Traditionally, the MESI SB RAS uses a hierarchical research scheme, in which economic and mathematical models are used at the aggregated level of researches of the energy sector and industry-specific energy systems, whereas physical and mathematical models are used at the next levels (Fig. 1). These models must be coordinated. Research on projecting energy development is carried out at the top level, based on the results obtained in the studies on the development of industrial energy systems at the following levels. The scheme includes several blocks, each of which corresponds to a set of mathematical methods, models, and software systems that are used to perform computational experiments using these methods and models [7].

The results of these studies can be used to substantiate the strategic decisions on energy sector development through a formal integration of software and information

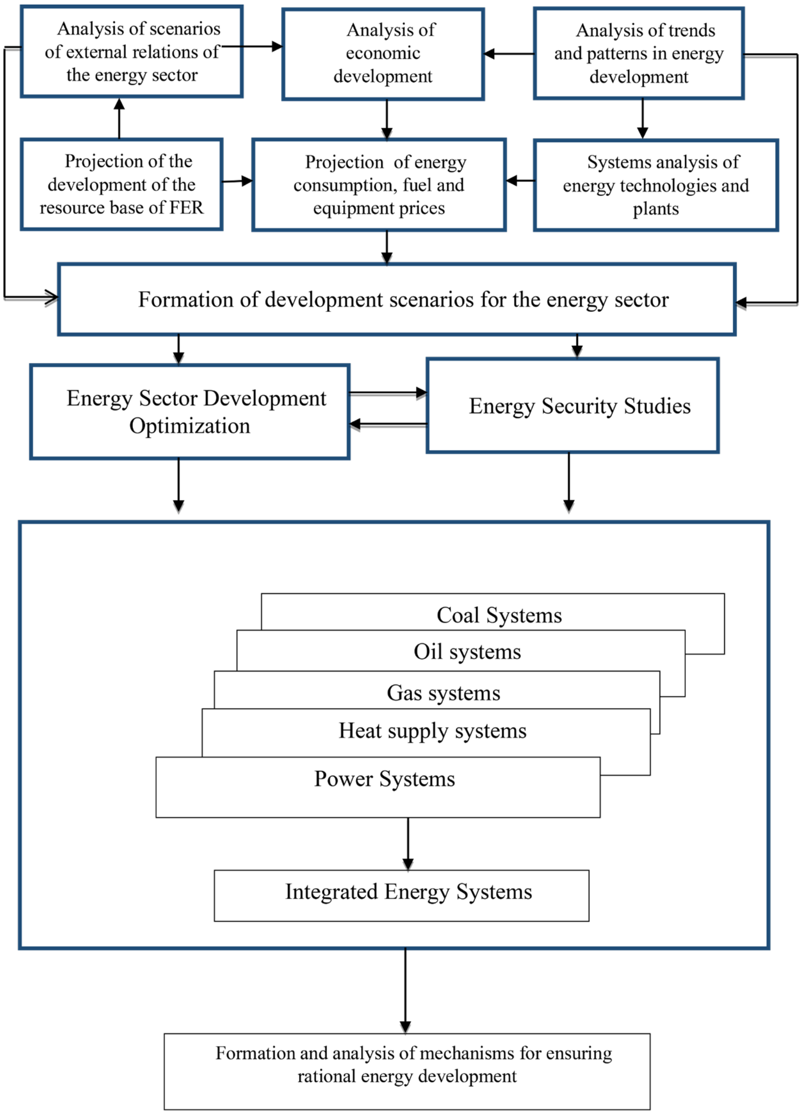

Fig. 1. A general scheme of hierarchical studies to substantiate the development of the energy sector

support to improve the hierarchical technology to justify the development of the energy sector as a whole, and its industry-specific and territorial components. The main attention, however, should be paid to the development of software and information interfaces between tasks in horizontal (between energy systems) and vertical (energy systems – energy sector – external conditions) terms.

The development and implementation of such interfaces should provide the following advantages of a complex hierarchical research technology: a) confidentiality of the main detailed data arrays supporting specific tasks should be preserved (ensured (with the necessary refinement of the required software tools); b) the information exchange should be formalized and thereby accelerated, and the uniqueness of the exchanged data should be provided; c) the information models used in solving various problems should be unified, which will need to be implemented to coordinate and develop interfaces; d) in general, the "harmony" and the validity of the hierarchical technology should be increased for substantiating the development of the energy sector and its components.

