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Aspects of implementation of intelligent control systems at infrastructure, energy and transport facilities. Monograph / S.M. Boiko, Kasatkina I.V., Beridze T.F., Zhukov O.A., Nozhnova M.A. – Warsaw: iScience Sp. z.o.o. – 2024 – 205 p.

The monograph discusses the issue of further development of energy systems, which requires restructuring of the electricity supply infrastructure based on modern "intelligent" Smart Grid systems; development of demand management mechanisms, introduction of Energy Storage System energy storage systems, Smart Metering accounting systems, and other innovative technologies, as well as introduction of modern intelligent systems in the transport industry.

Recommended for specialists, post-graduate students and students specializing in 141 - "Power engineering, electrical engineering, electromechanics", 275 - "Transport technologies", 272 - "Aviation transport" and in other related professions.

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A word to the Reader…

In the monograph "Aspects of the implementation of intelligent control systems at infrastructure, energy and transport facilities" the issues of innovative restructuring of the electric power industry in the conditions of the development of the electric power market, which involves the transition to energy systems of a qualitatively new level, are considered: the development of electric power transport; management of electricity demand in real time; development of electricity storage technologies, decentralized generation, including on the basis of renewable energy sources, as well as the issue of intellectualization of control systems at infrastructure, energy and transport facilities.

The trend of further development of energy systems requires the restructuring of the electricity supply infrastructure based on modern "intelligent" Smart Grid systems; development of demand management mechanisms, introduction of Energy Storage System, Smart Metering, and other innovative technologies, as well as introduction of modern intelligent systems in the transport industry.

Special thanks to the reviewers DSc. (Engineering), Prof., ***O. Kotov****, (National University Zaporizhzhia Polytechnic, Zaporizhzhia) and DSc. (Engineering), Prof.,* ***O. Sablin,*** *(National University Dnipro Polytechnic, Dnipro).*

The authors

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INTRODUCTION

Currently, road traffic should be considered as one of the most complex components of the socio-economic development of cities and regions. In this area, the most modern technologies for collecting and processing information on the parameters of traffic flows (density, speed, composition) should be used in order to ensure uninterrupted traffic on streets and roads. The significant socio-economic transformations taking place in the country put forward new requirements for the level of coherence of all spheres of life in society – including in the transport system. Meanwhile, in recent decades, the imbalance between the needs for transport services and the real capacity of all types of transport has been growing. The possibilities of an extensive way of meeting the needs of society in increasing the volume of passenger and cargo transportation by increasing the number of vehicles have largely been exhausted – especially in large cities. At present, development and implementation of intelligent transport systems (ITS) of various scales are underway in Ukraine.

Transport enterprises intensively implement and use information technologies (IT) and information systems (IS) for industrial purposes. The use of ERP, CRM, PDM and other systems leads to significant functional and organizational changes in the work of enterprises in the transport industry of Ukraine, ensuring the optimization of information flows and the reduction of structural units. At the same time, it is the ability to quickly respond to technical and organizational changes and reorient production that is currently the main condition for effective development and ensuring the competitiveness of the mentioned enterprises.

The step-by-step increase in the intensity of information flows and the increase in the volume of created and processed information requires continuous renewal of knowledge and professional development of specialists working in the field of IT and IS. For this purpose, it is necessary to constantly and systematically improve the qualifications of specialists in the energy and transport sectors of the economy, serving the relevant systems.

The monograph is a continuation of the scientific works of the authors in the direction 27 "Transport technologies" and 14 "Energy" and will be useful for students of higher educational institutions, postgraduates, scientists and specialists working in these fields. The authors seek to orient the readers of the scientific work to modern achievements in the direction of intellectualization and automation of the energy and transport sectors of the economy of Ukraine and the world.

CHAPTER 1
GENERAL ISSUES, PRIORITIES AND ISSUES OF IMPLEMENTATION OF INTELLIGENT CONTROL SYSTEMS

1.1 Review of methods of renewable energy introduction and further development in the world and Ukraine

Analytical Note #13 of The Ukrainian Bioenergy Association considers the current state and further development of renewable energy in the world, the European Union and Ukraine. It analyzes energy strategies of the EU in general and those of some EU and the world countries in particular, including Ukraine, focusing on the role of renewable energy sources (RES) in these important directions. Special attention is paid to the countries setting a goal of reaching 50% of renewable energy in the total energy consumption by 2050. It is shown that to achieve the goal it is necessary to not only increase renewable energy capacities, but also reduce total consumption of primary energy by introducing energy-efficient steps [1-3].

