

Development Of Digital Twins And Digital Shadows Of Energy Objects And Systems Using Scientific Tools For Energy Research

Lyudmila V. Massel¹, Alexey G. Massel^{2}*

¹ Doctor of Technical Sciences, Professor, Chief Researcher, Head of department of Artificial intelligence system, MESI SB RAS, Lermontov str. 130, Irkutsk

² Ph.d., Senior Researcher, department of Artificial intelligence system, MESI SB RAS, Lermontov str. 130,

Abstract. The article discusses an approach to the construction of digital twins and digital shadows, based on the use of scientific tools for complex energy research in Russia. It is proposed to use, as their basis, mathematical models of energy systems and software systems and databases developed at the Energy Systems Institute of SB RAS, for calculations using these models. For each area of research, an ontological model is developed, over which mathematical and information models are built and integrated, as the basis of digital twins and digital shadows of energy objects. In turn, scientific prototypes of digital twins and digital shadows can be used in complex energy studies. To support this research, a modified architecture of the multi-agent intelligent environment is proposed. It is considered as the basis of the future IT infrastructure that integrates modern information and intelligent technologies and implements a new approach to building digital twins and digital shadows using scientific tools.

Keywords. Energy systems, mathematical model, ontological model, intelligent technologies, digital twin, digital shadow

Introduction

In connection with the spread of digital energy concepts in Russia, the importance of strategic decisions on the development of interconnected technological and information and telecommunications infrastructures is increasing. Institute of Power Systems. Melentiev SB RAS (MESI SB RAS) traditionally conducts complex energy research, the results of which can be used to substantiate strategic decisions on the development of the energy sector.

To substantiate and support the adoption of such decisions, it is advisable to use intelligent information technologies and modern digitalization trends. Among the latter, digital twins and digital shadows are important.

The article examines these concepts and an approach to the construction of digital twins and digital shadows, based on the use of scientific tools for energy research: mathematical and information models, software systems and databases. A multi-agent instrumental environment for research support is described, combining mathematical and semantic methods, models and software developed at MESI SB RAS. It is proposed to develop and include in this environment scientific prototypes of digital twins and digital shadows that can be used in research. This allows us to view this environment as the foundation of the future IT infrastructure, integrating modern information and intelligent technologies and introducing a new approach

to building digital twins and digital shadows using scientific tools.

1 Hierarchical systemic studies of energy industry

MESI SB RAS is one of the leaders in the field of system research in the energy sector of Russia. The main scientific directions of ISEM SB RAS: theory of the creation of energy systems, complexes and installations and their management; scientific foundations and mechanisms for implementing the energy policy of Russia and its regions. Within the framework of these areas, the following studies is being carried out: of energy systems (electric power, gas, oil, oil products, heat power); of energy security of Russia; of regional energy issues; of interconnections of energy and economy; of promising energy sources and systems; research in applied mathematics and computer science [1].

Until recently, the main research tool was mathematical modeling and a computational experiment. In connection with the new development trends of 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 being implemented in Russia is now being actively developed. The federal project "Digital Energy Industry" is a part of this Program. The authors decide that the federal project "Digital Energy

* Corresponding author: amassel@isem.irk.ru

Industry” does not pay enough attention to such areas as intelligent support of strategic decisions making on the development of the technological infrastructure of the energy sector and ensuring cyber security of critical energy facilities. Below we consider in more detail the first direction. A major role in strategic decisions making should be played by their scientific justification, for which the scientific achievements of the institute can be used.

Traditionally, the MESI SB RAS uses a hierarchical research scheme in which at aggregated level researches of the fuel and energy complex (economic and mathematical models are used), and at the next more detailed levels studies industry energy systems (physical and mathematical models are used) (Fig. 1). These models must be coordinated. Research on forecasting the development of the fuel and energy complex is carried out at the top level, taking into account the results obtained in studies of the development of industrial energy systems at the following levels. The scheme includes a number of 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 [2].

