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Features of the System Approach to the Analysis of Electric Networks Energy Efficiency

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Abstract
The paper presents the features of the application of a systems approach to solving problematic issues in the electric power industry (design, analysis and modernization of existing systems, teaching complex subjects and their topics in educational institutions). An algorithm for solving the problem is proposed, the peculiarity of which is to consider the object and subject of the study as separate systems, modeling these systems in accordance with the principles of systems analysis in the following sequence: formation of a generalized model of the "black box" type and subsequent transformation (detailing, clarifying the structure and parameters) of the "black box" model into a structural (or functional) model of the system of the required level of detail. The proposed algorithm is explained using the example of explaining the basic concepts of "electrical network" and "energy efficiency of the electric network" in the process of teaching professional academic disciplines to students of the specialty "Electric Power Engineering, Electrical Engineering and Electromechanics". Practical use of the proposed algorithm promotes students' understanding of the structure of complex topics of academic disciplines, the relationships between topics and between individual disciplines, which helps to increase the efficiency of students' mastering the specialty program. This approach can also be applied by specialists in the process of solving problems of design, operation and modernization of real electric power facilities.

INTRODUCTION

Electrical networks (EN) are one of the main elements of city life support systems. The current environmental problems and the energy crisis have exacerbated the relevance of issues of rational use of available energy resources [1]. Nowadays, energy saving has become one of the priorities of the technical policy of the developed countries of the world, including Ukraine. Experts of the European Union claim that the energy crisis has become the biggest systemic risk for Europe [2, 3], noting the seriousness of the current energy situation in Europe. One of the main ways out of the energy crisis is solving the problem of energy efficiency, which has long been in the field of view of many researchers. These are works on the energy efficiency of the pulp industry in Germany [4], on energy efficiency in Poland [5], works on the assessment of the energy efficiency of electricity distribution companies in Great Britain [6], in Turkey [7], in Spain [8], in Ireland [9] and many others.

Energy efficiency at the state level is related to the use and consumption of energy and has a significant impact on the main macroeconomic indicators of the country's development [10]. For this reason, increasing the energy efficiency of national economies is one of the strategic tasks of the economic policy of many countries in the field of energy.

Among the factors that have a qualitative impact on the energy efficiency of the economy of any state, electric energy (EE) which has the highest level of quality [11] and directly affects the performance of all enterprises and organizations is distinguished.

The aim of this paper is to clarify the methodology for studying problematic issues in the tasks of designing or modernizing electric power facilities, teaching electric power disciplines in educational institutions. The methodology of systems analysis was chosen as the research method.

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The authors explain some features of systems analysis using the example of studying the concepts of "Electric network" and "Energy efficiency of the electric network". Thus, the object of research in this work is the tools of systems analysis, and the subject of the study is the features of applying the methodology of systems analysis to electric power facilities.

An important feature of the systemic approach to problem solving is the consideration and analysis of the problem as a system what allows to identify the main structural components and connections between them in the problem, to find out the influence of the components (system structure) and connections (processes in the system) on the system function. In our case, the system approach contributes to the analysis and systematization of factors affecting the efficiency of electric power systems and their individual components, and in the process of teaching academic disciplines, it allows us to simplify the presentation of issues, the construction and functioning of complex electric power complexes and systems, and the understanding of these issues by students.

The relevance of this approach is explained by the lack of a generally accepted definition of some concepts and categories of electric power engineering, for example, the category of "energy efficiency of the electric grid". Various authors conduct research on ways to increase the energy efficiency of the electrical network based on one of the characteristic indicators of energy efficiency, such as EE losses [12–14], power quality [15, 16], economic indicators of the operation of the Electrical network [12, 17], technical and economic indicators [17, 18], etc. Also the proposals for the use of integral indicators of energy efficiency of EN [19] are worthy of attention, which take into account the influence of a complex of factors on the Electrical network and suggest optimization methods applying for the analysis and assessment of energy efficiency of Electrical networks.

RESEARCH METHODOLOGY

Now, the methodology of systems analysis [20] is an effective tool that allows you to find a solution to the given problem. Features of the system approach when searching for a solution to our problem are as follows.