In 2012, the International Energy Agency prepared the analysis and three scenarios of our planet's development on the basis of various energy priorities. Scenario *2B8* which implies the average temperature increase by 2˚ C by 2050 is the most attractive and safest of all. To make this scenario come true, considerable changes should be introduced into the world energy system including double reduction of greenhouse gasses by 2050 compared with 2010. To fulfill Scenario *2DS* the energy intensity of the world economy should be decreased on a constant basis as well as the demand for energy (Fig. 1.1, 1.2). Without such reduction, it is too expensive and even impossible to achieve Scenario *2DS* [3].

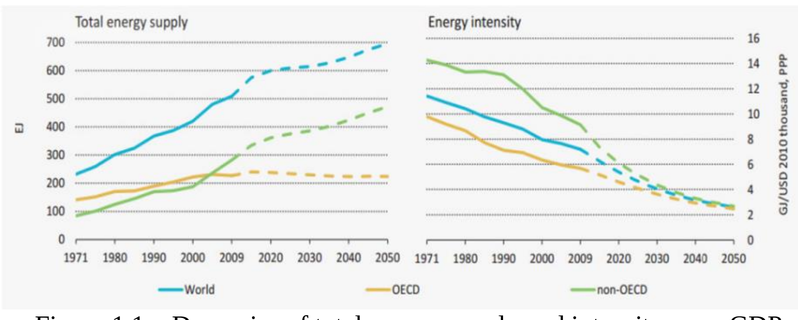

Figure 1.1 – Dynamics of total energy supply and intensity per a GDP unit under Scenario *2DS*

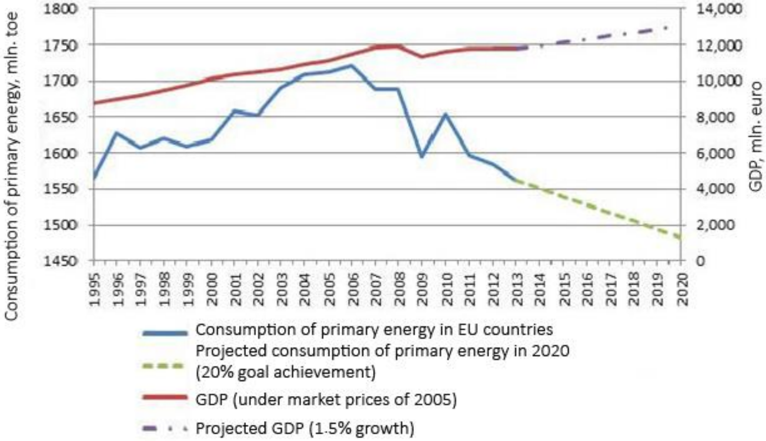

Figure 1.2 – Dynamics of primary energy consumption and GDP in EU-28

At present, renewable energy sources supply about 19% of the world final energy consumption, including conventional biomass – 9%, modern renewable energy sources – above 10% (generation of thermal and electric energy, the transport sector) (Fig. 1.3). In general, conventional and non-conventional biomass covers about 14% of the final energy consumption [1].

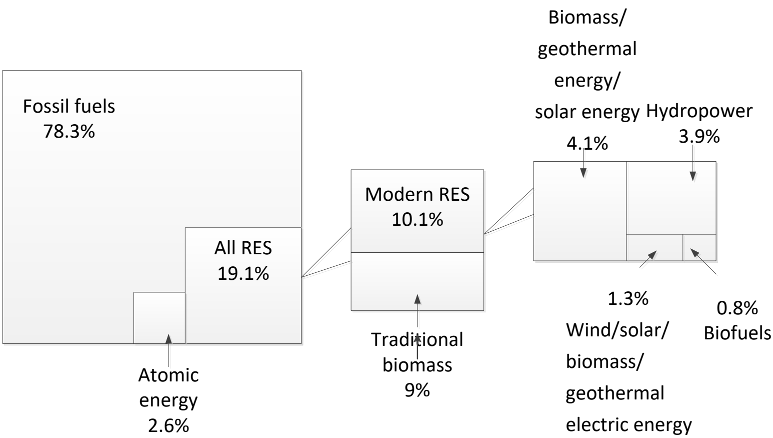

Figure 1.3 – The structure of the world final energy consumption in 2013

Renewable energy sources make up about 22.8% of the total energy production in the world, the major part being hydropower (16.6%). Wind energy and biomass are 3.1% and 1.8% correspondingly (Fig. 1.4) [1].

