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Systems, Decision and Control in Energy II

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Prospects for the Development of Energy in the World and Ukraine: A Novel View

Abstract The main priorities in the development of the energy industry both in Ukraine and in the world are considered. The analysis of the use of different energy sources in the world and in Ukraine, in particular gas, coal, nuclear energy, oil, and renewable energy sources, is carried out. The results of research by scientists in the energy industry, which are based in the Department of Physical and Technical Problems of Energy of the National Academy of Sciences of Ukraine, are presented. The main results are divided into four categories: electrical engineering, heat power engineering, cybersecurity and computer science, environmental safety. A special contribution to the creation of this book belongs to young scientists of the National Academy of Sciences of Ukraine.

Priority Areas of Energy Development

Energy is the basis for ensuring industrial production, the provision of services in the transport sector, the functioning of housing and communal services, the creation of favorable living conditions for the population, and energy is an industry, which largely determines the level of socio-economic development of the country. An important priority for the development of the energy sector in the long term should be the minimization of risks: economic, social, environmental, which should make the development of energy and the entire economy of any country sustainable.

Today's global energy market is hard to compare with the past, even within 5–10 years. The global striving for energy independence, environmental friendliness, global price fluctuations irrevocably change the usual relationship in the energy market. Renewable sources are no longer alternative. They are no longer the privilege of developed countries. Currently, many developing countries spend more on renewable energy sources than developed ones. A striking example in this matter is the experience of Ukraine in attracting foreign investment for the development of infrastructure for renewable energy sources.

In the world, the environmental factor in the energy sector is becoming an increasingly important priority for the formation of a new economy, modernization, technological renewal, which determines the need for a transition to sustainable development and green energy, structural and technological modernization, and transformation of the energy sector. However, there are still dialogues between the countries about what kind of energy should be—green, nuclear, or fossil.

On the one hand, the positive role of green energy is obvious—its use does not harm the environment, it is renewable. On the other hand, it also has disadvantages: high cost, generation instability. This is enough to compare its advantages with more economical nuclear power, which is cheaper, but at the same time is considered dangerous.

Undoubtedly, each country chooses its own unique path, taking into account its own resources and experience. The Baltic countries had a rather difficult time getting rid of their energy "unity" with the Russian Federation, while individual territories of Canada and the United States of America, on the contrary, cooperate more closely within the same energy system. France continues to develop nuclear energy, and Germany has embarked on a green energy course. For Ukraine, the practice of using certain energy sources by other countries can become an invaluable experience.

Energy Sources in the World and Ukraine

According to the State Statistics Service, for 2018, the distribution of energy consumption in Ukraine is shown in Fig. 1.

Despite the fact that the level of introduction of renewable energy sources is gradually increasing, according to this indicator, Ukraine is still far from the EU (Fig. 2).

However, global energy trends are not obvious enough. And the issues of using various types of energy resources in Ukraine and the world remains relevant.

Renewable Energy Sources

According to analytical materials from businessviews.com.ua, renewable energy is the most dynamically developing energy sector in the world. According to the forecasts of many experts, in 2050, this type of energy should take first place in the energy supply system. Renewable energy sources are now developing much faster than nuclear or oil energy in their time.

In Ukraine, the development of renewable energy is also very progressing. But some problems are already clearly visible.

Firstly, the tariff for renewable energy is so high that the country cannot afford to buy the volumes of energy that are currently being produced. In addition, in the near