To use the results of these studies for substantiation of strategic decisions on energy sector development, it is necessary to carry out a formal integration of software and information support in order to improve the hierarchical technology to justify the development of the energy industry as a whole and its industry and territorial components, while the main attention should be paid to the development of software and information interfaces between tasks in the horizontal (between energy systems) and vertical (Energy Systems - Fuel and Energy Complex - External Conditions).

The development and implementation of such interfaces should provide the following advantages of a complex hierarchical research technology: a) maintaining (with the necessary refinement of the required software tools) confidentiality of the main detailed data arrays supporting specific tasks; b) formalization and thereby accelerating the exchange of information and ensuring the uniqueness of exchanged data; c) a certain unification of the information models used in solving various problems, which will need to be implemented when coordinating and developing interfaces; d) in general, an increase in “harmony” and the validity of the hierarchical technology for substantiating the development of energy industry and its components.

In [3], an approach to solving this problem was proposed, but the concepts of digital twins and digital images were not used in it. At the end of the article, the main provisions of the previously proposed and described here approaches will be compared.

Further, the main concepts of the latest trends in the development of digital technologies are considered: digital twins and digital shadows, digital models and digital images.

2 Digital twins and digital shadows

The latest trend in the development of digital technology is the creation of digital twins. It is claimed that the “digital twins” has entered the top ten major strategic technological trends of 2019. The concept of a digital twin has several definitions. The concept of a digital double has several definitions, a review of which was performed, for example, in [4], based on sources [5-14].

Consider the definition of the chief engineer of the Intelligent Networks division of Siemens company by E. Litvinova: “A digital twin is a real display of all components in the product life cycle using physical data, virtual data and the interaction data between them, that is, a digital twin creates a virtual prototype of a real object with which you can conduct experiments and test hypotheses, predict the behavior of an object and solve the problem of managing its life cycle” [15]

According to experts [4], digital twins can be divided into three types:

1. Digital Twin Prototype. This is a virtual analogue of a real existing element. It contains information that describes a specific element at all stages — from the requirements for production and production processes during operation to the requirements for the disposal of the element.

2. Digital Twin Instance. It contains information on the description of the element (equipment), that is, data on materials, components, information from the equipment monitoring system.

3. Digital Twin Aggregate. It combines a prototype and an instance, that is, it collects all available information about the equipment or system.

For companies that operate electrical networks, the most relevant Digital Twin Instance. It is based on a mathematical model of network. Such a Digital Twin Instance can contain information about the technical parameters of the equipment used (cables, transformers, switches, etc.), the date of its commissioning, geographical coordinates, data from measuring devices. This information is used to carry out calculations for connecting new consumers, as well as various calculations of electric networks. For example, the calculation of modes, short circuit currents, coordination of relay protection settings and others.

For electric networks, the Digital Twin Instance includes a database with information about the network, which is integrated with other IT systems of the energy company (SCADA, geographic information system, asset management system, etc.). A Digital Twin Instance should synchronize data received from different sources, so that they exactly match the current state of the electrical network.

From the point of view of the construction area, digital twins of the product, process and system are distinguished [4]. A “digital product twin” is a virtual model of a specific product. “Digital process twins” - these models simulate production processes. The “digital system twins” are the virtual models of the system at a whole (for example, a digital twin of factory).