The object and subject of research are analyzed as systems in a systemic aspect. That is, the category (concept) "Electrical network" is considered as the "Electrical network" system, accordingly, the category (concept) "energy efficiency" is considered as the "Energy Efficiency" system. The research is conducted using the principles and recommendations of the theory of systems and the theory of systems analysis [21, 22]. The authors propose the following system research algorithm.

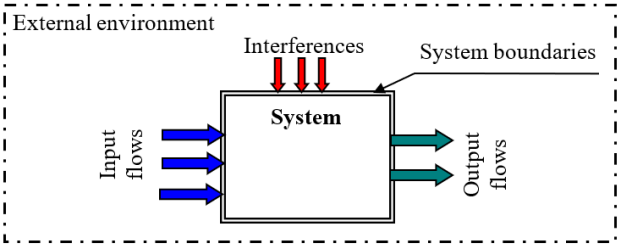

Figure 1. Model of the "Black Box" type system [23]

1. Consideration of the studied system (object, process) should begin with the formation of its model of the "Black Box" type [23], as a generalized abstract model of the system (see Fig. 1).

2. The next step is to carry out the first refinement of the "Black Box" system model, its agreement with a specific subject area, in particular, refinement of the function of the investigated system and the main parameters of the "Black Box" model. The parameters of the model include (Fig. 1): external environment, system boundaries, input and output flows, interference as factor of negative impact on the implementation of the system function.

3. Then, further detailing of the model of the system under study is performed by transforming its black box model into a structural model of the system. The level of detailing of the system structure largely depends on the purpose of the study and should provide conditions for constructing a refined structural model that provides answers to the research tasks.

RESULTS AND DISCUSSION

Considering the ambiguity of the use of systems theory terminology by different authors, we will provide an explanation of the main terms used in this work.

A system is a set of components (subsystems and elements) isolated from the external environment, united by certain connections (processes), which perform a certain function (realize the purpose of the system).

A subsystem is a component of a system that, in the process of analysis and further detailing of the system structure, can itself be considered as a system.

An element is a component of a system that is not considered as a system (as opposed to a subsystem) in the process of analysis. That is, the task of considering the structure of the element is not stated in the research.

The structure of the system is *the composition* of the system and the connections between the components. It is important that the number of components of the system and the number of connections between these components (the level of detail of the system) depend on many factors, the main of which is the purpose of the system research.

The composition of the system can be considered as a set of subsystems and elements that the researcher isolated from the external environment and combined into a system. The term "*subsystem*" is used when the task of research includes consideration of the structure of this system component. If consideration of the structure is not provided for, then the term "system *element*" is used.

Let's consider the proposed sequence of actions, namely the features of the system approach, using the example of consideration of the category "Energy efficiency of the Electrical network" in cases of teaching students of the specialty 141 – Power Engineering, Electrical Engineering and Electromechanics on topics of academic disciplines that consider the issues of energy efficiency of Electrical networks. We begin the consideration by defining the object and subject of research. We choose the Electrical network as the object of research. The energy efficiency of the electrical network is determined as the subject of research. Further, we explain to students that we consider the object of research and the subject of research (in our case, within the framework of studying a certain topic of one of the academic disciplines) as two systems. That is, we study the system "Electrical network" as an object of research and the system "Energy efficiency of Electrical network" as a subject of research. Then we explain the construction of "Black box" models for the studied systems. For example, for the "Electrical network" system we determine (formulate) the function (purpose) of the system first of all. It is usually well understood by students of the electrical engineering profile and is formulated as "providing consumers with electrical energy".

Next, we determine which parameters of the generalized "Black box" model should be taken into account in order to obtain a generalized model of the "Electrical network" system. According to the authors, at this stage of modeling, analyzing the environment of the "Electrical networks" system should be carried out, namely, considering the structural model of the "Electric power industry" supersystem (see Fig. 2). The "Electrical networks" system is one of the main components of the "Electric power industry" system and can be considered as its subsystem.

This approach (analysis of the supersystem of the studied system) makes it possible to analyze the functional links of the subsystem "Electrical networks" and to clarify its input and output flows.

