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# A hierarchical model of the information environment for railway power supply system critical objects control

***Abstract.*** *It is proposed to consider the hierarchical model of the information environment as a structure according to its functions (implemented by the software part) and architecture (responsible for effective implementation of functional capabilities). It is proposed to improve the information management system of Ukrzaliznytsia's critical power supply facilities, based on the developed hierarchical model of the information environment, which takes into account the presence of Ukrzaliznytsia's own generation sources by integrating the appropriate control subsystem into the information system structure. The model emphasizes the integration of software and hardware components for data collection, pre-processing, and decision-making, contributing to a highly automated and intelligent control system. It proposes a multi-level structure incorporating artificial intelligence and advanced technologies to optimize electricity consumption and improve operational efficiency within the railway power supply system.*

***Key words:*** *hierarchical model, control, power supply, information, railway.*

## Problem statement

Information plays a key role in ensuring effective management of objects of the railway power supply system.

The development of a hierarchical model of the information environment for railway power supply system critical objects control is an urgent scientific and technical task, which will allow to increase the effectiveness of management decisions by integrating different levels of information and ensuring its timely analysis in a single information environment. The importance of this problem is due to the complexity of power supply facilities, the need for prompt response to emergency situations, and the criticality of the consequences of possible system failures, the probability of which only increases due to the destruction of Ukrainian power plants by the Russian Federation.

As one of the largest consumers in Ukraine, Ukrzaliznytsia experiences a significant shortage of electrical energy, and the introduced consumption limits cover only 75% of the real needs to ensure the transportation process and current economic activity [1] of the company.

An increase in the deficit will have an impact on the smooth running of trains. The construction of gas power plants for the needs of Ukrzaliznytsia [1] created the need to rethink the information environment of the power supply system management, since previously the generation factor was not taken into account in the development of information systems for the power supply of railway transport in Ukraine.

## Literature review

If we set aside the subject area, the task of developing a model of the control information environment is common to the automation industry as a whole, so experience from other areas is taken into account to analyze the typical features of hierarchical models of information systems, not limited to research in the field of power supply, including the power supply of railway transport. For example, in the article [2], the author describes a hierarchical model of intelligent control in the military sphere through graph theory, while using the principles of automatic control theory.

The authors of the article [3] consider a three-level hierarchical system of monitoring and dispatching for the execution of business processes, which is similar in structure to the desired model of the information environment for railway power supply system critical objects control.

The method of forming information support is proposed in [4].

It is designed for a hierarchical network representation of a subject area and can be used for a decision support system for acquiring and applying knowledges.

Information networks of the electric power industry all over the world began to develop according to the concept, which is generally called Smart Grid [5]. It certainly cannot be ignored when developing a model of the information environment for controlling the power supply system of railway transport. Researches [6, 7] confirm the relevance of "intelligent" power grids of the Smart Grid concept in 2024.

A large number of scientific works are devoted to the intellectualization of the electric power industry in Ukraine [8-12].

The basic principles of monitoring as a fundamental component of "smart" electricity supply networks in Ukraine are laid down in work [8].

The relevance of modern information technologies for energy in the post-war reconstruction of Ukraine is confirmed in [9].

The need to increase the efficiency of the use of modern computer technologies in the field of energy is substantiated in the work [11]. Also, the work [11] reveals the essence of promising areas of application of artificial intelligence in energy, such as forecasting energy demand, optimization of energy consumption, use of "smart" networks.

In the information environment model for railway power supply system critical objects control, it is necessary to take into account the tendency to organize microgrids on the basis of existing distribution electrical networks with local energy sources, studied in [12] as one of the ways to reduce the military impact on the power system.

**The aim of the work**

The purpose of the study is to develop a hierarchical model of the information environment for railway power supply system critical objects control, which will take into account the presence of Ukrzaliznytsia's own generation sources.

**Main part**

The performance of the information system for managing complex dynamic objects largely depends on the availability of a complex of software and hardware tools that provide data collection and pre-processing. Therefore, it is worth considering the hierarchical model of the information environment as a structure based on its functions, which are implemented by the software part, and the architecture that is responsible for the effective provision of their implementation.