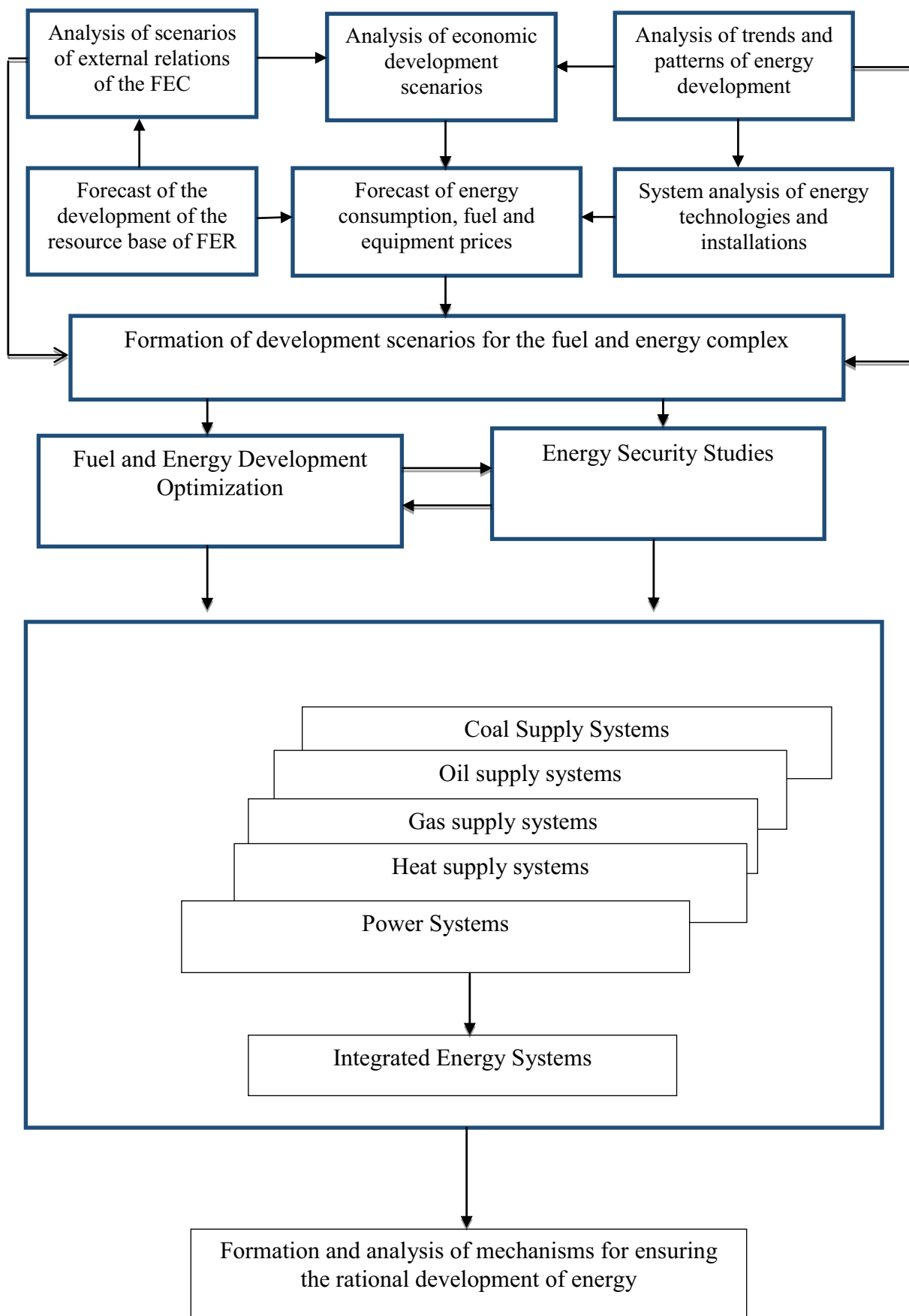


Fig. 1. The general scheme of hierarchical studies to substantiate the development of energy industry

In addition, the term digital shadow is used. A digital shadow can be defined as a system of relationships and dependencies that describe the behavior of a real object, as a rule, under normal working conditions and contained in excess big data obtained from a real object using industrial Internet technologies. A digital shadow is able to predict the behavior of a real object only in those conditions in which data was collected, but it does not allow simulating other situations. Comparison of digital twins and digital shadows is considered, for example, by A. Borovkov [16].

3 Transition from mathematical and informational models (computer programs and databases) for energy research to digital twins and digital shadows.

Based on the analysis of the sources cited and their own experience in the development of intelligent DSS and research infrastructure, the authors propose the following approach to the organization of system research in the energy sector using modern digitalization trends.

Justification of the possibility and feasibility of such a transition can be confirmed by a digital twin scheme based on an ontological model, which is a generalization of the scheme proposed by Dr.Sci. S.P. Kovalev (IPU RAS) with coauthors [17, 18] (Fig. 2).