III. The proposed approach to solving the integration problem of software, information support, and intelligent information technologies.

Implementation of the proposed integration capabilities can be provided using the following information technologies: a) a common information and communication environment for software components; b) semantic integration of data, knowledge and software components; c) tools for situational management and semantic modeling.

The study proposes the implementation of a unified information and communication environment for the interaction of software components in the form of a cloud service. This service will provide network access to a common pool of configurable computing resources (for example, servers, storage devices, applications, and services, etc.) on demand. To ensure the necessary level of security, it is advisable to implement the information and communication environment in the form of a corporate cloud [8].

For semantic integration of data, knowledge and software components, we propose using the concept of knowledge management and applying it, as a methodological, fractal approach to structuring the knowledge [9].

The main idea of the fractal approach is that the concepts of information space and information worlds (subspaces) are introduced. The Fractal Stratified (FS) model is defined as a set of disjoint strata (information worlds) and their mappings in the information space. Each level has its stratum of this space, and, therefore, its information world; the sequence of mappings reflects the process of cognition. Graphically, the FS-model is conveniently represented as a set of nested spherical shells. An information object, conventionally designated by a dot on one of the spheres, in turn, can be stratified, if necessary, to study it in more detail. Mappings are introduced from any stratum to each. Since we, as a rule, consider a part of the information space (our own "fractal" of knowledge), it can be represented by a "clipping" from the information space, which can be represented as a cone or a pyramid, corresponding, for example, to the selected disciplines when we study the real world. The application of the FS-model is illustrated in Fig. 4.

There are two approaches to knowledge management: classical (based on a combination of existing, already proven technologies for support of various subprocesses of working with knowledge) and semantic (based on the use of an interconnected set of methods and technologies for working with meaning, or semantics of data, information, and knowledge) [10].

In the framework of the latter approach, ontologies of subject areas, technologies for their construction and maintenance, semantic metadata, semantic search, logical inference systems, semantic profiling of expert knowledge, semantic portals and networks, etc. are used. As a rule, they are accompanied by appropriate technological support for description languages, models, software tools and systems. The team led by the authors is developing the second approach.

The integration of mathematical and semantic modeling tools is proposed to justify strategic decisions on the energy sector development. Below we consider the concepts and content of semantic modeling.

Table 1. Comparison of ontological, cognitive, event and probabilistic modelling

Technology	Purpose of Use	Formalization apparatus	Use in energy security (ES) research
Ontology modeling	To describe declarative pieces of knowledge	Ontologies (Special languages (OWL, RDF, XML, etc.))	For identification, classification, and specification of basic concepts in energy research
Cognitive modeling	To identify causal relationships of concepts	Cognitive maps (graph theory)	For analysis of energy security threats
Event modeling	To build behavioral models. Identification of the development dynamics of emergency	Event Maps (Joiner Networks Theory)	For analysis of the development and consequences of emergencies
Probabilistic modeling	To construct probabilistic models. Assess the risk of ES threat occurrence	Bayesian Trust Network	For assessment of risks of emergencies

A semantic model in a generalized form is an information model that reflects the concepts of the subject area and the relationship between them. The authors consider semantic modeling on the example of ontological, cognitive, event and probabilistic (based on Bayesian trust networks) models [11, 12]. Table 1 shows a comparison of semantic modeling technologies applied for energy security research.

Ontological modeling is the construction of ontologies, in both a graphical form and a formalized form. Ontologies are defined as a knowledge base of a special kind, or as a «specification of a conceptualization» of a subject domain [13]. The latter means the classification of the basic terms of the subject area with the definition of basic concepts (concepts) and the establishment of relations between them. In turn, the specification process consists in describing the ontology in a graphical form ("light" or heuristic ontologies) or in one of the formal languages (XML, RDFS, OWL, etc.) ("heavy", or logical ontologies). To work with experts, the team represented by the author uses a graphical representation of ontologies; Ontologies are stored using their representation in XML.