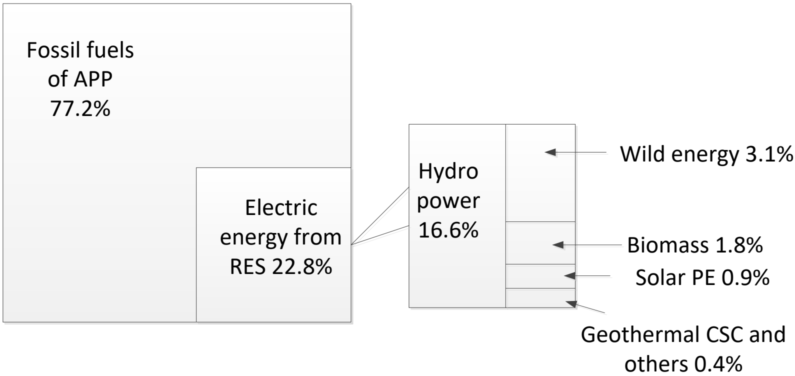

Figure 1.4 – The structure of the world electric energy production in 2014

China, the USA, Germany, Italy, Spain, Japan and India are the major producers of “green” electric energy, which together generate 71.5% of the world total capacity (470GW without hydropower) (Fig. 1.5) [1].

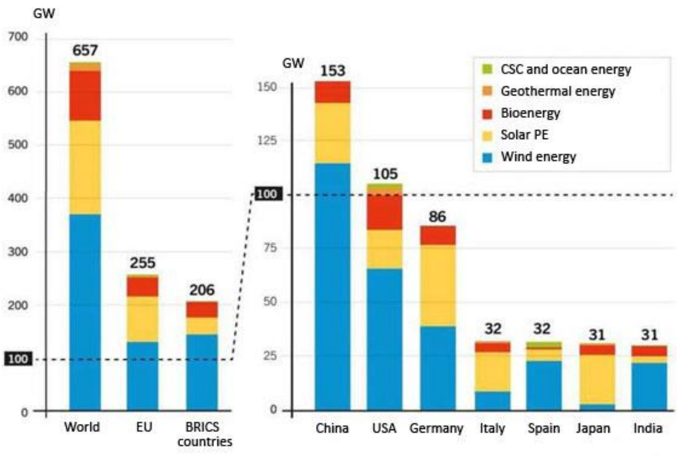

Figure 1.5 – Established electric capacity of the world RES, 2014

The International Renewable Energy Agency (IRENA) worked out the Road Map of doubling the RES fraction in the world energy consumption during 2010-2030 *(REmap2030)* from 18% in 2010 to 36% in 2030. Modern RES are to supersede conventional biomass gradually. As in 2010 conventional biomass made half of 18% of RES, the fraction of modern RES is to triplicate and make up to 30% by 2030 while conventional biomass will account for only 6% (Fig. 1.6) [1].

It is interesting to compare the Road Energy Map REmap2030 of the IRENA with the forecasting of the World Energy Council (WEC). The WEC developed two scenarios of the world energy development up to 2050 [2]. Scenario 1 ("Jazz") provides a rather slow development of RES making 20% of the total primary energy supply in 2050 and a considerable increase of the total primary energy supply by 38% compared with 2010 (from 546 J/year in 2010 to 879J/year in 2050). This scenario seems to have little chance of working as its objective as for RES has already been achieved. Scenario 2 ("Symphony") is more probable. It provides predominant development of RES and increase in energy efficiency. Thanks to this, the RES fraction may reach about 30% in the total primary energy supply and make 50% of electric energy production. At the same time, the total energy supply in 2010-20150 will increase by 22% only [3].