In this scheme, it is important for us that the layer of mathematical models of the digital twin “gathers” over the ontological model. If we return to hierarchical studies to justify the energy development at ISEM SB RAS, it seems that on the basis of ontological and mathematical (physic-technical) models of industrial energy systems, digital twins of these systems can be constructed. Digital shadows are developed on the basis of information models, at the first stage, in the form of databases. After solving the issues of providing mathematical and simulation models with data, the issues of information interaction with data streams and conducting computational experiments on digital twins, they can be recommended for practical use in the management of the corresponding energy systems.

We can suggest the following stages of the transition to "digital twins" in the study of energy systems:

- 1) analysis of existing mathematical models and computer programs implementing them (software systems);
- 2) ontological engineering of the subject area (the corresponding power system) and the construction of its ontological model;
- 3) determination of the initial data or data flows (composition, sources of receipt, the possibility of obtaining operational data, databases, etc.), as a basis for building digital shadows, and their interaction with mathematical models;
- 4) modification, if necessary, of mathematical models and reengineering of software systems (if they moved into the category of legacy software);

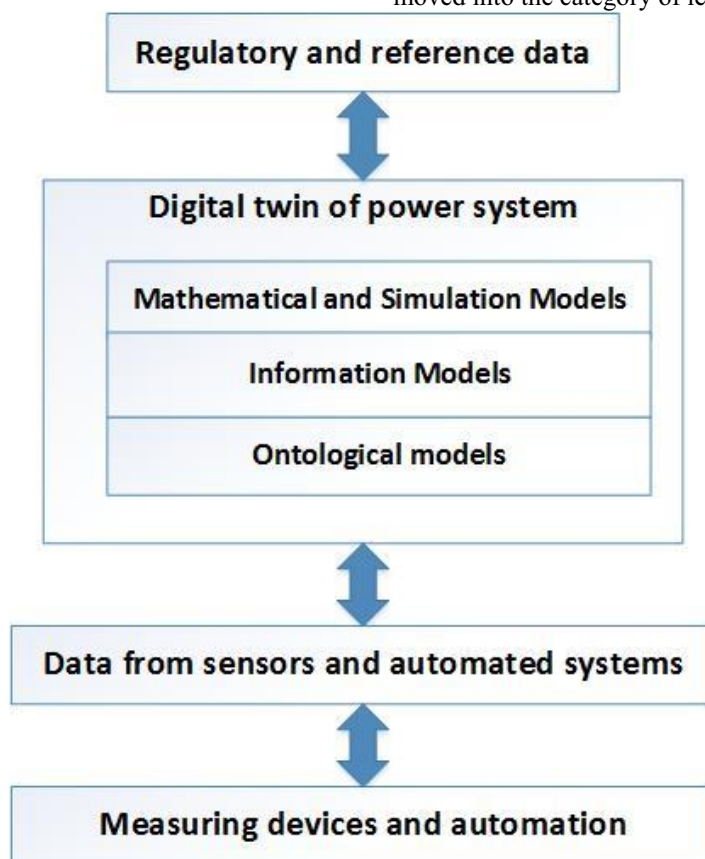


Fig. 2 . Energy system digital twin architecture.

5) development, based on the reengineered digital programs, web-applications and web-services for the development of digital twins.

6) development of digital twins prototypes of energy systems

The general final stage: the creation of IT infrastructure for hierarchical integrated researches using digital twins and digital shadows.

4. Infrastructure for support complex research in the energy sector using digital twins and digital shadows.

The basis of the infrastructure for conducting hierarchical comprehensive research in the energy sector using digital twins and digital images can be the modified architecture of the multi-agent intellectual environment (Fig. 4), proposed by the authors earlier in [3].

The levels (stages) of energy systems research and tools supporting them are shown in Fig. 3.

The following research levels (stages) and the supporting tools are identified:

1. The level of information analysis (using semantic modeling), supported by Intelligent IT environment.
2. The level of collective implementation of coordinated decisions (can be used semantic modeling, methods for coordinating decisions and others) - is supported by the Intelligent Support System for Collective Expert Activity [19].
3. The level of substantiation of decisions (the options proposed at the previous stage are calculated using traditional software systems for research on Fuel and Energy Complex and Energy Systems).
4. The level of presentation of the proposed solutions (using visual analytics and cognitive graphics).

