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Structure of a model for scientific research of complex electrical objects

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ABSTRACT

One of the main directions of systems research is systems analysis and systems approach. Systems theory, as a subdivision, is one of its main concepts and, along with model theory, control theory, and information theory, belongs to the methodological base in scientific research. It is essential to examine the laws and principles that facilitate effective research into the structural transformation of research organization. In practice, a systems approach involves systems coverage, systems representation, and systems orientation in research. System coverage requires considering the problem from different aspects and perspectives. Systems representation is achieved by building a single model that can replace a real object and provide relevant information about the object being modeled. Using systems analysis, an assessment of the network topology is carried out - the number of substations, line lengths, voltage levels. The formation of systemology is based on a systems approach and is used in the construction of more intelligent control systems. Ensuring the organization of research is of no small importance, which means identifying the problem; internal analysis of the problem; external analysis of the problem; system identification: goals, constraints, trends, factors, properties; model synthesis; model behavior analysis – system operation modeling; system optimization. Planning an optimization experiment, experimental model identification. Analysis of the results of the experiment with the model. Interpretation of the results in relation to the system solving the problem P. Solution implementation. Within the framework of the system approach, the tasks of analysis and synthesis are interconnected, alternating with a given regularity and characterizing two sides of a single cycle in the research process. The described cycle of problem solving applies to both the quantitative and qualitative system approaches. In this case, identification and imitation are implemented at an intuitive, heuristic level. The main disadvantage of the qualitative approach is that counterintuitive behavior that manifests itself in complex socio-economic systems is overlooked and not analyzed. The advantage of the qualitative approach over the quantitative one is a significant saving of time and money for conducting research. The set of methodological tools used to prepare and justify decisions regarding complex, scientific, and technical issues includes system analysis. System analysis is defined as a set of methods for studying complex objects by presenting them in the form of systems and further analyzing such systems. The order of stages of system analysis includes: problem formulation (choosing the object of study, determining the goal and criteria for its study); isolation and structuring (or decomposition) of the system under study, i.e., dividing it into subsystems that are relatively clearly described; creation of a mathematical model of the system. The article presents graphical and analytical stages of making evaluative management decisions based on network modeling. The results obtained proved the feasibility of using a structured system-parametric approach in the study of power supply systems. This is the difference between system analysis and the local approach, which consists of studying the structure and functional features of autonomous, separately taken elements of the system. The inability to comprehensively cover all parties, connections and «mediation» allows, during the system analysis, on the one hand, to strive for maximum completeness of the description, and on the other hand, to carry out a reasonable simplification of the object. This is especially relevant and appropriate in the field of research on processes in power supply systems.

Keywords: System analysis; system approach; methodology; principles; graph-analytical methods; graph; modeling; management; modern power supply

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INTRODUCTION

The current stage of development of technical systems, including electrical engineering systems, is characterized by the widespread use of a systematic approach to their study. A systematic approach is a comprehensive study of complex technical systems as a single whole from the perspective of systems analysis. In turn, systems analysis is a methodology for studying any objects by representing them as systems and analyzing these systems.

The general methodological basis for studying complex systems is the use of the deductive method of studying object models. In this regard, the basic concept in the scientific study of any object is the object model, which represents a simplified description or simulation of the structure of the object, the process of functioning (behavior) of the object in interaction with the environment. Thus, any quantitative description of an object, which is naturally incomplete, should be accepted as part of the modeling process, i.e., a description of the model, but not of the object. When describing and studying an object, it is important to distinguish between the concepts of an element and a system. Any object functions in an environment.

The methodological specificity of the systematic approach is determined by the fact that it focuses research on revealing the integrity of the object and the mechanisms that ensure it, on identifying various types of connections of a complex object and combining them into a single theoretical picture. That is, researching its properties as a single whole, a single system [1].

The environment consists of factors that are external to the system and have a significant impact on it. Considering the postulate of open systems–the exchange of energy, matter, and information–it is relevant to study the systemic approach in general and systemic analysis in particular with regard to the interaction of the object of study with the external environment.

The purpose of this work is to study the methodology of applying a systematic approach in scientific research regarding the possibility and feasibility of its implementation in the field of analysis and synthesis of complex electrical engineering objects using the example of a modern power supply system.

RELATED WORKS

System analysis is a methodological tool that allows identifying, describing, and optimizing the structure, functions, and interrelationships of complex technical systems. In the energy sector, the objects of system analysis are electric power systems (EPS), which include power sources (PS), power lines, transformer substations, consumers, and control systems.