The railway power supply network is a complex and widely dispersed control object. This determines the complex structure of the hierarchical model of the information environment with controlled systems. The complex structure accumulates a high level of automation not only of the processes of preparing information for decision-making, but also of the processes of producing decision options, which are based on the knowledge obtained by the information system.

Taking this into account and taking into account the current trends in the development of information technologies in the energy sector and the level of their integration in the information environment for railway power supply system critical objects control in Ukraine, it is proposed to carry out its formation according to the structure (fig. 1), which provides for increasing the functionality of the current management system in order to reduce the cost of purchasing electricity by optimizing the transportation process and effectively using own generation sources. The proposed structure of the information environment (fig. 1) consists of several complex subsystems, each of which performs its specific tasks.

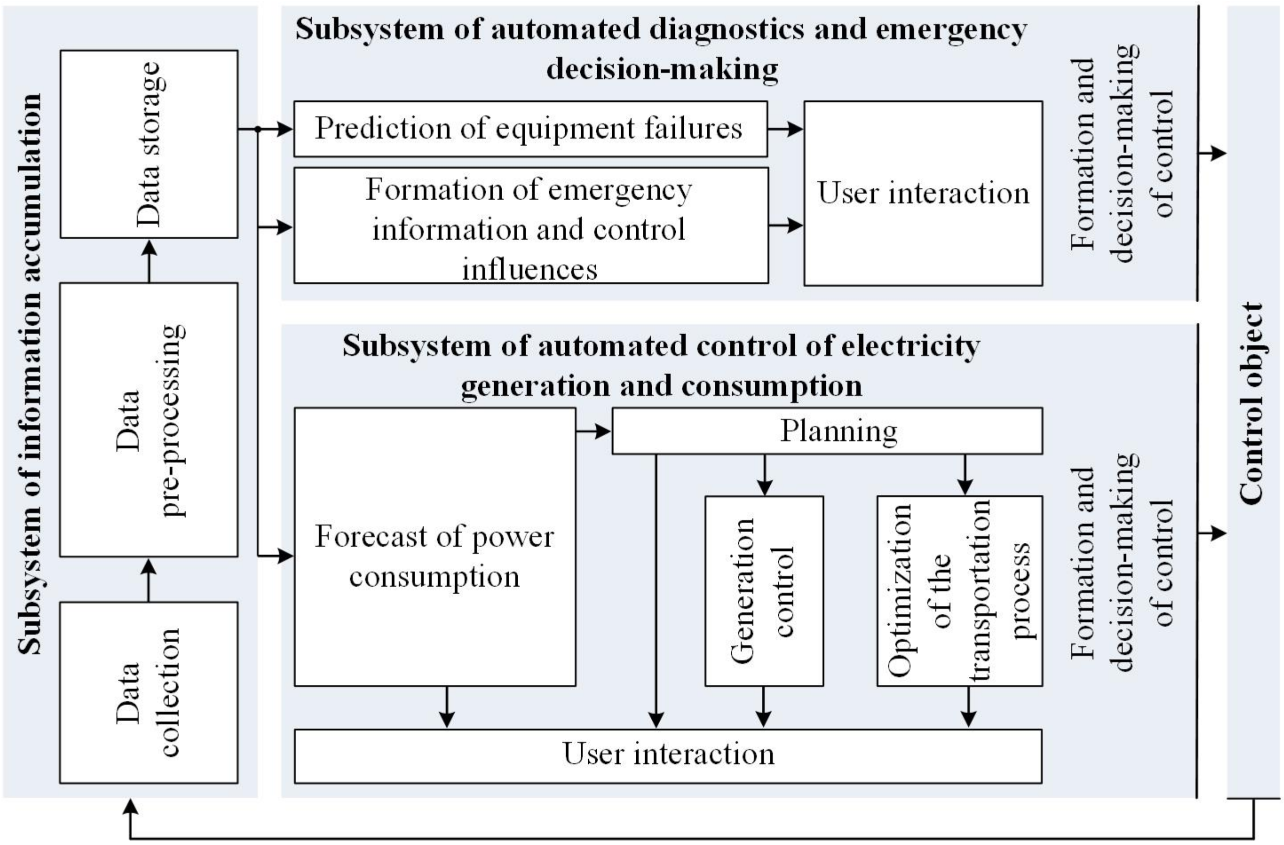


Figure 1. The structure of the information environment for railway power supply system critical objects control