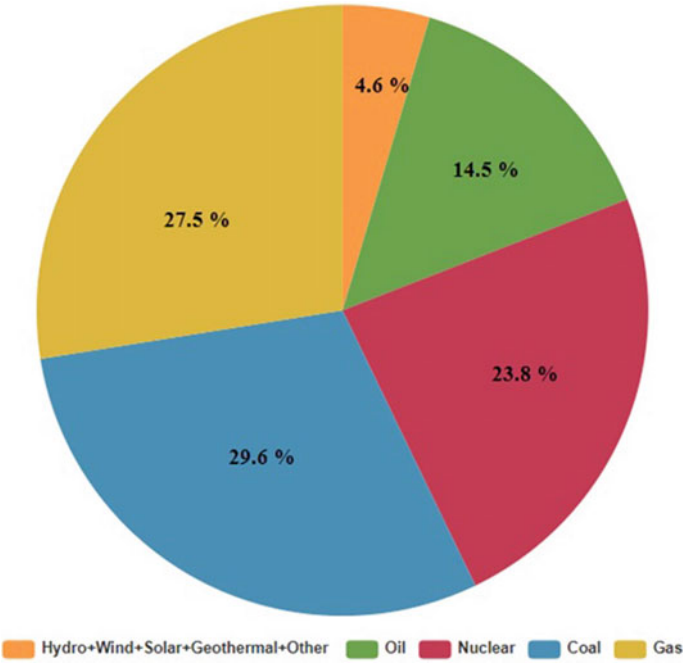

Fig. 1 Distribution of consumption of energy resources in Ukraine in 2018

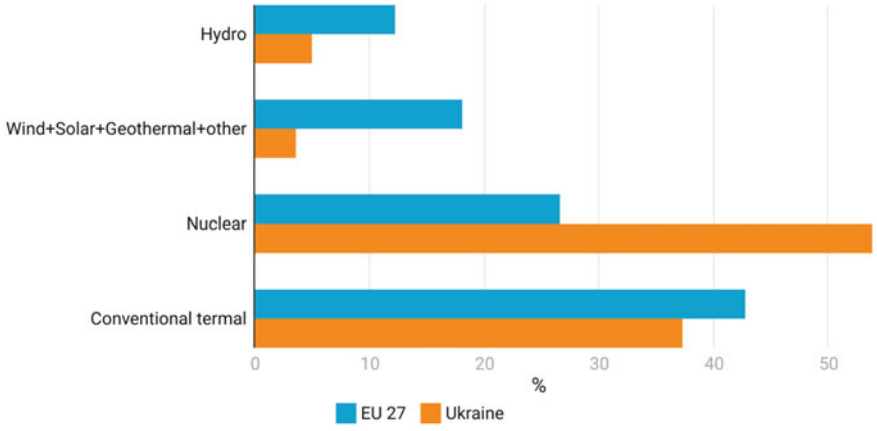

Fig. 2 Distribution between various sources of electricity generation in Ukraine and the EU for 2019

future, this will lead to an increase in electricity tariffs. The Ministry of Energy of Ukraine is currently planning a reform to gradually reduce the green tariff.

Secondly, renewable energy sources strongly destabilize our energy system. Our power grids are outdated and cannot accept the volumes of electricity that are being produced. In addition, Ukraine cannot store electricity in large quantities, so at the moment exactly as much electricity is produced as it is consumed. An increase in the share of renewable energy sources in the country's energy balance will lead to the shutdown of nuclear power plants or thermal power plants.

Gas

Gas is the second most dynamic source of energy in the world after renewable energy sources. By 2050, the increase in gas consumption in the world by more than half (58%) will be provided by domestic production. Liquefied gas will account for 28% of consumption in the countries of the world. The least demand will be for pipelines. In advanced economies, gas will displace oil, coal, and nuclear power. Gas is relatively easy to produce and store, is one of the most environmentally friendly fuels with low emissions, and its price tends to decrease.

Ukraine's gas problems are primarily related to its ineffective use. Gas production is also underdeveloped in Ukraine. Of the 30 billion cubic meters of gas that we consume, 20–22 billion cubic meters have to be imported.

According to many experts' opinions, the best option for Ukraine is to develop its own gas production. However, the relatively long return on investment in drilling the well is currently slowing production rates.

Nuclear Energy

The role of nuclear energy in the world as a whole remains constant, but its balance is changing. Developed countries reduce their share in the total energy balance while developing countries increase it. This is primarily due to the fact that nuclear power plants (NPPs) in developed countries were built a long time ago, but now they are already outdated. Therefore, they are gradually being decommissioned. And the construction of new NPPs is quite expensive and takes a long time. China currently occupies a leading position among countries in the world in the development of nuclear energy.