Cognitive modeling is the construction of cognitive models, or, in other words, cognitive maps (oriented graphs), in which the vertices correspond to factors (concepts) and the arcs correspond to the connections between factors (positive or negative), depending on the nature of the causal relationship. In the simplest case, the weights of the connections can have the values +1 or –1 or take fuzzy values from the interval [–1, 1] or some linguistic scale. The use of cognitive models is most consistent with the qualitative analysis [14].

Event modeling is the construction of behavioral models, and both people and technical objects can act as modeling objects. The essence of the event modeling method is to track the sequence of events on the model in the same order in which they would occur in a real system. The sequence of events defined by the model — the chain of events — describes scenarios of the system's reaction to the occurrence of an initiating event at the beginning of the chain. As a result, the event model allows obtaining many alternative scenarios for the development of a given situation in the system, which is the main goal of event modeling [15].

Probabilistic modeling is the construction of graphical models that display the probabilistic dependencies of many variables, and allow probabilistic inference using these variables. Recent publications in this area have combined the results of the studies carried out mainly in the 1980s. The results of the authors applying this approach in the energy sector using Bayesian trust networks are considered, for example, in [16].

Semantic models are developed based on expert knowledge and allow the use of both explicit and implicit knowledge based on the experience, erudition, and intuition of experts. For example, cognitive models that