The subsystem of information accumulation includes both software components of data processing for the purpose of obtaining knowledge, and physical devices for registration, storage and transmission of primary monitoring data to other subsystems. This subsystem provides for the integration of data from external sources to ensure the intellectualization of the control system in accordance with modern needs and technologies. Further, these data can be used to solve specific tasks of control. This subsystem most closely depends on the computer architecture of the information environment.

The subsystem of automated diagnostics and emergency decision-making is aimed at reducing the influence of the operative personnel human factor during the elimination of abnormal (emergency) situations in the power supply network, which corresponds to the Smart Grid concept. This subsystem consists of a prediction equipment failures unit and a formation of emergency information and control influences unit. The prediction equipment failures unit determines the remaining resource of power devices. The formation of emergency information and control influences unit informs the dispatcher about abnormal situations, provides data on the current mode of operation and offers possible ways to eliminate accidents in case the dispatcher’s intervention is necessary. Thus, through the user interaction unit, the formation of emergency information and control influences unit performs the functions of a support and decision-making system.

A modern decision support system allows predicting the impact of decisions on the further development of the control object [13].

If it is possible to eliminate the consequences of an emergency situation without the involvement of operative personnel, the subsystem of automated diagnostics and emergency decision-making should independently eliminate them with the help of intelligent algorithms.

The subsystem of automated control of electricity generation and consumption consists of interconnected units – forecasting and planning. They prepare the input information for the generation control and optimization of the transportation process units. All units of the subsystem interact directly with the dispatcher and provide data in the form of prepared reports and decisions.

Based on the data from the subsystem of information accumulation, the forecast of power consumption unit is designed to forecast the value of power consumption at individual traction substations and at individual feeders, if it is technically possible. The predicted values are transferred to the planning unit and reported to the user interaction unit.

The main purpose of the planning unit is to save costs for the purchase of electricity. It is achieved by analysing the available electricity tariffs and the current train schedule, using the obtained forecast values.

Generation control and optimization of the transportation process units are necessary according to the needs determined by the planning unit in order to use own sources of generation in an automated mode in cases of electricity shortage in the country's power system or on the condition that the cost price of electricity of own production is lower than the price of the wholesale energy market and for adaptation of the train schedule [14-16] to the current tariff conditions.

The task of the subsystem of automated control of electricity generation and consumption is also the automatic formation of annual, quarterly and monthly electricity balances for separate control objects (it can be a traction substation, its separate feeder or even a separate workshop or any other stationary consumer that is powered by this feeder and has its own automated accounting devices (automated system of commercial electricity accounting). These balances can be used to analyze the use of electricity, its losses, and determine ways to save.Planning, generation control and optimization of the transportation process units provide the formed control influences to the dispatcher for their further approval, correction or transfer to other structural divisions of Ukrzaliznytsia.

The information environment for control objects of the electric power system is a structure with a complex topology of connections between its elements [17]. In the power industry, workstations of monitoring systems mostly interact through local servers, which makes it expedient to optimize the network, in particular, to segment it by workgroups so that the main volume of traffic remains within the local segment [8]. At the same time, the communication infrastructure should use all available paths and ensure data transmission via the shortest routes [18].

The main architectural feature that distinguishes the information environment of an intelligent control system from others is the connection of data storage and processing mechanisms necessary in conditions of dynamic changes in input data or their uncertainty under the influence of external factors (changes in the parameters of the external environment, tasks, characteristics of the control object etc).