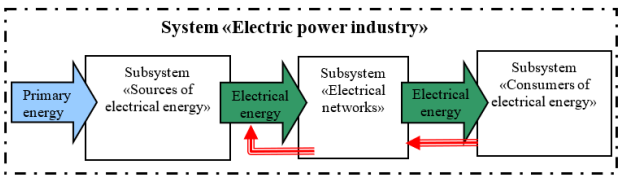

Figure 2. Structural model of the "Electric power industry" system: green arrows – flows of electrical energy; red arrows – flows of influence on indicators of the power quality

The level of detail of the structure of the "Electric power industry" system and the connections between its components is chosen in such a way that the conditions for forming a generalized model of the "Energy efficiency of the Electrical network" system and explaining the methodology of developing the algorithm of the analysis and assessment of the energy efficiency of the "Electrical networks" system are provided.

In this paper, we begin the examination of the "Electrical networks" system by examining its environment, in which we distinguish two systems adjacent to it (see Fig. 2) - the "Electrical energy sources" system and the "Electrical energy consumers" system. These three systems are connected by a common technological process of production, transportation, distribution and consumption of EE. It can be said that they provide the implementation of the main function for both the "Electrical networks" system and the "Electric power industry" system. And this function is formulated as "providing consumers with electrical energy".

The systems "Electrical energy sources", "Electrical networks", "Electrical energy consumers" are considered as subsystems of the supersystem "Electric power industry", which simplified structural model is shown in Fig. 2.

Further consideration of the "Energy efficiency of the Electrical network" system depends on the research task and may involve taking into account all known factors affecting the energy efficiency of the electrical network (deterioration of power quality indicators, electrical energy losses, economic indicators, etc.), or a detailed consideration of a separate indicator. For example, the investment analysis of options for the implementation of the Electrical network construction project requires a separate consideration of such indicators as the payback period of capital investments, return on investment, etc. This approach can be applied to the case of teaching this topic to students of the economic profile.

In the case of teaching academic disciplines to students of an electrical engineering profile and considering issues of energy efficiency of electrical networks, one of the convenient and well-understood for students is the criterion of conformity of electrical energy to its quality indicators [24]. Indicators of the power quality are considered by the majority of researchers [15, 16] as one of the main factors of increasing the energy efficiency of both electricity supply systems generally and their components, "Electrical networks".

In our case, in the process of analyzing the structural model (see Fig. 2), the interaction of the "Electrical networks" system with the "Electrical energy sources" system (the question of the influence of the "Electrical networks" system on the EE quality indicators at the output of the "Electrical energy sources"

system) can not be considered, because in the vast majority of practical situations, the sources deliver electrical energy to the "Electrical networks" system that meets the normative indicators of the power quality.

It is important to analyze the interaction of the "Electrical networks" system with the "Electrical energy consumers" system, since the factor of significant influence of electrical energy consumers on the indicators of the quality of electrical energy in electrical networks, and therefore on the energy efficiency of electrical networks, is considerable. The energy efficiency of the "Electrical energy sources" system is not considered in our statement of the research purpose. Electric energy at inputs to the "Electrical networks" subsystem usually complies with regulatory quality indicators [24] and, if necessary, the impact of the "Electrical networks" system on its input flows, and not in general on the "Electrical Energy Sources" subsystem, is researched.

One of the energy efficiency criteria of the "Electrical networks" system is considered to be the compliance of the EE quality indicators with its regulatory requirements at the inputs to the "Electrical energy consumers" system.

Consideration of the structure of the "Energy efficiency of the Electrical network" system depends on the approach to the consideration of the "Electrical networks" system, namely, on the degree of detail of its structural model.

Consider possible options for presenting the composition of the "Electrical networks" system. According to the classification of the International Electrotechnical Commission [25], electrical networks are divided into *electricity transmission networks* ([25], subsection 601-01-09) and *electricity distribution networks* ([25], subsection 601-01-10). In Ukraine Electrical networks are divided into EE transmission (the term transportation is also used) networks (networks with a voltage of 220, 330, 500 and 750 kV) and EE distribution networks (networks with a voltage of 0.4, 10(6), 35, 110 (150) kV). Consequently, two approaches are possible here, depending on the choice of regulatory documents regarding the classification of electrical networks. And in the case when the value of the voltage of the electrical network is an important factor within the framework of the research, a third approach with detailed consideration of the voltage class is also possible.