According to the classic works of L. von Bertalanffy and N. Wiener, any complex technical system is characterized by integrity, structure, and the presence of feedback loops [2], [3]. These principles became the basis for the development of system analysis in the energy sector, which took shape in the 1960s–1980s in the works of J. Forrester, R. Ackoff, D. Kleiner, V. Glushkov, and other researchers [4], [5], [6].

In modern energy, a systematic approach is necessary to solve problems related to optimizing the operating modes of energy systems, assessing reliability, forecasting electricity consumption, and managing power flows [7].

The domestic scientific school of systems analysis in energy is represented by the works of O. M. Sukhodol, S. I. Chumachenko, O. G. Melnik, S. P. Denisyuk, and others.

Sukhodolia O. M. emphasizes that a systematic approach allows formalizing the decision-making process in planning the development of energy systems and ensures coordination between technical, economic, and environmental criteria [8]. Chumachenko S. I. (2018) emphasizes the importance of systematic analysis for assessing the reliability of energy systems, proposing methods for modeling failures and optimizing reserves [9]. Melnik O. G. and others consider the energy system as part of an ecological and economic complex in which energy is a basic element of sustainable development. The author notes that a systematic approach allows for the consideration of inter-sectoral links between energy, ecology, and the economy [10]. Denisyuk S. P. studies the application of a systematic approach in the context of the digitalization of energy and the development of Smart Grid. He defines smart grids as open, dynamic systems that combine energy and information flows. His research focuses on developing systems that automatically respond to changes in the grid, optimize energy flows, and ensure the stability of the power system as a whole [11].

Fedorchuk S. O. and Nemirovsky I. A. use system analysis to model energy balances and optimize distribution network configurations [12].

In foreign scientific literature, the systematic approach is widely used for: planning the development of energy systems; modeling energy and information flows; analyzing the reliability of electrical networks; optimizing the integration of renewable energy sources [13]. Thus, *Billinton & Allan* developed systematic methods for assessing the reliability of electrical systems based on probabilistic modeling. *Lund's* research is devoted to the systematic planning of the integration of wind and solar power plants into the grid, which requires the use of a systematic approach to balance energy production and consumption [14].

RESEARCH METHODOLOGY

The history of the systems approach developed primarily out of the need to develop a methodology for studying complex (large) systems, which could not be described using any specific mathematical theory. General systems theory involves the development of general methodological principles for studying systems.

The following main tasks can be identified in systems theory:

- development of a unified formalized method for describing systems of any nature as a holistic entity;
- building generalized models of systems and their functioning processes;
- studying the internal organization of systems at the level of the structure of goals, objectives, and functions of the system;
- research of information, energy, and material flows within the system;
- research into behavioral and management processes;
- determining the properties and characteristics of the system.

The tasks listed above are exclusively systemic and were not developed by classical sciences prior to the development of systemic concentrations. The failure of attempts to define a system at the verbal level is probably due to the complexity and diversity of the manifestation of system properties. Therefore, two concepts are currently emerging in the definition of a system. The first concept is based on a complete definition of a system based on a list of its most general and essential properties. The second is based on a broad interpretation of the concept of a system at a level of abstraction that would allow us to cover the entire diversity of existing systems. When studying power supply systems, the basic principles of a systematic approach are applied.

1. Integrity – viewing the power system as a single entity, where the operation of each element (generator, substation, consumer) affects the efficiency of the system as a whole.
2. Hierarchy – the system is divided into levels: national EPS → regional energy systems → local networks → individual consumers.
3. Interdependence of elements – a change in the load mode of one consumer affects the voltage, frequency, and energy loss parameters throughout the entire system.
4. Optimality – system analysis involves searching for optimal solutions regarding network structure, transformer placement, reactive power compensation, etc.

System analysis in the field of power supply systems usually includes the following stages [15]:

- setting the task – defining the research objective (e.g., reducing electricity losses or improving supply reliability);
- system model development – description of key elements (source, network, consumer) and their interrelationships;
- collection of initial data – technical characteristics of equipment, load parameters, consumption graphs;
- analysis and synthesis of structure – determination of optimal network configuration, selection of line cross-sections, transformer types, backup schemes;
- performance evaluation – technical and economic analysis of various system options (minimum losses, maximum reliability, optimal cost);
- decision-making and optimization – selecting the best solution based on technical, economic, and environmental criteria.