The integration of tools is carried out using the knowledge management language (KML), which is considered as a simplified version of the previously developed language of situational management (Contingency Management Language - CML) [20]. Knowledge Management Language is used for integration of these components and for call of the required component.

The main components (agents) of MAIE are:

1. Software Systems and Data Bases for research of the fuel and energy complex together with Software and Data Bases, for example, for energy security research.
2. Data and Knowledge Warehouse.
3. Intelligent IT-environment for supporting of semantic modeling [21].
4. Intelligent system for supporting of collective expert activity.
5. Software component for visual analytics (GEO-visualization component).
6. Repository for descriptions storage 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 – Ontological Knowledge Space.

The modification of this schema consists in the fact that software systems in the upper blocks of the circuit will be replaced with digital twins prototypes and databases became of digital shadows prototypes. This allows us to view this environment as the foundation of the future IT infrastructure, integrating modern information and intelligent technologies and introducing a new approach to building digital twins and digital shadows using scientific tools.

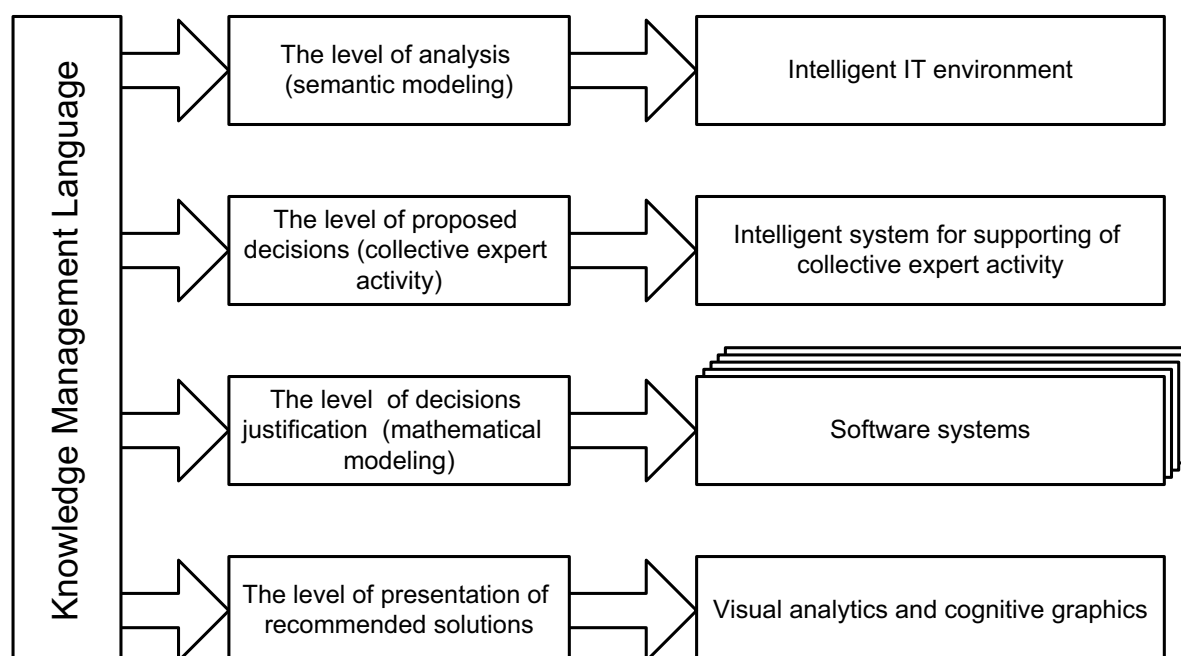


Fig. 3. Levels (stages) of energy systems research and tools supporting them.