In the case of consideration of these issues in the process of teaching academic disciplines to students of electrical engineering specialties, it is advisable to conduct a more detailed analysis for distribution networks, since they directly interact with consumers of electric energy (Fig. 2), which affect the mode of operation of these networks, and therefore their energy efficiency. This analysis, and accordingly the structural models of the systems, require an in-depth detailed consideration of the interaction processes of the "Electrical energy consumers" subsystem and the "Electrical networks" subsystem (shown by red arrows in Fig. 2).

The implementation of the described methodology in the educational process of the Department of Urban Power Supply and Power Consumption Systems, in particular in the process of teaching the disciplines "Consumers of Electric Energy" [20, 22, 23] and "Automated Dispatch Control Systems" [26], showed an increase in the efficiency of students' assimilation of complex issues of interaction of components of electric power systems.

CONCLUSIONS

The authors recommend the following sequence of using of the system analysis principles in the process of academic disciplines complicated topics explaining to students is considered. The object and subject of the topic are explained (considered) as systems. The explanation begins with the formation of generalized abstract models of the "Black Box" type of the "Topic object" system and the "Topic subject" system. At the next stage, the parameters of the "Black Box" type models are specified. Namely, taking into account the specific subject area, the parameters of "system boundaries", "input and output flows", "system disturbances" are determined. Consideration of the supersystem of the system under study at this stage allows for a more accurate determination of the input and output flows of the system. The obtained models of the "Black Box" type are transformed of the into the structural model of the "Object of research" system and the structural model of the "Subject of research". The degree of detailing of structural models is determined by the research task. Thus, in the case of the application of this technology in the process of academic disciplines teaching, the degree of detail is affected by the subject of academic disciplines studied in previous courses.

The proposed technology of practical use of principles of systems analysis in the educational process makes it easier for students to understand the topics of complex disciplines, the connections between individual topics of academic disciplines, as well as the connections between individual disciplines of the specialty in which students are studying.

The main attention in this work is given to the peculiarities of considering the object of research as a system, taking into account the factors that determine the structure of the system. The subject of further research of this work may be clarification of the features of the research subject as a system. From the point of view of systems analysis, the subject of research can be considered as new, unknown processes in the research object. For example, in the education

system, it is important to have a clear understanding of what topics of an academic discipline are considered new for students and how to explain topics encountered by students in other academic disciplines. These issues have not been covered sufficiently in scientific publications yet.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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Особливості системного підходу до аналізу енергоефективності електричних мереж

Вячеслав Охріменко, Віталій Маляренко, Геннадій Локтіонов, Костянтин Боровой

Анотація. Показано особливості застосування системного підходу для вирішення проблемних завдань електроенергетики (проектування, аналіз та модернізація існуючих систем, викладання складних предметів та їх тем у навчальних закладах). Запропоновано алгоритм вирішення проблеми, особливістю якого є розгляд об'єкта та предмета дослідження як окремих систем, моделювання цих систем відповідно до принципів системного аналізу у наступній послідовності: формування узагальненої моделі типу «чорна скринька» та подальше перетворення (деталізація, уточнення структури та параметрів) моделі "чорний ящик" у структурну (або функціональну) модель системи необхідного рівня деталізації. Запропонований алгоритм пояснюється на прикладі пояснення базових понять «електрична мережа» та «енергетична ефективність електричної мережі» у процесі викладання професійних навчальних дисциплін студентам спеціальності «Електроенергетика, електротехніка та електромеханіка». Практичне використання запропонованого алгоритму сприяє розумінню студентами структури складних тем навчальних дисциплін, взаємозв'язків між темами та між окремими дисциплінами, що сприяє підвищенню ефективності освоєння студентами програми спеціальності. Цей підхід може бути застосований фахівцями у процесі вирішення завдань проектування, експлуатації та модернізації реальних об'єктів електроенергетики.

Ключові слова: енергоефективність; електроенергія; електричні мережі; теорія систем; чорна скринька; структурна модель; якість електроенергії

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