The practical application of the systematic approach is used in the following areas: optimization of the structure of electrical networks. With the help of systematic analysis, the topology of the network is assessed – the number of substations, the length of lines, and voltage levels. For example, the use of linear programming or simulation modeling methods allows minimizing power losses in low-voltage networks. In terms of analyzing the reliability of the power supply system, the systematic approach involves building models of component failures (generators, cables, switching devices) and assessing the probability of an uninterrupted power supply system. Such calculations form the basis for the creation of backup power supply schemes. The focus on a systematic approach is reflected in the construction of intelligent control systems. Recent studies [16] demonstrate that system analysis is the basis for designing Smart Grids-intelligent electrical networks that integrate energy, information, and communication technologies. Such systems use system analysis algorithms to optimize energy flows, balance loads, and reduce energy consumption.

One of the main general requirements of system analysis is adaptability. Adaptability means that the system must adapt to changes in consumption, emergencies, and fluctuations in frequency and voltage.

If an object model is defined only by describing its behavior in the environment, then we will call such a model a system element. By defining an object as a system element, we thereby abstract from the internal processes occurring within the system. With a more complete description of the object (penetrating its structure and processes), the model is interpreted as a system. This sufficiently characterizes the feasibility of such an approach for analyzing processes in systems that are difficult to describe mathematically, such as the power supply system.

The various definitions of the concept of an «abstract system» can be summarized as follows [1]: let *Z* be a certain property of an object, *M* be a certain set of objects constituting it, and *R* be a relation on the set M. If a certain relation *R* appears on *M*, this does not mean that this set forms a system. Objects $m \in M$ form a system only if a certain relation that interests us is satisfied on *m*. This means that relation *R* must possess a certain property that interests us. According to L. Bertalanffy, this relation is a connection; in other cases, it is a relation of order. Thus, a set forms a system when a predetermined relation *R* with fixed properties *P* is realized on it.

Using the property as a pair relation, M. Mesarovic gave an even shorter definition: a system is a relation or a proper subset of Cartesian products on *M* [2]. According to the above, it is quite natural to define a system as a relation in the language of set theory (objects) M_i forming the system, and relations R_j defined on this family of sets, each of which is a subset of the Cartesian product of sets M_i, i.e., $R \subseteq M_1 \times \ldots \times M_n$.

The variety of possible objects and types of relations encountered in real systems necessitates the introduction of a universal (empirical) system of relations. Let us call a system with relations a tuple $S =< M_1,\ldots,M_n; R_l,\ldots,R_m >$, whose components are a family of sets of objects $M_1,\ldots,M_n$ and a family of sets of relations $R_1,\ldots,R_m$. If a tuple has one relation *R*, then the model reflects one side, one aspect of the system, then $S =< M, R >$. The complexity of systems does not allow for a complete description, so the system is presented in the form of a model. A model of a system is a description of it in terms of operations that connect objects (elements) of the system, and modeling is the process of constructing and studying the model. Modeling is based on preliminary study of the object, identification of its essential characteristics (properties) from the perspective of the research objective, and construction of a verbal and then mathematical model of the object and study of the model. A mathematical model can be defined as a set of mathematical objects and the relationships between them. Systems theory models have a weak mathematical structure (they do not provide a detailed description of the system), but that is why they have a commonality that allows them to describe complex systems that are not amenable to detailed mathematical analysis [17].

When choosing a model, it is essential to determine the quality of the reflection of the system's properties in the model's properties, i.e., the adequacy of the model to the object. The adequacy of the model is related to concepts such as isomorphism and homomorphism. A model is called isomorphic if its properties are identical to those of the real system. Two systems or their models $< M, R_1,\ldots,R_s >$ and $< N, Q_1,\ldots,Q_t >$ are isomorphic if they are similar, i.e., they have the same number $(s = t)$ and separate relations (for example, $R(m_1, m_2)$ and $Q(n_1, n_2)$). In addition, there exists a one-to-one mapping $\phi : M \to N$ such that if $n_i = \phi(m_i)$ and $n_j = \phi(n_i)$, then $m_i R m_j \Leftrightarrow n_i n_j$.

Mutual unambiguity implies the existence of a reverse reflection $\phi^{-1} : N \to M$. Mutual unambiguity is a very strict condition, and due to the complexity of systems, in many cases it is impossible to implement it when building a model [18]. Therefore, simplified modeling is used-the construction of a homomorphic or similar model for which only the condition of unambiguous correspondence is preserved.