In Ukraine, the share of nuclear power in electricity generation is more than 50%, and all the plants were built in Soviet times. 75Seventy-five percent of them will must be closed in the period 2030–40 due to the expiration of the service life. And there are currently no plans to replace them. It is possible that their service life will be extended again.

Oil

Oil consumption in the world as a whole remains quite stable. This is mainly due to the growing demand for plastics and space products, as well as through the development of air travel. Transportation does not increase oil consumption due to the growth of the electric vehicle industry and biofuel production, as well as the energy efficiency of vehicles.

Oil production in Ukraine at present does not meet the own needs of the population. Ukraine imports over 50% of oil. The total amount of imported gasoline is difficult to calculate since the "gray" market for oil products is highly developed. Own production is also poorly developed. As with gas production, oil wells have a long payback period.

Coal

The total consumption of coal in the world is not falling; however, in advanced economies, it is gradually abandoning its use. Some countries generally implement an absolute ban on its use. So, France plans to close all coal power plants in 2021, Sweden—in 2022, Great Britain, Austria, and Italy—until 2026.

The use of coal is growing at the expense of India. This country accounts for more than 50% of the increase in coal consumption among developing countries. China is the largest consumer of coal. But even China is starting to reduce its use of coal, preferring renewable energy sources.

Coal provides 70% of the capacity of thermal power plants, producing about 30% of electricity in Ukraine. Compared to the European Union (EU), Ukraine has very low standards, and therefore large volumes of emissions of harmful substances. Ukraine lacks funds to carry out a general ecological modernization of heat-generating facilities. At the same time, Ukraine also cannot currently provide itself with coal completely, therefore, part of it is also imported. However, Ukraine must gradually abandon the use of coal. This is one of the conditions for Ukraine's integration into the EU.

Review of Current Scientific Research

The materials presented in the monograph "Systems, Decision and Control in Energy II" represent an integrated approach of Ukrainian scientists to the development of the energy industry both in Ukraine and the world as a whole. The authors' teams of the chapters of the book united the best scientific institutions into the universities of Ukraine, in particular Institute of Engineering Thermophysics of NAS of Ukraine (Kyiv), .G.E. Pukhov Institute for Modelling in Energy Engineering of NAS

of Ukraine (Kyiv), Institute of Electrodynamics of the NAS of Ukraine (Kyiv), Institute of General Energy of NAS of Ukraine (Kyiv), State Institution "The Institute of Environmental Geochemistry of NAS of Ukraine" (Kyiv), National Aviation University (Kyiv), National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," V.N. Karazin Kharkiv National University (Kharkiv), Admiral Makarov National University of Shipbuilding (Mykolaiv), Kyiv International University (Kyiv), National University of Civil Defence of Ukraine (Kharkiv), National Pedagogical Dragomanov University (Kyiv), Interregional Academy of Personnel Management (Kyiv), Polissia National University (Zhytomyr), State University Zhytomyr Polytechnic (Zhytomyr), Institute of Telecommunications and Global Information Space of the NAS of Ukraine (Kyiv), NPC "UKRENERGO" (Kyiv).

The content of the monograph is divided into four subsections: electrical engineering, heat power engineering, cybersecurity and computer science, environmental safety.

Electrical Engineering

In subsection 1, the authors pay attention to contemporary issues related to the development of the electric power industry, electrical engineering, the physics of electrical phenomena, and renewable energy sources (such as solar energy and wind energy).

In particular, chapter "Corona Discharge Problem in Extra High Voltage Transmission Line" [1] is devoted to the corona discharge problem in the extra high-voltage transmission line. Corona discharge is a phenomenon that occurs on extra high-voltage transmission lines. Because of corona, there is much loss that occurs in the transmission system. Due to the large error in determining the type of weather along the overhead route, empirical methods for calculating corona losses are unacceptable for the efficient operation of electrical systems. The developed system allows determining the components of the total power loss in extra high voltage power lines, primarily the power loss per corona in real time, which will allow to optimize the operating mode in order to reduce these losses and achieve energy savings.