The proposed hierarchical model of the information environment for railway power supply system critical objects control involves the use of artificial intelligence methods and technologies, which were studied in works [19-21], as the main tools for dealing with the uncertainty of external influence. It can be the basis for expanding the automated control system at critical traction power supply facilities of Ukrzaliznytsia with the aim of introducing additional functionality and rationalizing the use of technical means.

The hierarchical multi-level structure has the following essential characteristics: possibility of vertical decomposition of the system into subsystems; priority of actions or possibility of upper-level subsystems intervention; upper-level subsystems actions dependence from actual performance of their functions by the lower levels [3].

The hierarchical model of the information environment architecture for Ukrzaliznytsia's power supply system critical objects control (fig. 2) provides decentralized information processing, which makes it possible to transfer the load to the lower levels of the hierarchy. This approach makes it possible to implement local automated control and diagnostics based on servers of power supply distances.

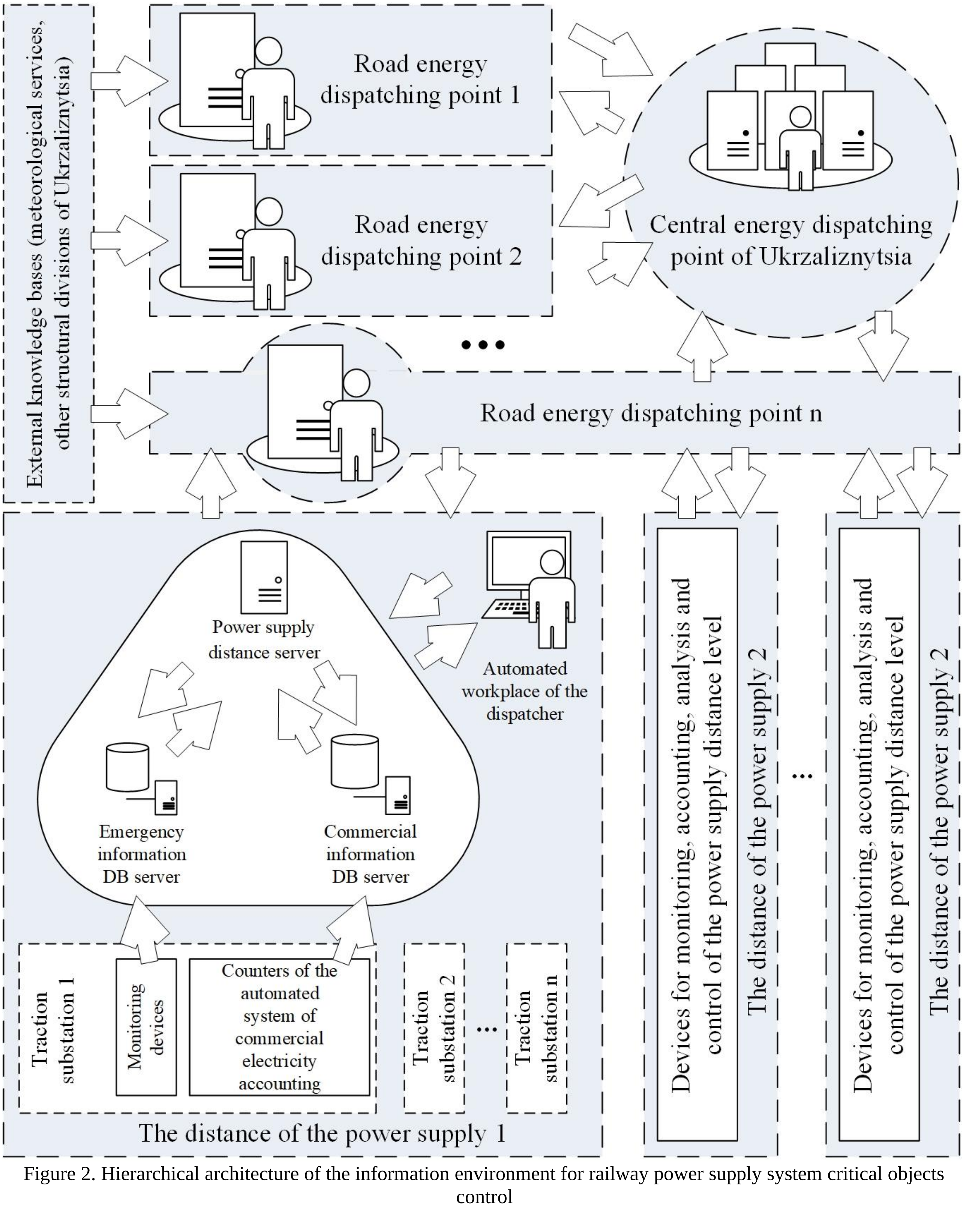


Figure 2. Hierarchical architecture of the information environment for railway power supply system critical objects control

According to the concept of Smart Grid [5, 19], one of the key elements of an "intelligent" network is a digital substation, which is equipped with control, protection, and management systems that collect and process the entire volume of data about the state of the power grid and manage the equipment in a digital format.

Collected primary data is archived and stored in raw form for the prescribed period in accordance with regulatory documents.

The railway industry is both a producer of data and a consumer of knowledge derived from datasets [23]. The model (fig. 2), which contributes to the effective transformation of large volumes of data into useful information and knowledge necessary for the optimization of railway transport operations, is proposed using the ideas of building industrial information systems described in the book [24] by Thomas Bushe and Ali Yalchin and taking into account that the lower levels of the architecture are not only the main sources of information, but also its biggest consumers. The most intensive data transfer occurs at the lower levels.

Thus, a significant part of the information channels is placed in the relevant subsystems, and this saves traffic and computing resources at the upper levels of the hierarchy [24].

Data transfer protocols must ensure reliable and correct operation. Therefore, it is necessary to use the Ethernet protocol and the TCP/IP model for data transmission in a local network. They are widely used by leading manufacturers of computer equipment, in particular hardware of automated control and monitoring systems [8, 25]. This is due to their well-developed technology, low cost and wide distribution.