Thus, model building involves two stages. At the first stage, the researcher constructs a verbal homomorphic model of the system, i.e., a simplified description of it, an abstraction, a departure from the properties of the object that are irrelevant to the achievement of the given goal. In the second stage, a model is constructed that is isomorphic to the previously obtained homomorphic model. Isomorphism as a relation has the properties of reflexivity, symmetry, and transitivity and therefore generates a class of isomorphic models [19], [20].

The model can reflect the internal structure of the object and reproduce the relationships between its elements. In other cases, when the internal structure of the object is unknown, the model reflects only its behavior or functioning, determining the dependencies between the inputs and outputs of the system. Such a model is called a “black box.” By influencing the inputs of the system and observing its outputs, the researcher can construct a relationship equation that gives an idea of the processes occurring in the system. An example of this research method is the construction of a response function (regression model) in experimental design.

The structure of systems can be classified as follows.

1. By the number of levels of division of the system into subsystems. There are single-level and multi-level systems. The latter, in turn, can be homogeneous (the functions and characteristics of subsystems of the same level are identical) and heterogeneous;

2. According to the principles of management and subordination. There are decentralized, centralized, and mixed systems;

3. By functions performed and intended purpose. A distinction is made between the structure of planning, operational management, information, and other systems. Depending on the constancy of the number of system elements with fixed (rigid) and variable (controllable or variable) structures;

4. By the principles of dividing system elements into subsystems. A distinction is made between the structure of systems in which elements are combined according to functional and object principles. In object division, the structure of industry systems, regional systems, etc. is distinguished.

Graphical models are commonly used to describe structures. The representation of a system as a tree of subsystems is based on the concept of system «separability». A graphical representation of a decompositional model of a system (its structure) is a tree-order graph (tree). Fig. 1 shows a three-level graph.

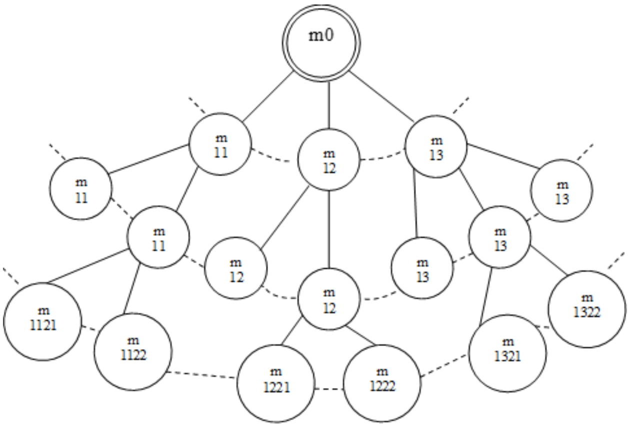

Fig. 1. **System decomposition graph**

***Source*: compiled by the authors**

The root area forms the first level (vertices $\left(m_{11},\ldots,m_{13}\right)$. The surroundings of all vertices of the first level form the second level $\left(m_{111},m_{112},\ldots,m_{133}\right)$, and so on. In a system whose mathematical model is a tree, the roots of the tree are identified with the system itself, as something integral. Selecting the first level of vertices means selecting the first-level subsystems, selecting the second level of vertices means selecting the second-level subsystems, and so on.

In general terms, system decomposition can be described as follows. The system is assigned a certain set M^0, for example, elements of a control object. The set M^0 is divided into subsets M_i^1 such that $\underset{i\in I^0}{U} M_i^1, M_{i_1} \cap M_{i_2} = \varnothing$ at $i_1 \neq i_2$, where I^0 is the set of indices of subsets.

The set M^0, and thus the control object as a whole, corresponds to the central body (or control unit), while the subsets M_i^1 correspond to the first-level control subsystems (or bodies, units). The same applies to the division of second-level control subsystems, etc. In step 1, each of the subsets M_i^l can be divided into subsets, and (l + 1)-level management bodies can be formed. The root of the tree corresponds to set M^0, i.e., the central control body.

The spatial graph of goals and objectives with logic and/or is the most important tool for the systematic analysis of complex goals, allowing the formalization of the goal decomposition procedure, the identification of alternative options for achieving goals, and, finally, the identification of the best solution from a set of alternatives [21].

The graph of goals and objectives is identical to a tree graph, where the vertices correspond to goals and objectives of different levels, and the edges correspond to the relationships between them.

Fig. 2 shows an l-level graph of goals and objectives (goals of any level can be considered as objectives, the solution of which leads to the achievement of goals of a higher level).