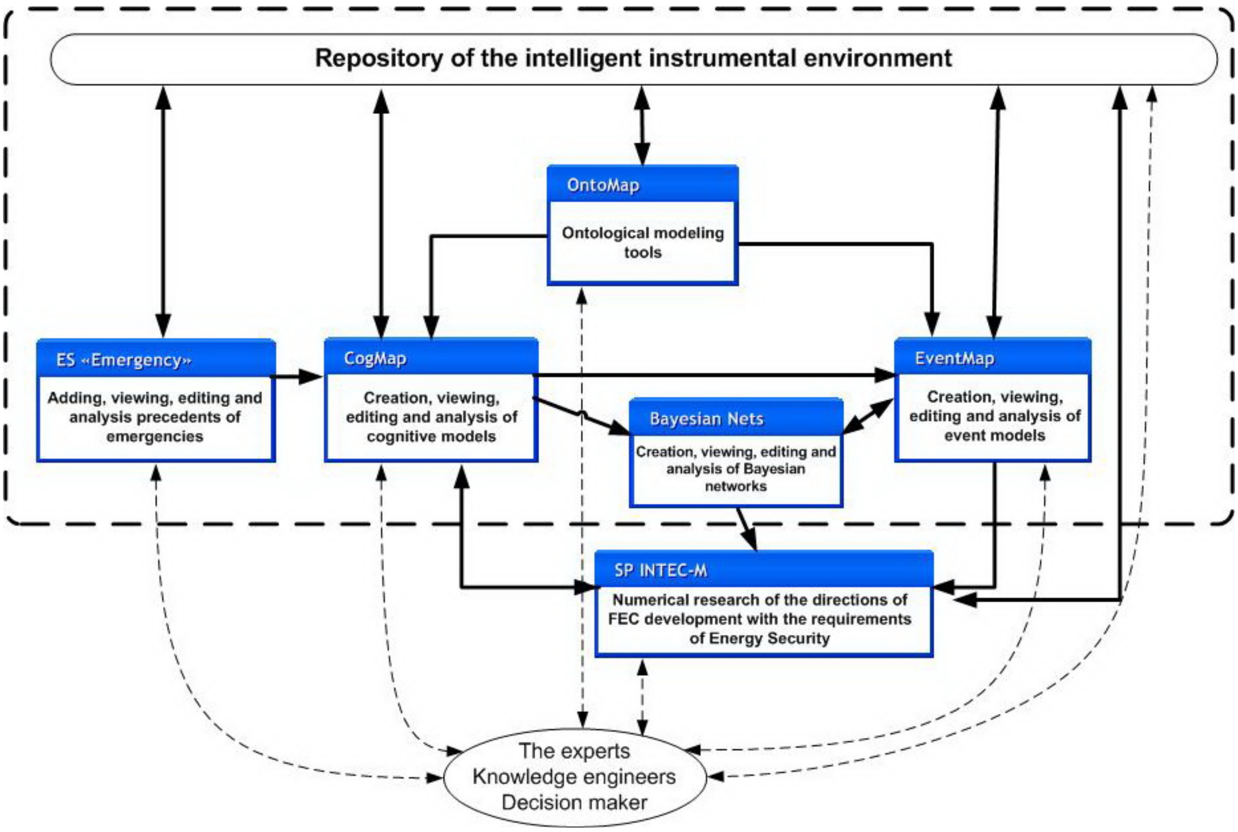

Fig. 2. Tools interaction in intelligent IT-environment

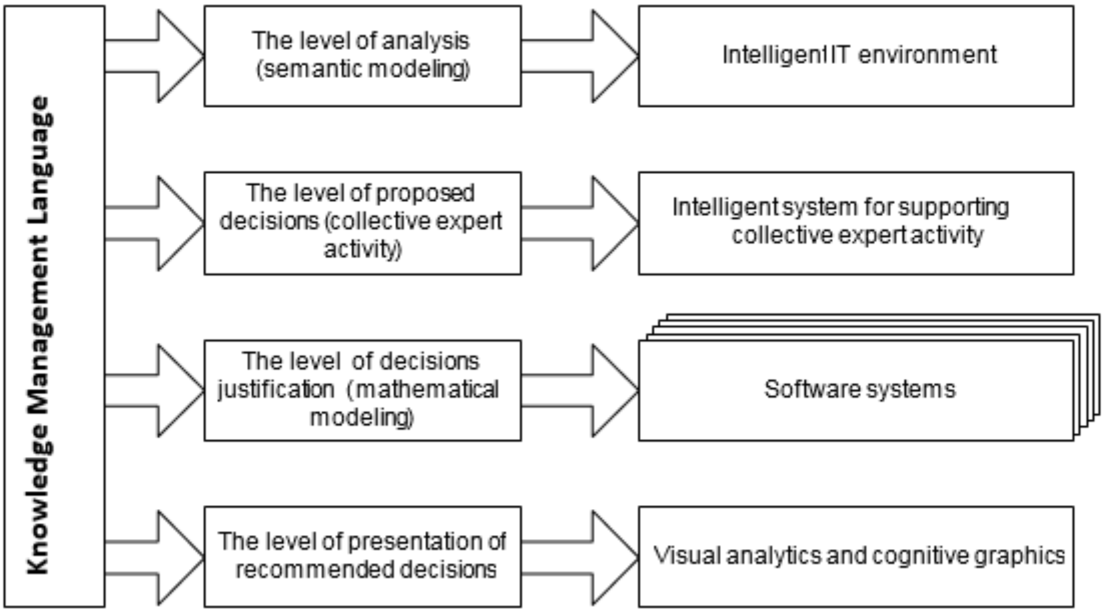

Fig. 3. Levels (stages) of energy systems research and tools supporting them.

display causal relationships can be used to describe and analyze scenarios of external relations of the fuel and energy complex, scenarios of economic development and development of the energy sector. Event and probabilistic models allow us to consider options for the development of various situations determined by the selected scenarios. After an expert evaluation of various development variants using semantic models, traditional software systems that implement mathematical models of industry-specific energy systems and the energy sector are used and optimization problems are solved to justify the recommended solutions.

In our study, the situational management concept is used following the works by D.A. Pospelov and his students [17]. Recently, some researchers have proposed using this concept for operational control but we believe it can be applied in the field of substantiation of strategic decisions. We use a modern interpretation of situational management, considered in [18]. The situational management concept is used to justify and support decision-making to ensure energy security. This is considered, in particular, in [19].

The integration of mathematical and semantic modeling tools is proposed to justify strategic decisions in the energy sector [20]. In this case, both basic technologies are used: agent-oriented and cloud computing, and problem-oriented: semantic and mathematical modeling. The two-level technology for the research integrating semantic and mathematical modeling, and supporting its intelligent IT-environment is developed. The latter includes semantic modeling tools and provides the ability to integrate with traditional software systems (Fig.2) [12].