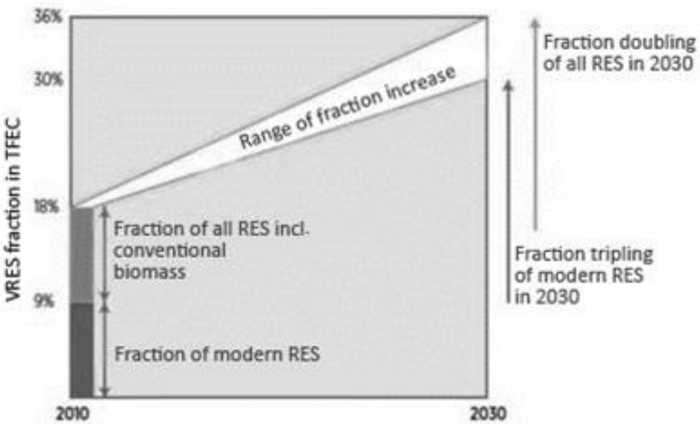

Figure 1.6 – Plans of doubling RES fraction in the total final energy supply of the world according to the *REmap 2030* (IRENA)

In the European Union, the development level of renewable energy is close to the world average indices. RES contribution to the final energy supply accounts for 15% (2013), including biomass (about 9%). The RES fraction in electric energy generation makes 25.4% including about 5% of biomass. More than 19% of the total thermal energy in the EU is produced from RES, mostly biomass [3].

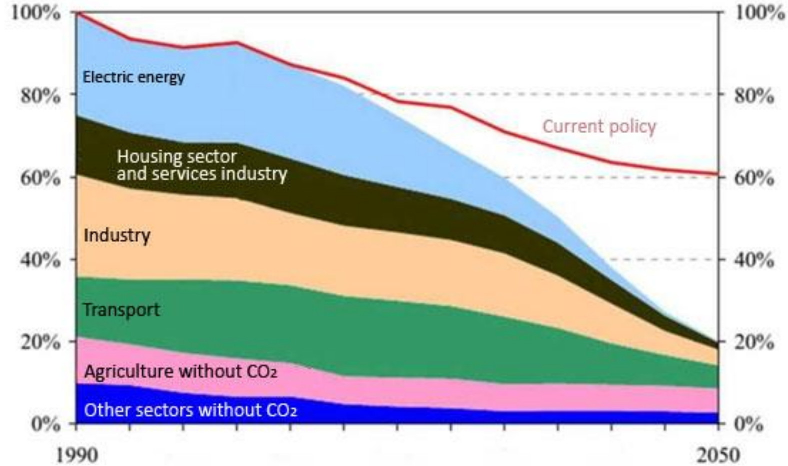

Figure 1.7 – The strategy of reducing greenhouse gas emissions in the EU by 80% by 2050 compared with 1990 according to the EU countries' obligations

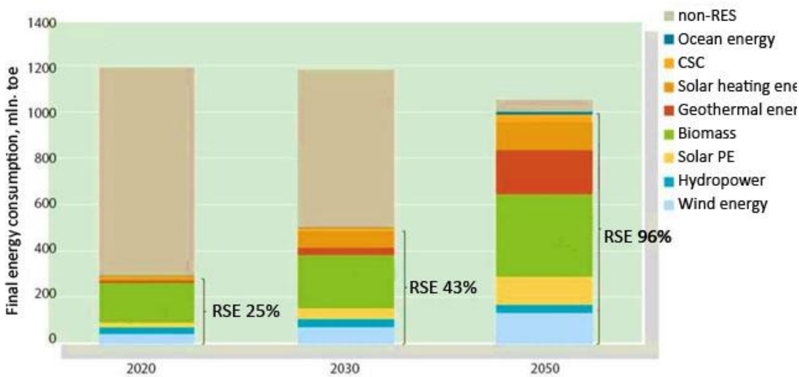

Figure 1.8 – Contribution of RES to the final energy supply in the EU according to *"RE-Thinking 2050" (EREC)*

In 2011, the EU confirmed its official objective of reducing greenhouse gas emissions (decarbonization) by 80-95% in 2050 compared with those in 1990 in order to follow Climate Change Scenario 2DS (Fig. 1.7) [4]. Considering this, the European Commission developed *the Road Energy Map up to 2050* [9], which analyzed the ways of reducing greenhouse emissions and enhancing reliability and competitiveness of energy supply systems.

It is worth mentioning that "RES Scenario" complies to the projected prospects of the EU energy development prepared by the European Council with RES (EREC), «*IRE-Thinking 2050*» [11]. The EREC analysis reveals real possibilities of covering the EU energy needs by almost 100% in 2050 due to RES application (Fig. 1.8) [4].