The graph of goals and objectives is a tree with roots only on a subset of first-level vertices (formed by non-intersecting subsets). At lower levels, there are cross-links, indicating the interconnection of solving l-level problems to achieve (l-1)-level goals. However, when constructing a graph of goals and objectives, in this case, the structure is also referred to as tree-like if the connections provided by the formal model of the tree-like structure dominate over others.

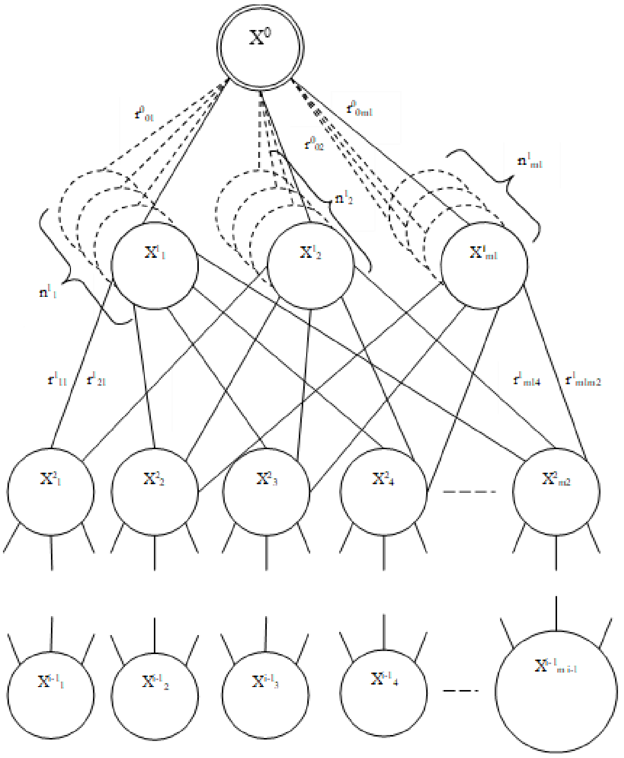

Fig. 2. **Graph of goals and objectives**
***Source*: compiled by the authors**

In column $G=(X,R)$ of goals and objectives, we will highlight the tuple $X=\left\{X^0,X^1,\ldots,X^{l-1}\right\}$, which consists of a set of goals of different ranks. The rank in the column of goals and objectives is the level of the tree vertices relative to its root. The rank of a vertex is determined by its ordinal number along the path from the root of the tree to that vertex, not counting the root itself.

The *X*-corridor includes X^0 is the general goal (zero rank) and $X^i=\left\{X^i_1,X^i_2,\ldots,X^i_{m_i}\right\}$ is a set of goals of rank *i* $(0\le i\le l-1)$. The multitude of arcs of graph $R=\left\{r^i_{i^v}\right\},0\le j_i\le m_i,1\le v_i\le m_{i+1}$ are relationships of conditions for achieving top-level goals that have I logic.

According to the I logic, the goal of a higher level, for example X^0, is achieved if X^1_1 and $X^1_2,\ldots$, other $X^1_{m_1}$ are achieved. Solid lines correspond to the I logic graph. In the notation of arcs $r^i_{i^v}$, the upper index indicates the rank of the goal from which the arc originates, the first lower index *j* is the number of the vertex of the *i*-th rank goal from which the arc originates, and *v* is the number of the vertex of the (*i*+1)-th rank into which the arc enters.

A graph of goals and objectives can be constructed as an alternative if the top-level goal is contrasted with a set of options for achieving this goal at the lower level. In this case, the set of arcs of graph $R=\left\{r^i_{j^v\mathfrak{R}}\right\}$ represents the conditions for achieving the top-level goals, corresponding to logic, or, for example, goal X^0 is achieved if either X^1_1 ,…, or $X^1_{n_2}$, etc. are achieved on the logic graph or correspond to the dotted lines. If there are n^1_1 solutions to problem X^1_1, n^1_2 solutions to problem X^1_2, ... and $n^1_{m_1}$ solutions to problem $X^1_{m_1}$, then the total number N^1 of alternative ways to achieve goal X^0 is equal to $N^1=n^1_1*n^1_2*\ldots*n^1_{m_1}$.

There may be incompatible options in set *N*, where the solution to one task excludes the solution to another task.

A spatial graph of goals and tasks with logic and/or is the most important tool for the systematic analysis of complex goals, allowing the formalization of the goal decomposition procedure, the identification of alternative options for achieving goals, and, finally, the identification of the best solution from a set of alternatives.