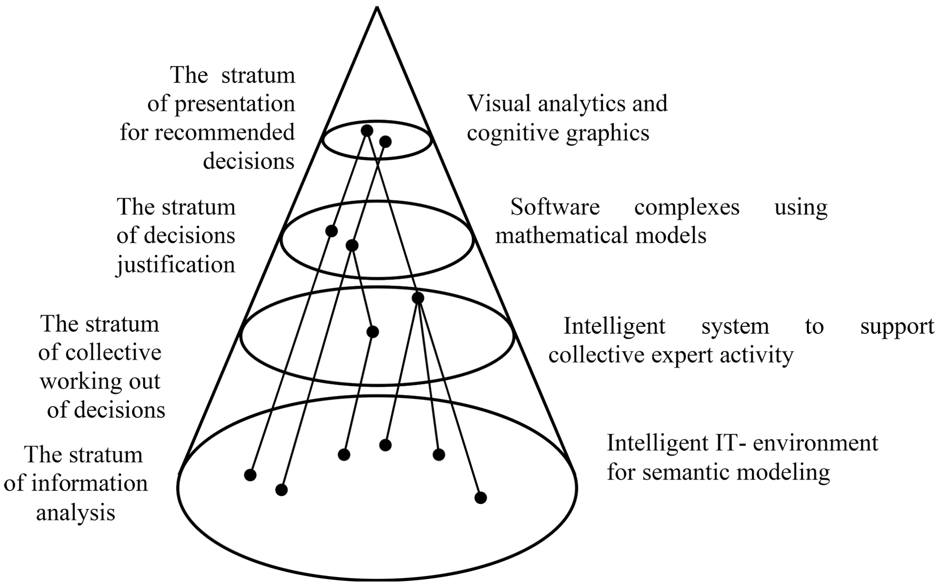

Fig. 4. FS-model of strata (stages) of research (left) and tools supporting them (right).

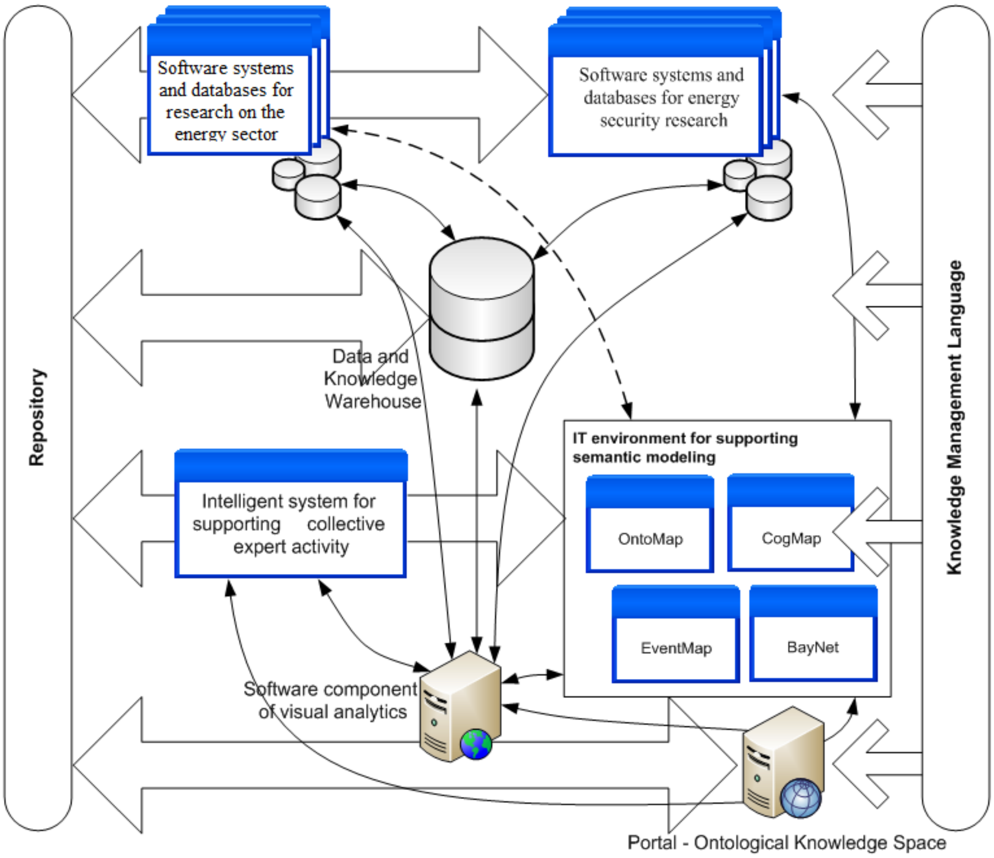

Fig. 5. The architecture of the multi-agent intelligent environment (MAIE).