Table 1.1 provides data on key indices of long-term energy strategies of some world countries [5].

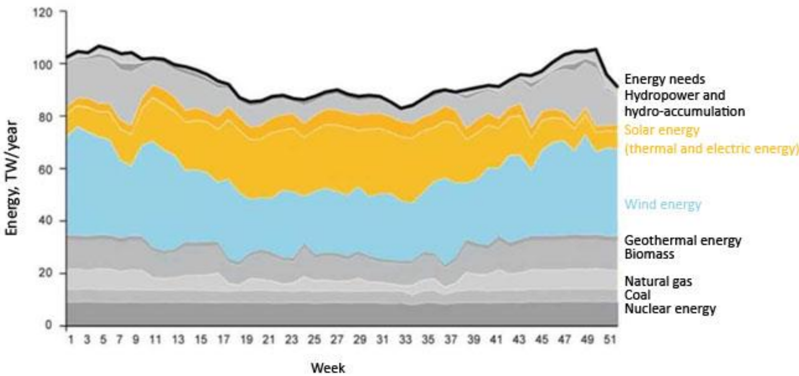

Figure 1.9 – Yearly energy balance, RES fraction of 80%

Constant increase of consumption volumes of energy carriers to meet energy needs make politicians search for new solutions. One of the widely spread solutions in the EU is the idea of a united energy system aimed at leveling the loads and peaks as well as optimal application of various RES in energy generation. In winter periods, more electric energy is produced by wind power plants located in northern EU countries, in summer – by solar power plants located in southern countries. By 2050, it is planned to cover 80% of the total energy production by RES and the main "flow" is expected in directions of "Spain-France" (47GW of the established capacity) and "France-Germany" (20 GW) (Fig. 1.9) [6].

Table 1.1 – RES fraction of in the gross final energy consumption of some world countries according to official data on their energy strategies

Country	2014	2020	2030	2040	2050
Austria	30%	34% 16%[4)] (1990) 17%[5)] (2005)			
Denmark	25% 20%[5)] (2005)	33%	55%	68%	100%
Wales	12,4% (in 2013) 27%[4)] (1990) 9%[5)] (2008)	18% 40%[4)] (1990) 20%[5)] (2008)	30% 55%[4)] (1990) 30%[5)] (2008)	45% 70%[4)] (1990) 40%[5)] (2008)	60% 80%[4)] (1990) 50%[5)] (2008)
Sweden	52,1% (in 2013)	50% 40%[4)] (1990) 20%[5)] (2008)	100%[3)]		100%[4)]
Switzerland	17,5% (in 2010)	45% 16%[5)]		56% (in 2035) 45%[5)] (in 2035)	60%
India	13%[1)] (in 2015)		40%[2)] 33-35%[4)]		
China	13% (in 2010)			55%[1)]	
USA (Hawaii)	20%	30%	40%	70%	100% (in 2045)
Costa-Rika	95-99% 100%[1)] (in 2015)	100%[4)] (in 2021)			
Island	99%				
Saudi Arabia	1% (in 2015)			100%	

Notes: the year of comparison or index achievement is in brackets

1) In electric energy generation 2) Fraction of energy generating capacities per RES 3) In the transport sector 4) Reduction of greenhouse gas emissions. 5) Energy efficiency increase

Currently, the Energy Strategy of Ukraine for the period up to 2030 is valid [10], which was adopted by the Cabinet of Ministry of Ukraine on 24 July 2013 and strongly criticized at once. In order to solve this problem, some projects of a new document, the Energy Strategy for the period up to 2035, have been developed.

The basic configuration of the energy security formula includes energy saving and energy efficiency + the country's own energy resources *(coal, natural gas, uranium ore, oil, biomass + other renewable energy sources)* + import diversification + strategic reserves + integration into the EU energy space (united and synchronized energy networks) + protection of the critical energy infrastructure [12].

In 2015, the structure of primary energy resource consumption is characterized by a great fraction of natural gas (36.1%, 31 mln toe) in the total primary energy supply. Atomic energy accounts for 27.9% (24 mln toe), coal – 20.8% (18 mln toe), oil products – 9.4% (8 mln toe), biomass – 4.3% (4 mln toe), hydropower plants – 0.9% (1 mln toe) and wind/solar power plants – 0.6% (1 mln toe). The total fraction of all RES is 5.8%. Optimization of the structure of the total primary energy supply aimed at decreasing the gas fraction is one of the government's permanent tasks in reforming the energy sector [3, 12].