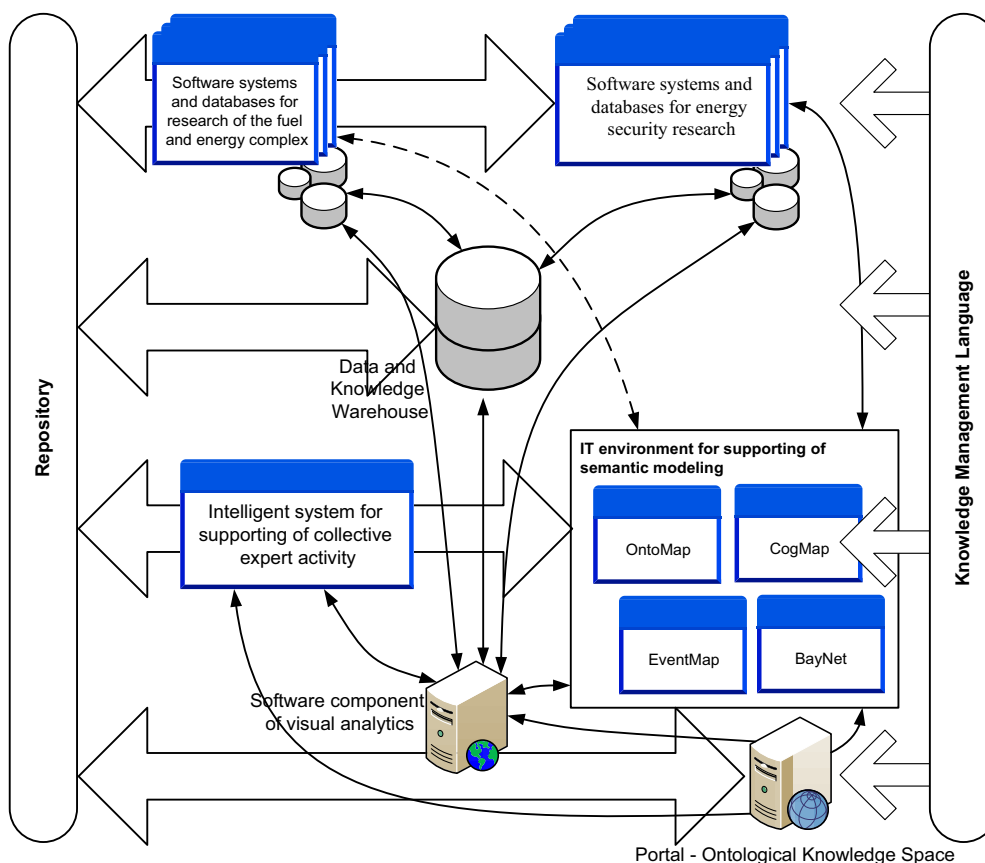


Fig. 4. The architecture of the multi-agent intelligent environment (MAIE) as the basis of the IT-infrastructure for support of complexes energy research using digital twins and digital shadows

Conclusion

1. One of the main trends of digitalization are considered: digital twins and digital shadows.
2. It is proposed to use the integration of mathematical, information and ontological models in energy research as base for construction digital twins and digital shadows.
3. The stages of transition from mathematical models, software systems and databases to digital twins and digital shadows are determined.
4. An infrastructure is proposed to support complexes energy research using digital twins and digital shadows.
5. The modified architecture of a multi-agent intelligent environment as the basis of a new IT-infrastructure for energy research is considered.

Acknowledgment

The results were obtained within the framework of the project under the state assignment of the ISEM SB RAS AAAA-A17-117030310444-2 (project No. 349-2016-0005) and with partial financial support from RFBR grants No. 19-07-00351, No. 18-07-00714, No. 17-07-01341.