The search for the best solution includes the following steps: identifying incompatible options in the set *N*; constructing planar target graphs of compatible solution options; analyzing the effectiveness of achieving goals for each option and ranking the options in order of preference. The last operation requires setting an efficiency (optimality) criterion, which in general can be vectorial.

Hierarchy is a type of management system structure that assumes that:

1. The system consists of a family of interacting subsystems;
2. The system has decision-making subsystems (decision-making elements);
3. Decision-making elements are arranged hierarchically, i.e., some of them are influenced or controlled by other decision-making elements.

A block diagram of this type of system is shown in Fig. 3. The level in such a system is called an echelon. We will also refer to these systems as multi-echelon systems.

A distinctive feature of the formal description of hierarchy is the need for a more precise definition of the vertical interaction between subsystems. In the decision hierarchy, there is formally one element at each level. In an echelon hierarchy, there are usually several elements at each level. In this case, it becomes particularly important to correctly arrange the elements of the system in accordance with the priority of action.

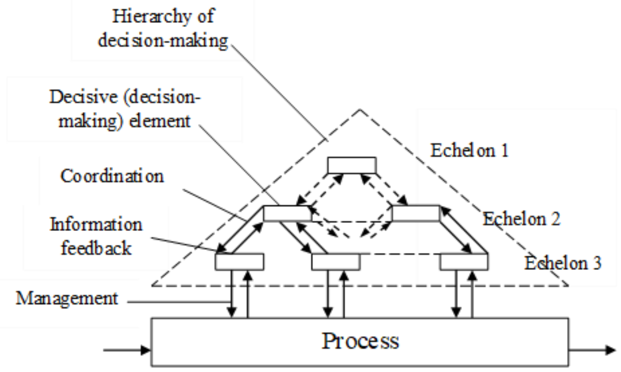

Fig. 3. **Organizational hierarchy**

***Source*: compiled by the authors**

Let *M* be a family of systems $S_i, i \in I$, where *I* is a finite set of values of index *i*. If > is a relation that partially (but strictly) orders *I*, then (*M* >) is called a hierarchy of systems. A hierarchy (*M* >) is called a decision-making hierarchy if the relation > is such that *i* > *j* and S_j has priority over S_j. The allocation of levels in the decision-making hierarchy is performed using a strict (partial) order relation >, which describes priority. The first level consists of minimal elements with *M*. Family $M^1 = \{S_i : i \in I_1 \subset I\}$ is called the first level if $i \in I_1$ is the minimal element in *I*. A similar set $M^k = \{S_i : i \in I_k \subset I\}$ is called a *k*-th echelon if $i \in I_k$ is the smallest element of the set $I - (I_1 U I_2 U \ldots U I_{k-1})$.

Multi-level hierarchies can be defined as a subclass of decision-making hierarchies. A decision-making hierarchy (*M*, >) is a multi-level hierarchy if, for any *i* and *j* from *I*, there is no more than one $k \in I$ such that, for any *l* from *I* $(l > i, l > j) \Rightarrow l > k$.

This condition means that for any member of hierarchy *M* in the echelon located directly above it, there will be at least one element that has priority of action over it. A multi-echelon hierarchy can be interpreted in this way. If the relationship > is such that $i > j \Leftrightarrow S_j \subset S_i$, then *M* is a multilevel system in which lower-level systems are subsystems of systems located at higher levels.

The most typical example of multi-level hierarchical systems is organizational systems, which represent a decomposable set of subsystems of different levels characterized by hierarchical relationships between the decision-making elements of these systems.

The search for the best solution includes the following steps: identification of a set of incompatible options; construction of planar target graphs of compatible decision options; analysis of the effectiveness of achieving goals for each option and ranking of options by preference. The latter operation requires setting an efficiency (optimality) criterion, which in general can be vectorial.

Moreover, the multi-vector application of the system-parametric approach is reflected in modern leading scientific publications [22], [23].

Network modeling methods are widely used in the modeling of complex systems (Fig. 4). They are practiced for the analysis of complex dynamic systems in which independent devices operate in parallel. The behavior of such systems becomes very complex and non-deterministic. In this case, it is not so much the function of the system that is modeled as its structural characteristics and properties. The system model must be structurally similar to the object and is constructed separately, like the system. Network methods allow studying phenomena in complex parallel systems. One class of such models is called Petri nets.