Chapter "Efficiency Increase of Open Phase Modes in Bulk Electrical Networks" [2] considered to efficiency increasing of open-phase modes in bulk electrical networks. The chapter proposes a method for determining the reduction in line capacity in open-phase mode (single-phase automatic reclosing). On the basis of the proposed method, the reduction of the throughput for the actually operated EHV lines is analyzed. Through the use of modern reactive power compensation devices, the ineffectiveness of the use of controlled shunt reactors and STATCOM for the purpose of increasing the line capacity during the single-phase auto reclosure pause was determined.

Chapter "Nonlinear Mathematical Model of Optimal Solar Photovoltaic Station Design" [3] focused on the nonlinear mathematical model of optimal solar photovoltaic station design. To assess the minimum production cost of electricity generated by solar photovoltaic station, a simple nonlinear mathematical model of optimal solar

photovoltaic station design is proposed. The examples of calculations made with the model demonstrate that essential changes in the production cost of electricity could be achieved depending only on the equipment structure of the solar photovoltaic station which depends on its geographical location.

Simulation of efficiency enhancement of electric power generation by wind turbines in wind cadaster various zones presented in chapter "Simulation of Efficiency Enhancement of Electric Power Generation by Wind Turbines in Wind Cadaster Various Zones" [4]. A new mathematical model was pioneered for calculating a capacity factor with regard to the operation time period in the zone of strong winds and also a new model of multiple linear regression for defining the dependence of the operation duration in the zone of strong winds upon the hub height, and rated wind speed of power characteristic of the wind turbine. The said models enable the calculation of annual production of electric power based only on the three passport parameters (rating, hub height and rated wind speed of the wind turbine) without reference to power curve and wind cadaster of the expected construction site of the wind power station.

Comparative analysis and recommendations for use of frequency regulation technologies in integrated power systems with a large share of wind power plants are given in chapter "Comparative Analysis and Recommendations for the Use of Frequency Regulation Technologies in Integrated Power Systems with a Large Share of Wind Power Plants" [5]. With the use of the author's model, which takes into account these nonlinear constraints, a series of calculations was performed to identify the possibilities of using each of the known classes of power plants and electrical units for automatic frequency control in the integrated power systems (IPSs) with powerful wind power plants (coal, gas-oil power plants, gas piston units, battery energy storage systems (BESSs)). Variants for each of the technologies where the frequency in the IPS met the requirements of the European power system ENTSO-E and the IPS of Ukraine were considered. It was found that for IPS, which are comparable to IPS of Ukraine in terms of the combination of operating conditions, only BESSs are available for use as a frequency regulator in terms of technological and economic factors.

Chapter "Increasing Vertical Resolution in Electrometry of Oil and Gas Wells" [6] considered new software implementation of effective methods for well electrometry modeling. For electrical logging, it is based on the original approach of using the integrated current method. That made it possible to quickly and accurately solve the problem of determining the influence of the location of the return electrode in the electrical logging probes at a finite distance on the vertical resolution of the method. For induction logging, the proposed method allows not only to quickly and accurately solve the direct problem. These methods allow not to change the type and number of equations in the system of linear algebraic equations during modeling of cuts changes, but to change only values of system coefficients. Proposed methods were implemented in software, tested, and successfully used for modeling in geophysical research for complicated well cuts. These approaches have made it possible to improve the accuracy of solving the iterative inverse electrometry problem. It uses the result of solving the direct problem at each iteration step.

Heat Power Engineering

Subsection 2 is devoted to modern problems in heat power engineering and considers modern means and methods that increase the efficiency and reliability of the functioning of heat power facilities.

In chapter "Optimization Models of Industrial Furnaces and Methods for Obtaining Their Numerical Solution" [7], optimization models of industrial furnaces and methods for obtaining their numerical solution are considered. The chapter describes two mathematical optimization models for research and improving the efficiency of modern industrial and muffle furnaces on an electrical basis. The first mathematical model involves finding the temperatures of internal spot heaters, the location of which is known in advance. The second mathematical model assumes finding the locations of the furnace spot heaters, the temperatures of which are already known. This chapter presents a general nonlinear case of this mathematical model. The numerical solution of the optimization models is obtained using high-speed optimization methods that are derived from the classical Newton's method. Also, a comparative analysis of the work of the methods by the number of calls to the procedure for solving the direct problem of heat conduction is given.