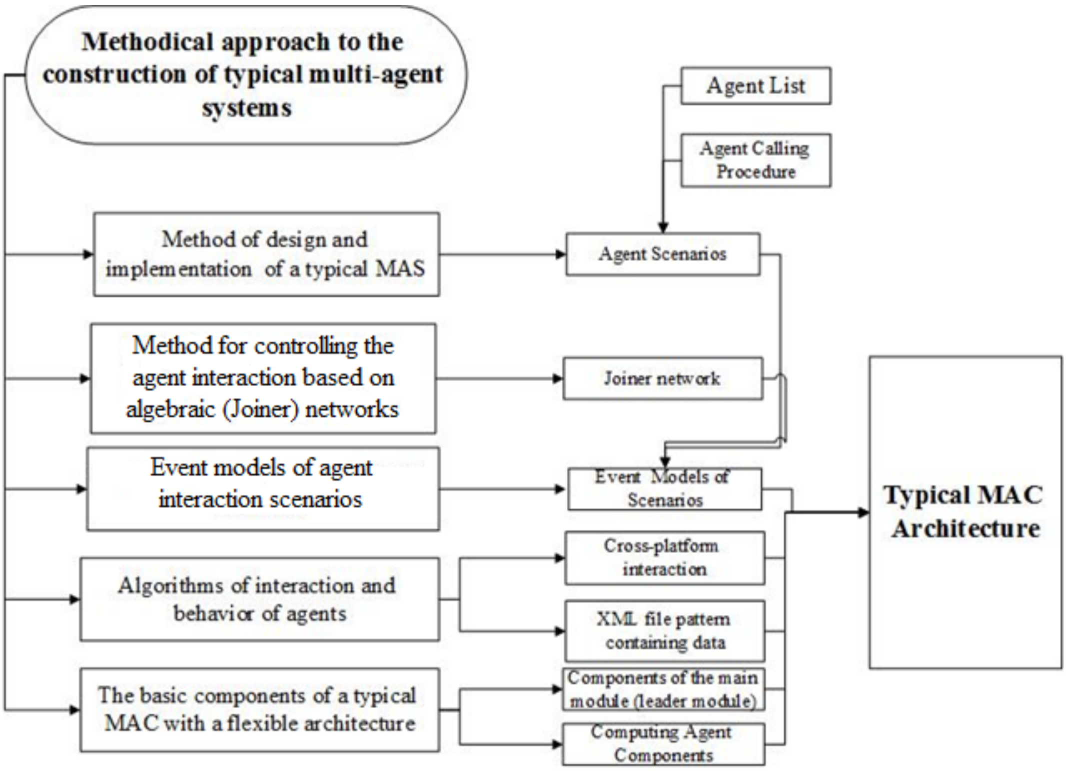

Fig. 6. Methodical approach to the construction of multi-agent systems.

Tools supporting the upper quality level of the proposed technology are circled by a dotted line. OntoMap, CogMap, EventMap, and Bayesian Nets, respectively, are tools for supporting the ontological, cognitive, event, and probabilistic modeling. The expert system Emergency contains precedents for extreme situations in the energy sector, which can be used in the construction of semantic models. The Geocomponent is a 3D-geovisualization tool. The block bottom left shows the multi-agent software system INTEC-M, used at the second, quantitative level of the proposed technology for state estimation and prediction of development options for the energy sector.

An intelligent IT environment is considered as a prototype Multi-Agent Intelligent Environment (MAIE) to support hierarchical research, a diagram of which is shown in Fig. 1. The following research levels (stages) and the supporting tools are identified for this scheme (Fig. 3). Their stratification using the FS model is illustrated in Fig. 4.

These levels are:

1. The level of information analysis (using semantic modeling), supported by the Intelligent IT environment.
2. The level of collective implementation of coordinated decisions (one can use semantic modeling, methods for coordinating decisions and others) supported by the Intelligent Support System for Collective Expert Activity [20].
3. The level of substantiation of decisions (the options proposed at the previous stage are calculated using traditional software systems for research on the energy sector and energy systems).
4. The level of presentation of the proposed decisions (using visual analytics and cognitive graphics).

The MAIE architecture was developed to support the adoption of strategic decisions in the energy sector using the proposed methodological approach and scientific prototypes of tools [21] (Fig. 5).