The combination of intelligent communication protocols with energy transfer in the general architecture provides the possibility of implementing distributed management [26]. For this, the principle of a single system-wide measurement of the railway power industry primary data is important. It is key to obtaining information that shows the excited modes of the power supply system operation as a territorially distributed complex structure and allows timely response to external influences and minimizing damages, quickly returning the system to normal functioning.

According to the four-level hierarchy of the proposed architecture, the data access levels necessary to protect information from unauthorized access must be provided in the information system.

Microprocessor devices and components of the monitoring and diagnostics network form the lower level of the hierarchical control model of the Ukrzaliznytsia's power supply system (fig. 2). Traction substation level functionally provides technological control of objects and processes on the contact network and traction substation.

Means for recording primary data, located at the lower level, serve as the basis for the intellectualization of power supply. With their help, the tasks of commercial and technological electricity accounting and continuous equipment diagnostics are automatically solved. Continuous diagnostics of the equipment consists in determining the type and location of the accident and recording pre-accident, emergency and post-accident power supply modes with time synchronization and activation of protection systems. Information from this level is transmitted to all higher levels of the hierarchy.

Each of the railways has several power supplies distances (power supply distance level), where operational control and monitoring functions are performed, primary data is collected from microprocessor recorders of traction substations, operational dispatching organizational and technological control of the power supply distance is carried out.

Distributed databases (DB) of emergency and commercial information are implemented on separate servers of the power supply distance level (fig. 2) and the information is formed for transmission to a higher level.

One of the reasons for such an architectural solution is the use of the computer network "multi-user" operation mode, which causes many interrelated issues regarding the protection of information on servers.

The developed model of the information environment facilitates the separation of access, since emergency and commercial information are processed independently on separate devices. This reduces the risk of data leakage or loss.

In this process, algorithms are implemented that provide management functions in accordance with the Smart Grid concept: modeling and forecasting the reliability of the electric energy transmission and consumption systems operation, assessment of equipment condition, formation of management decisions.