Development of a system for diagnosing heat power equipment based on IEEE 802.11s is presented in chapter "Development of a System for Diagnosing Heat Power Equipment Based on IEEE 802.11s" [8]. The possibility of using a mesh network for diagnosing heat power equipment is considered. A comparison is made between traditional Ethernet and IEEE 802.11s based networks. A working prototype of a measuring module of a system for diagnosing energy equipment, which is an element of a mesh network, has been developed. A functional diagram of the relationship of the measuring modules of the equipment diagnostic system has been constructed. Aspects of the installation and management of communications, energy saving in IEEE 802.11s are considered.

Modeling the coal industry technological development considering environmental restrictions is presented in chapter "Modeling the Coal Industry Technological Development Considering Environmental Restrictions" [9]. The purpose of the article is to develop mathematical models and tools for optimizing the technological development of coal mining based on the use of environmental and economic indicators of the efficiency of coal production advanced technologies, taking into account the capture and utilization of coalbed methane. A model of production type has been constructed, based on production activities of coal mining and taking into account the formation of coalbed methane. The software implementation of the model made it possible to determine the effective technologies and the optimum complete set of treatment complexes for re-equipment of state mines for achieving maximum production and ensuring environmental safety. The volume of coalbed methane emissions reduction for the period up to 2040, as well as the volume of solid waste generated in the process of coal production, have been determined.

Comparative efficiency assessment of using biofuels in heat supply systems by levelized cost of heat into account environmental taxes is considered in chapter

"Comparative Efficiency Assessment of Using Biofuels in Heat Supply Systems by Levelized Cost of Heat into Account Environmental Taxes" [10]. The authors show that "Levelized Cost of Heat" (LCOH) indicator can change significantly over time due to changes in fuel prices, environmental tax rates, etc., so the corresponding risks when investing in various heating projects must be taken into account. This work is aimed at revealing the essence of these risks, as well as to determine the change in LCOH on the example of boilers with a capacity of 100, 500, and 1000 kW, which burn the following fuels: natural gas, anthracite, wood chips, wood pellets, sunflower husk pellets, straw briquettes, wood, peat briquettes. Thirteen variants of LCOH calculations were made for boilers with a capacity of 100 kW, 10—for boilers of 500 kW, and 9—for boilers of 1000 kW (a total of 32 variants) for the prices of 2016 and 2020 in Ukraine. In addition, it should be noted that the authors summarized the specific emissions of pollutants (kg/t of fuel) and emissions of pollutants for fuel (g/GJ) for the above fuels. Among the pollutants, the following NO_x, SO_x, CO_2, and PM_{10} were taken into account.

The Cybersecurity and Computer Science

Subsection 3 is devoted to issues of cybersecurity of critical facilities, in particular energy facilities, as well as the development of computer science and the introduction of modern information and measurement systems in the energy sector.

Requirements for taxonomy of cyber threats of critical infrastructure facilities and analysis of existing approaches are presented in chapter "Requirements for a Taxonomy of Cyber Threats of Critical Infrastructure Facilities and an Analysis of Existing Approaches" [11]. This chapter presents a unified approach to the systematization of cyber threats. The essence of this approach is to eliminate uncertainties regarding the description of cyber threats. Given the possible risks of information security and cybersecurity of information systems and process control systems at critical infrastructure facilities, a study of known cyberattacks has been conducted. Based on the experience of the world community in the field of cybersecurity and information technology, the classification of methods of intrusion and types of attacks on information systems. Using a formalized approach with the help of drawings and diagrams, the vectors of attacks, the structure of the attack, and the development of the information security incident are presented. The results of this study can be useful for assessing information security risks, in particular in determining the criticality of the organization's assets, in creating information security management systems, and developing appropriate technical regulations to ensure the continuity of business processes of the organization.