Petri nets allow modeling very complex discrete dynamic systems, the description of which can be represented using a specialized algorithmic language. The mathematical apparatus of Petri nets has powerful modeling capabilities.

The main concepts of event-driven models and their representation in Petri nets are highlighted:

- Object – a real or virtual entity used in the modeled system. Each object has a name and a set of attributes;
- Attribute – a characteristic of an object. Each attribute has a name and is characterized by a set of possible attribute values. The set of specific values of all attributes characterizes the state of the object;
- An event is a momentary change in the state of an object, consisting of a change in attribute values. Each event has a name and may have its own event attributes.
- Process – a stable, purposeful set of events that transforms the state of objects.

Fig. 4 shows a schematic solution to problems based on Petri nets.

By identifying heterogeneous sources of electricity generation in the system that are interconnected to achieve a specific goal, we can form a Petri net. Using the properties studied, we have grounds for forming and analyzing a model based on network modeling methodology.

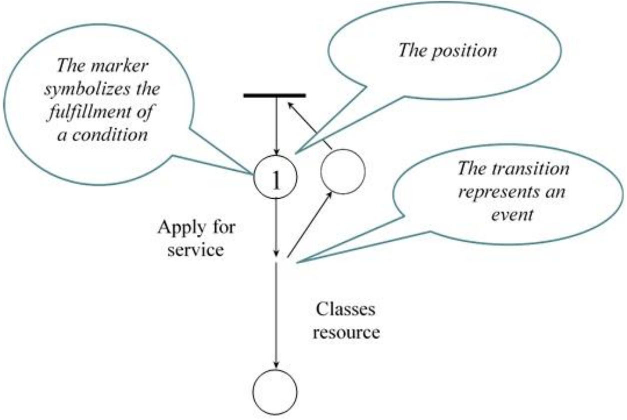

Fig. 4. **Schematic representation of problem solving based on Petri nets**
***Source*: compiled by the authors**

For example, let's consider a verbal problem. There are several substations that supply electricity to an object. These substations are of different types – wind, solar, and conventional (3 in total). The substations operate at different times, depending on the type: wind substations when there is wind, solar substations when there is sun, and conventional substations when there is not enough energy from the previous two or when they are not turned on at all. Question: the sequence of substation activation to ensure uninterrupted operation of the facility with minimal losses.

Let us consider the mathematical formulation of the problem. Let T be the duration of time during which the object is supplied with electricity.

Note that P_1 is the wind power source; c_1 is the cost of electricity from the wind power source; W_1 is the amount of electricity supplied by the wind power source, which is a random number; $f_1(w_1)$ is the probability density of the volume of electricity when the wind source of electricity is operating; P_2 is the solar source of electricity; c_2 is the cost of electricity from the solar source; W_2 is the volume of electricity supplied by the solar source, which is a random number; $f_2(w_2)$ – probability density of the volume of electricity when the solar source of electricity is operating; P_3 – conventional source of electricity generation; c_3 – cost of electricity from a conventional source; W_3 – volume of electricity supplied by a conventional source of electricity.

It should be emphasized that the considered time intervals of operation of the power sources are subsets of the total time interval, i.e., $(0,T_i) \subset (0,T),(i=1,2)$. The maximum power supply value of the object is set equal to W_0. According to the task, the amount of electricity generated during the specified time period must be no less than the specified value W_0.

According to the terms of the task, power supply to the facility's power sources, since this process is random, can have four options:

Option 1. All power sources are operating simultaneously.

Option 2. The first power source, i.e., the wind power source, is not operating. Other power sources are operating.

Option 3. The second power source, i.e., the solar power source, is not working. Other power sources are working;

Option 4. The first and second sources of electricity, i.e., wind and solar, are not working. Only the conventional source of electricity is working.

Fig. 5 shows a Petri net represented by corresponding matrices.

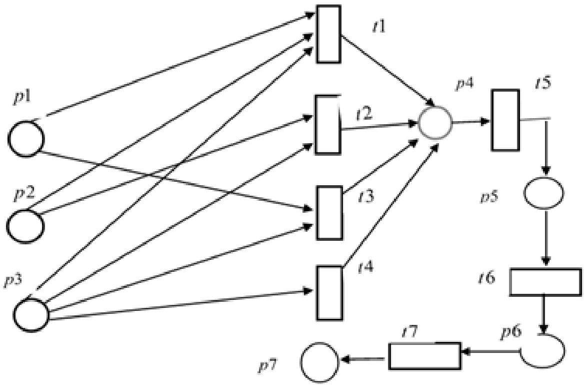

Fig. 5. **Petri net**
***Source*: compiled by the authors**

Thus, we can note the relevance and expediency of applying the methodology of structural modeling of power supply systems.