The main components (agents) of MAIE are:

1. Software Systems and Databases for research of the energy sector together with Software and Databases, for example, for energy security research;
2. Data and Knowledge Warehouse;
3. Intelligent IT-environment for supporting semantic modeling;
4. An intelligent system for supporting collective expert activity;
5. Software component for visual analytics (GEO-visualization component);
6. Repository for storage of descriptions of all intelligent and information resources supported by MAIE.
7. Knowledge Management Language (KML) to ensure the interconnection and interaction of all components (agents) of MAIE.
8. Portal supporting Ontological Knowledge Space in the field of energy.

Knowledge Management Language is used for the integration of these components and the call of the required component.

We have developed a methodological approach to the construction of multi-agent systems and propose it to implement MAIE (Fig. 6). Its novelty is determined by the fact that a method is proposed to control the interaction of agents based on algebraic networks. For the implementation of the method, event models of agent interaction scenarios are developed. This approach was tested in the development of a multi-agent system for the state estimation of electric power networks [23].

Now we have scientific prototypes of all basic components of this scheme (2-8), which can be used after their adaptation, and integration in the implementation of MAIE. The testing of the method is required to solve practical problems in this area.

Full inclusion of the software and databases for research on the energy sector and energy systems as agents in the MAIE (p. 1 of the previous list) will require their reengineering since most of them have moved into the category of legacy software. At the first stage, we can limit the inclusion of software and database on the level of information exchange. In this case, the studies are carried out autonomously, their results are transferred to the Data and Knowledge Warehouse, and the fact of transfer is recorded in the Repository.

The above architecture does not include cybersecurity tools, as this should be a set of measures that take into account possible cyber vulnerabilities and reflect the current state of cybersecurity tools (preventing cyber attacks); we also have results in this area [24].

IV. Conclusion

The study emphasizes that the concept of digital energy does not pay attention to such issues as intelligent support for strategic decisions on the development of the technological infrastructure of the energy sector, and cybersecurity of critical energy facilities. We propose eliminating these shortcomings by using the results of the hierarchical studies conducted at the MESI SB RAS, which integrate the existing results in mathematical and semantic modeling; situational management; agent, cloud, and intelligent computing. We present the approach to integrating software, information support and intelligent information technologies required for research. The architecture of a multi-agent intelligent environment integrating heterogeneous components is proposed, and the state of the development is considered.

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References

[1] Berdnikov R.N., Bushuev V.V., Vasiliev S.N., Veselov F.V., Voropay N.I. et al. The concept of an intelligent electric power system with an active-adaptive network. M.: FGC UES, 2012. – 219 p. (in Russian).

[2] Voropai N.I., Stennikov V.A. Integrated Intelligent Energy Systems // News of the Russian Academy of Sciences. Energy. №1. 2014. Pp. 64-78 (in Russian).

[3] Voropay N.I., Gubko M.V., Kovalev S.P., Massel L.V., Novikov D.A., Raikov A.N., Senderov S.M., Stennikov V.A. Problems of the development of digital energy in Russia // Management Problems. № 1, 2019. Pp. 2-14. DOI: http://doi.org/10.25728/pu.2019.1.1 (in Russian)

[4] Expert and analytical report "Digital transition in the electric power industry of Russia" https://www.csr.ru/issledovaniya/tsifrovoj-perehod-v-elektroenergetike-rossii/ (access date 08.10.2018) (in Russian).

[5] Materials of the 2nd industry conference "Digital Transformation of the Electric Power Industry of Russia", Moscow, October 2017: http://digitenergy.ru/ (access date 11.13.2017) (in Russian)

[6] Systemic research in the energy sector: Retrospective of scientific directions SEI – ISEM / resp. ed. N.I. Voropay. Novosibirsk: Nauka, 2010. – 686 p. (in Russian)

[7] Voropai N.I., Kler A.M., Kononov Yu.D., Saneev B.G., Senderov S.M., Stennikov V.A. Methodological foundations of strategic planning for the development of energy // Energy Policy, issue 3, 2018. – Pp. 35-44 (in Russian).