Chapter "A New Task Scheduling Algorithm for GRID Systems with Non-alienable Resources" [12] considered new task scheduling algorithm for GRID systems with non-alienable resources. The analysis of existing algorithms of planning of GRID systems which are constructed on the basis of not alienable resources is carried out. The most used planning algorithms are listed. This chapter describes a

new approach to solving the problem of scheduling task flows on processes or GRID nodes of a system with non-alienable resources. The proposed approach is universal and allows to plan tasks for both static and dynamic systems. A new scheduling algorithm, developed on its basis, is also presented.

Concept of the architecture and creation of SIEM system in critical infrastructure is viewed in chapter "A Concept of the Architecture and Creation for SIEM System in Critical Infrastructure" [13]. In this chapter the analysis of the existing models, systems, and methods for cyber threats detection in critical infrastructure was carried out for their disadvantages defining. A model of cloud service has been developed; it allows to ensure the security of cloud service and conduct appropriate simulations. An improved method for cyber threats detection has been developed, it allows to detect cyber threats in cloud services and classify them. The developed method was experimentally investigated using NSL-KDD dataset. It was proved the correctness of its work and the possibility of application in cloud services as well as increase efficiency of cloud system security by 48.02%. Cloud service model has been developed which can be used to build cloud services based on the various architectures. Also, the structural scheme of the main concept of the architecture and creation for SIEM was constructed, that can be used in energy and other sectors of critical infrastructure.

The application of virtual and augmented reality at NPPs is considered in chapter "Application of Virtual and Augmented Reality at Nuclear Power Plants" [14]. The research examined publications on positive aspects of virtual and augmented reality technologies application for various industries, in particular for nuclear energy. Practical examples of the application of virtual and augmented reality technologies for the operation of NPPs are described. As a result of the study, it is determined that currently virtual and augmented reality technologies for NPPs are used in the following areas: modeling of various nuclear energy processes; operation, repair, and maintenance of equipment; presentation of activities, construction of the station; staff training and education. Use of virtual and augmented reality technologies for NPPs confirms its economic efficiency through the reduction of cost and time costs of staff travel to facilities; elimination of design errors before the beginning of the stage of construction and installation works; increasing the level of industrial safety; improving the management of NPPs.

Theoretical aspects of the application of material measure in measurements are summarized in chapter "Application of Material Measure in Measurements: Theoretical Aspects" [15]. The issues of using material measures to assess the results of measurement of physical quantities are considered. The concept of matching the material and probability measures with the aim of forming a unified approach to the assessment of the result and characteristics of measurement uncertainty is proposed. An example of using a set of material and probability measures in hardware and software modules of information-measuring systems is shown.

The Environmental Safety

Subsection 4 deals with the problems of rational use of natural resources, accounting for emissions of harmful substances, environmental issues at energy facilities, as well as the development of a methodology for environmental safety.

Innovative developments to solve major aspects of environmental and radiation safety of Ukraine are considered in chapter "Innovative Developments to Solve Major Aspects of Environmental and Radiation Safety of Ukraine" [16]. This study presents innovative developments that were created by the scientific team of the Department of Nuclear, Radiation and Technogenic-Ecological Safety of the State Institution "The Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine." The results of scientific research and development in the following areas are presented. Among them are a plasma-chemical unit to clean nuclear power plants wastewaters; a system of operative radiation control (high speed) on the basis of the aircraft; a system of radiation control and identification of ionizing radiation on the basis of a solid-state detector with high metrological and operational characteristics; identifier-spectrometer based on a solid-state detector for nuclear fuel cycle facilities and others.

Chapter "Ecological Situation of Post-mining Regions in Ukraine" [17] is analyzed the ecological situation of post-mining regions in Ukraine. The chapter compares the protective potential of the geological environment (GE) of the Chernobyl accident zone and the Donbas region, as well as performs an expert assessment of the environmental protection potential of the post-mining in the leading coal mining areas (MA) of Ukraine. It is shown that a new model of mineral resources use, structure of geological exploration works, scientific substantiation of maximum allowable changes of GE at the closing of "old" and formation of new MA, improvement of environmental monitoring based on GIS technologies and remote sensing of the Earth is needed.