References

1. Systemic research in the energy sector: Retrospective of scientific directions SEI – ISEM / resp. ed. N.I. Voropay. Novosibirsk: Nauka, 2010 . – 686 p. (in Russian).
2. 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).
3. Massel L.V. Methods and intelligent technologies for the scientific justification of strategic decisions on the digital transformation of energy // Energy Policy. 2018. № 5. Pp. 30–42. (in Russian)
4. Kokorev D.S., Yurin A.A. Cifrovye dvojniki: ponjatie, tipy i preimushhestva dlja biznesa. [Digital twins: concept, types and benefits for business]. Colloquium-journal / Technical science. No. 10 (34). 2019. Pp. 31–35. DOI: 10.24411 / 2520-6990-2019-10264 (in Russian)
5. Tolstykh T.O., Gamidullaeva L.A., Shkarupeta E.V. Key factors for the development of industrial enterprises in the context of digital production and Industry 4.0 // Economics in Industry. 2018. T. 11. № 1. Pp. 11–19 (in Russian)

6. Bolton R. N. et al. Customer experience challenges: bringing together digital, physical and social realms // *Journal of Service Management*. 2018. T. 29. №. 5. Pp. 776–808.
7. El Saddik A. Digital twins: the convergence of multimedia technologies // *IEEE MultiMedia*. 2018. T. 25. №. 2. Pp. 87–92.
8. Glaessgen E., Stargel D. The digital twin paradigm for future NASA and US Air Force vehicles // 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA. 2012. Pp. 1818.
9. Lee J., Bagheri B., Kao H. A. A cyber-physical systems architecture for industry 4.0-based manufacturing systems // *Manufacturing letters*. 2015. T. 3. Pp. 18–23.
10. Michael W. Grieves Digital Twin: Manufacturing Excellence through Virtual Factory Replication – LLC. 2014. 7 p.
11. Rosen R., Wichert G., Lo G., Bettenhausen K. About The Importance of Autonomy and Digital Twins for the Future of Manufacturing. IFAC-PapersOnLine. 2015. Pp. 567–572.
12. Qia Q., Taoa F., Zuoa Y., Zhaob D. Digital twin service towards smart manufacturing // *Procedia CIRP*. 2018. Vol. 72. Pp. 237–242.
13. Tao F. et al. Digital twin-driven product design framework // *International Journal of Production Research*. 2018. Pp. 1–19.
14. Söderberg R. et al. Toward a Digital Twin for real-time geometry assurance in individualized production // *CIRP Annals*. 2017. T. 66. №. 1. Pp. 137–140.
15. Nikitina E. Caught in the network: how digital doubles work in the electric power industry. Available at: <https://pro.rbc.ru/news/5db1b59a9a79474bb142a3fe> (accessed 11.24.2019) (in Russian)
16. Borovkov A. Digital twins and digital shadows in the high-tech industry. Available at: <https://4science.ru/articles/Cifrovie-dvoyniki-i-cifrovie-teni-v-visokotekhnologichnoi-promishlennosti> (accessed 11.24.2019) (in Russian)
17. Andryushkevich S.K., Kovalev S.P., Nefedov E. Approaches to the development and use of digital twins of energy systems] // *Cifrovaja podstancija. = Digital substation*. № 12. 2019. Pp. 38–43. (in Russian)
18. Andryushkevich S.K., Kovalyov S.P., Nefedov E. Composition and application of power system digital twins based on ontological modeling // *Proc. 17th IEEE Intl. Conf. on Industrial Informatics INDIN'19*. Helsinki-Espoo, Finland: IEEE. 2019. Pp. 1–6.
19. Kopaygorodsky A.N. Knowledge management in collective expert activity on the substantiation of recommended solutions in the energy sector // *Trudy Proceedings of the XX Russian Scientific Conference "Enterprise Engineering and Knowledge Management"*. 2017. Moscow. REU named G.V. Plekhanov. Pp. 128–135. (in Russian)
20. Massel L.V., Massel A.G. Language for describing and managing knowledge in an intelligent system of semiotic type // *Proceedings of the XX Baikal All-Russian Conference "Information and mathematical technologies in science and management"*. T. 3. Irkutsk. ESI SB RAS. 2015. Pp. 112 - 124. (in Russian)
21. Massel L.V., Massel A.G. Intelligent computing in studies of energy development directions // *News of Tomsk Polytechnic University*. 2012. V. 321. № 5. Management, computer engineering and computer science. Pp. 135-141. (in Russian)