CONCLUSIONS

Thus, systematicity provides tools for modeling and obtaining optimal solutions in management processes in technical systems such as power supply systems, which are complex and dynamic in terms of their functioning structure. In the course of this study, scientific research in the field of a systematic approach to structuring power supply system modeling was further developed. System analysis is a key tool for researching and improving power supply systems. Its application allows for: increasing the reliability and efficiency of power supply; optimizing the structure of electrical networks; ensuring the rational use of resources; and promoting the development of intelligent energy systems. Thus, a systematic approach to the study of electricity supply provides a holistic view of processes, their interrelationships, and opportunities for optimization, which is the basis for the sustainable development of Ukraine’s energy sector.

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АНОТАЦІЯ

Одним із основних напрямів дослідження систем є системний аналіз та системний підхід. Теорія систем, як підрозділ є одним з основних її понять та поряд з теорією моделей, теорією управління, теорією інформації відноситься до методологічної бази в наукових дослідженнях. Актуальним є вивчення законів та принципів, за допомогою яких можливе ефективне дослідження структурної трансформації організації досліджень. На практиці системний підхід – це системне охоплення, системне подання, системна орієнтація досліджень. Системне охоплення вимагає розгляду проблеми в різних аспектах з різних позицій. Системне подання досягається шляхом побудови єдиної моделі, здатної заміщувати реальний об’єкт і надавати актуальну інформацію про об’єкт, який моделюється. В статті представлені графічно-аналітичні етапи прийняття оціночних управлінських рішень на засадах мережевого моделювання. Отримані результати довели доцільність застосування структурованого системно-параметричного підходу при дослідженні складних електричних об’єктів на прикладі сучасних систем електропостачання. За допомогою системного аналізу проводять оцінку топології мережі – кількості підстанцій, довжини ліній, рівнів напруги. Становлення системології ґрунтується на системному підході й застосовується в побудові інтелектуальніших систем керування. Не маловажним є забезпечення організації дослідження, що означає ідентифікацію проблеми; внутрішній аналіз проблеми; зовнішній аналіз проблеми; ідентифікацію системи: цілі, обмеження, тенденції, фактори, властивості; синтез моделі; аналіз поведінки моделі – моделювання роботи системи; оптимізацію системи. Планування оптимізаційного експерименту, ідентифікація експериментальної моделі Аналіз результатів експерименту з моделлю. Інтерпретація результатів стосовно системи, що вирішує проблему Р. Реалізація рішення. У рамках системного підходу задачі аналізу й синтезу взаємопов’язані, вони чергуються із заданою регулярністю і характеризують дві сторони єдиного циклу процесу дослідження. Описаний цикл вирішення проблеми відноситься як до кількісного, так і до якісного системного підходу. При цьому ідентифікація та імітація реалізуються на інтуїтивному, евристичному рівні. Основним недоліком якісного підходу є те, що проти інтуїтивна поведінка, яка проявляється у складних соціально-економічних системах, упускається з виду і не аналізується. Перевагою якісного підходу перед кількісним є суттєва економія часу і коштів на проведення досліджень. Сукупність методологічних засобів, що використовуються для підготовки й обґрунтування рішень стосовно складних, наукового, технічного характеру містить системний аналіз. Системний аналіз визначають як сукупність методів дослідження складних об’єктів шляхом подання їх у вигляді систем і подальшого аналізу таких систем. Порядок етапів системного аналізу включає: постановку задачі (вибір об’єкта дослідження, визначення мети і критеріїв його вивчення); виділення й структуризацію (або декомпозицію) системи, яка досліджується, тобто поділ її на підсистеми, котрі відносно чітко описуються; створення математичної моделі системи. У цьому полягає відмінність системного аналізу від локального підходу, який полягає у вивченні структури й функціональних особливостей автономних, окремо взятих елементів системи. Неможливість повністю охопити всі сторони, зв’язки й «опосередкування» дозволяє в ході проведення системного аналізу, з одного боку, прагнути максимальної повноти опису, з другого – здійснювати розумне спрощення об’єкту. Це особливо актуально та доцільно в сфері досліджень процесів в системах електропостачання.

Ключові слова: системний аналіз; системний підхід; методологія; принципи; графоаналітичні методи; граф; моделювання, управління; сучасна система електропостачання

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