Information from power supply distances and external sources (for example, meteorological services) is sent to the road energy dispatching point and subject to further processing. Operational dispatching organizational, economic and technical management of the railway power supply service is carried out at the road energy dispatching point level.

The central energy dispatching point of Ukrzaliznytsia is the highest control level. All information from the six regional branches of Ukrzaliznytsia comes here. Coordination of management actions, which ensures coordinated and effective functioning of the entire power supply system, is carried out at this level.

Preparation of information for organizational and economic management and creation of reports of the appropriate level is carried out at the highest levels of the hierarchical model.

Effective organizational and economic management, as well as energy efficiency, are achieved due to increasing the awareness of management personnel and the possibility of applying various computational methods in the processes of forming management decisions.

Organizational and technological management ensures a reduction in electricity consumption due to the use of traction power supply economic modes, ensuring an energy-optimal train schedule, intellectualization of the processes of electricity payment tariff system effective use, as well as timely provision and increase of information reliability.

Technological management of traction power supply equipment ensures management efficiency by increasing the efficiency of management decision-making.

The proposed hierarchical model of the information environment architecture for railway power supply system critical objects control is a combined. Along with the automation subsystems based on the DB in the architecture (fig. 2), the integration of non-formalized knowledge represented in the architecture by the central energy dispatching point of Ukrzaliznytsia and the automated workplace of the dispatcher at the power supply distance level is provided.

The proposed hierarchical model is based on the principle of a single information space and represents a distributed system with geographically distant objects, where the top level is occupied by the central energy dispatching point of Ukrzaliznytsia. Its implementation involves the use of existing local computer networks of various levels, modernization of software and increased use of microprocessor devices.

**Conclusions**

It is proposed to consider the hierarchical model of the information environment as a structure based on its functions, which are implemented by the software part, and the architecture, which is responsible for the effective provision of their implementation.

A hierarchical model of the information environment, which takes into account the availability of Ukrzaliznytsia's own generation sources by integrating appropriate control subsystem into the information system structure, is developed.

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**Гайденко О. С., Голуб Г. М., Кульбовський І. І.**
**Ієрархічна модель інформаційного середовища керування критичними об'єктами системи електропостачання залізничного транспорту**

***Анотація.*** *Розробка ієрархічної моделі інформаційного середовища керування критичними об'єктами системи електропостачання залізничного транспорту є актуальною науково-технічною задачею, що дозволить підвищити ефективність управлінських рішень шляхом інтеграції різнорівневої інформації та забезпечення її своєчасного аналізу в єдиному інформаційному середовищі. Важливість даної проблеми обумовлена складністю об'єктів електропостачання, необхідністю оперативного реагування на нештатні ситуації та критичністю наслідків можливих відмов системи, імовірність яких лише зростає через руйнування об'єктів електроенергетики України російською федерацією разом із посиленням дефіциту електроенергії в об'єднаній енергетичній системі України. Тому сьогодення вимагає переосмислення інформаційного середовища керування системою електропостачання, зокрема й у зв'язку з будівництвом газових електростанцій для потреб Укрзалізниці.*

*Ієрархічну модель інформаційного середовища пропонується розглядати як структуру відповідно до її функцій (реалізованих програмною частиною) та архітектури (відповідає за ефективну реалізацію функціональних можливостей).*

*Пропонується удосконалювати інформаційну систему управління критичними об'єктами електропостачання Укрзалізниці на основі розробленої ієрархічної моделі інформаційного* *середовища, що враховує наявність власних джерел генерації Укрзалізниці, шляхом інтеграції відповідної підсистеми керування в структуру інформаційної системи. Модель підкреслює інтеграцію програмних і апаратних компонентів для збору даних, попередньої обробки та прийняття рішень, сприяючи побудові високоавтоматизованої інтелектуальної системи керування, пропонує багаторівневу структуру, що передбачає використання передових технологій обробки даних і штучних нейронних мереж для оптимізації перевізного процесу, ефективного управління власними джерелами генерації задля зменшення витрат на закупівлю та виробництво електричної енергії.*

***Ключові слова:*** *hierarchical model, control, power supply, information, railway.*

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