Development of teaching methodology in the field of environmental monitoring of atmosphere is considered in chapter "Development of Teaching Methodology in the Field of Environmental Monitoring of Atmosphere" [18]. The article substantiates the importance of conducting environmental monitoring of the surface layer of the atmosphere using specialized software-modeling systems. Information software is described for the tasks of monitoring and controlling the ecological status of urbanized areas (AISEEM system), which was developed by the authors. The features of the special course for training future specialists in the field of ecology and environmental protection using specialized software and modeling systems are considered.

Chapter "A Transdisciplinary Analytical System for Supporting the Environmental Researches" [19] considered a transdisciplinary analytical system to support environmental researches. The main aspects of man-caused impact and efficiency of contact and remote methods of data acquisition on the ecological situation within the framework of environmental monitoring were analyzed. The method of calculation

of multi-parametric dynamic correlation is developed for the analysis and interpretation of ecological datasets. Mathematical framework of the proposed approach is Pearson correlation coefficient calculating. The proposed method is implemented in the form of information technology and tested on the example of a long-term array data analysis on water pollution in Ukraine. Test locations for method implementation are situated in the river basin of Ustia, Rivne region, and river basin of Prut, Chernivtsi region. The proposed approach and developed software for its use can become a part of the analytical system for support of environmental researches. The concept of transdisciplinary integration of information about environmental situation and their scientifically substantiated interpretation in problems of ecological management on the basis of geographic information technologies were offered.

The conceptual approach to the development of software tools for analysis and synthesis of geophysical monitoring systems models are showed in chapter "A Conceptual Approach to the Development of Software Tools for the Analysis and Synthesis of Geophysical Monitoring Systems Models" [20]. The main purpose of this study is the presentation of the conceptual approach to the development of software tools for the analysis and synthesis of a geophysical monitoring systems model. To achieve this goal, two approaches are proposed to describe the interaction "humanity—the environment." The first approach is based on the use of "game principles." At the heart of the second approach, the environment is considered as a system characterized by fluctuations under the influence of anthropogenic load. The present chapter substantiates the model of the geophysical monitoring system based on the Lagrange equations for an oscillatory system with two or more degrees of freedom in the "factor space," and the model based on "game principles."

Estimated efficiency of biogenic elements removal from wastewater in the ideal displacement photobioreactor is carried out in chapter "Estimated Efficiency of Biogenic Elements Removal from Waste Water in the Ideal Displacement Photobioreactor" [21]. Surface water bodies' eutrophication problem caused by their pollution by nutrients coming together with wastewater is considered in the chapter. It is proposed to use a technological scheme at municipal and other sewage treatment plants, which provides for the organization of additional wastewater treatment by using them as a medium for the cultivation of energy microalgae. The use of the absorption process of nutrients by microalgae organisms due to the metabolism of the latter is proposed. To implement the process, the use of closed photobioreactors of ideal displacement is proposed. To design such photobioreactors, nutrient removal efficiency calculating model, namely nitrogen and phosphorus compounds from wastewater during the operation of such a photobioreactor, is proposed.

Conclusions

Energy consumption in Ukraine is characterized by an imperfect structure, namely, the largest share of energy sources falls on fossil fuels, and the share of renewable energy sources remains significantly lower than in Europe and the world as a whole.

The level of energy intensity of Gross Domestic Product in Ukraine remains one of the highest in the world. In addition, the volume of traditional fuel and energy resources in the country is rather limited. All this has a negative impact on the competitiveness of the domestic economy.

However, Ukraine has good enough potential to correct all the shortcomings of the energy sector and form a good energy balance, which will be formed on economically advantageous indicators and high environmental standards. Ukrainian scientists, including young scientists of the Department of Physical and Technical Problems of Energy of the National Academy of Sciences of Ukraine, work in various branches of energy and are able to generate results not only on a regional but also on a global scale. This statement is supported by this book.

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