[8] Massel L.V., Gribova V.V., Kopaygorodsky A.N. "Cloud" structure of energy-information systems // In the book: Innovative Electric Power-21 / Ed. Batenin V.M., Bushuev V.V., Voropay N.I. M .: IC "Energy", 2017. – Pp. 556-577 (in Russian)

[9] Massel L.V. Fractal Approach to Constructing Ontological Knowledge Space / Published in 2018 3rd Russian-Pacific Conference on Computer Technology and Applications (RPC) Publisher: IEEE. Pp. 1-5. DOI: 10.1109/RPC.2018.8482138 https://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=8469127

[10] Tuzovsky A.F., Chirikov S.V., Yampolsky V.Z. Knowledge management systems (methods and technologies). – Tomsk: NTL Publishing House, 2005. – 260 p.

[11] Massel L.V., Massel A.G. Semantic technologies based on the integration of ontological, cognitive and event modeling // III international scientific and technical conference OSTIS-2013: proceedings. Belarus. Minsk. BSUIR, 2013. – Pp. 247-250 (in Russian).

[12] Massel L.V., Massel A.G. Intelligent computing in studies of energy development directions // News of Tomsk Polytechnic University. 2012. T. 321. № 5. Management, computer engineering, and computer science. – Pp. 135-141 (in Russian).

[13] Gavrilova T.A., Khoroshevsky V.F. Knowledge bases of intelligent systems. St. Petersburg: Peter, 2001. – 384 p. (in Russian)

[14] Trachtengerts E.A. Computer decision support. M.: SINTEG, 1998. – 376 p. (in Russian)

[15] Stolyarov L.N. The philosophy of event modeling on the example of the scenario of an energy disaster // International Conference "Information Technologies in Science, Education, Telecommunications and Business": proceedings. Ukraine. Gurzuf, 2010. – Pp. 197-200 (in Russian).

[16] Massel L.V., Pyatkova E.V. The use of Bayesian trust networks for the intellectual support of research on energy security problems // Vestnik ISTU. № 2, 2012. – Pp. 8-13 (in Russian).

[17] Pospelov D.A. Situational management. Theory and practice. Moscow: Science, 1986. – 284 p. (in Russian).

[18] Vasiliev V.I., Ilyasov B.G. Intelligent control systems. Theory and practice. M. Radio engineering, 2009. – 392 p. (in Russian)

[19] Pyatkova N.I., Massel L.V., Massel A.G. Methods of situational management in studies of energy security problems. News of the Academy of Sciences. Energy. № 4, 2016. – Pp. 156-163 (in Russian).

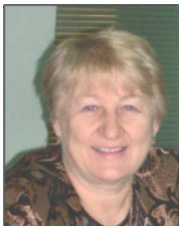
[20] Massel L.V. Integration of semantic and mathematical modeling in studies of energy security problems // International Conference "Modeling-2012": proceedings. Kyiv. IPME NAS of Ukraine, 2012. – Pp. 270-273 (in Russian).

[21] L. Massel, A. Massel. Intelligent support tools for strategic decision-making on Smart Grid development / International Conference "Green Energy and Smart Grids" (GESG 2018): Proceedings. Pp. 1-8. DOI: https://doi.org/10.1051/e3sconf/20186902009, https://www.e3s- conferences.org/articles/e3sconf/abs/2018/44 /contents /contents.html

[22] Kopaygorodsky A.N. Knowledge management in collective expert activity on the substantiation of recommended solutions in the energy sector / Proceedings of the XX Russian Scientific Conference "Enterprise Engineering and Knowledge Management (EE & KM – 2017)." M .: REU them. G.V. Plekhanov. – Pp. 128-135 (in Russian).

[23] Massel L.V., Galperov V.I. Development of multi-agent systems for the distributed solution of energy problems using agent scenarios / Bulletin of Tomsk Polytechnic University. T. 326. № 5, 2015. – Pp. 45-53 (in Russian).

[24] Massel A.G. Technique of threat analysis and risk assessment of information-technological security breaches of energy complexes // Proceedings of the XX Baikal All-Russian Conference "Information and Mathematical Technologies in Science and Management", vol. III. – Irkutsk: ISEM SB RAS, 2015. – Pp. 186 – 195 (in Russian).



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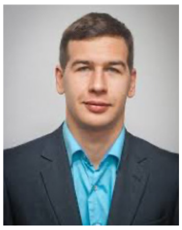

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