In 2015, Ukraine established the energy generation capacity of 54.8GW including 3.2GW at the uncontrolled territories of the east and south of Ukraine. These capacities comprise 24.5 GW of thermal power plants (TPP), 6.5 GW of combined heat and power plants (CHPP), 13.8GW of nuclear power plants (NPP), 5.9GW of hydropower plants (HPP)/pumped storage plants (PSP), 0.4 GW of solar power plants (SPP) та 0.5 GW of wind power plants (WPP) [3, 13].

These capacities are mostly worn out as 50% of them are more than 40 years old. Thus, capacities supplying about 80% of current production (about 20-25GW) should be withdrawn out of operation in 2025-2040 including 11GW of 50-year-old nuclear power plants if their operation terms are doubled. Among VVER-1000 blocks, the Ukrainian blocks are some of the oldest. Plans of withdrawing them out of operation (of 50 years) may be revised after considering the practices of Nine Mile Point and Oyster Creek Nuclear Generating Stations [14]

The RES fraction in Ukraine's final energy consumption of 2015 was about 5.6% considering all national hydropower plants. This figure is three times less than the average EU-28. At the same time, about 20% of Ukraine's RES energy was produced by hydropower stations, which have been in operation for decades and located mostly on the Dnipro River. Approximately 30% of RES energy was produced from products of biological origin (solid biomass, biogas, biofuel, etc.) [15].

RES application can both enhance the energy security level and reduce the technogenic load on the environment. That is why, along with the energy efficiency increase, it can become one of Ukraine's energy policy priorities.

While considering RES, it is advisable to distinguish three basic aspects of the problem – wind and solar energy, biomass and hydropower.

As of 2016, these types of RES have the following capacities: 0.5GW of solar power plants and 0.5GW of wind power plants [15].

In 2015-2035, the structures of thermal and electric energy generation and the primary fuel consumption are expected to be changed, this resulting in 11% increase of the total supply of primary energy as compared with 2015 up to 95-98 mln toe in 2035. Yet, the index of the total primary energy supply will be lower by about 17% as compared with that of 2013 [3, 15].

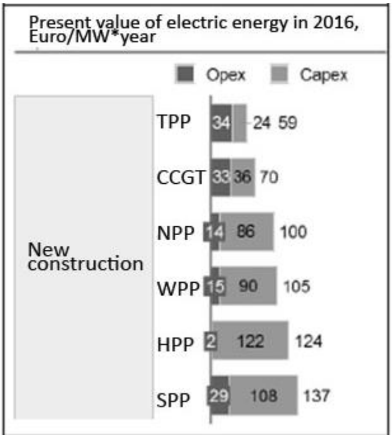

Figure 1.10 – Comparison of costs of different electric energy generation types in Ukraine

RES energy production will increase thanks to the development of Ukraine's alternative energy after 2025. The RES fraction in the total primary energy supply is expected to increase at a fast pace from 5.7% in 2015 to 21.7% or by 3.8 times (without considering HPP/PSP – from 4.9% to 20.4%).

1.2 Features and trends of modern power industry development

Specifying Smart Grid notion with regards to electric power systems of various technical level gave rise to the emergence of such terms as StrongSmartGrid (SSG) – electric grids with the voltage over 110 kV, RegionalSmartGrid (RSG) – the voltage from 3 to 110 kV, and MicroSmartGrid (MSG) – the voltage 0.4–3 kV, typical directly for the systems themselves and arising at their integration, which determines the features of equipment construction in their connection points and in the nodes of loads connecting. The practical solution of these tasks can be performed on the basis of power electronic means and, in particular, on the basis of the wide implementation of electrical energy parameters' converters. Power electronic means are natural elements of the systems under consideration, without them there is no question of the Smart Grid construction.

Selection of the type and structure of semiconductor converters, which are suggested for the connection of different systems, should be carried out with account for the nature of the variation of electrical energy parameters typical for one or another system. The major feature of SSG, RSG and MSG systems is an essential distinction in their electrical energy parameters variation in time. SSG systems are characterized by a relatively high stability of energy parameters [1].

In RSG systems, as a rule, some variations of the electric energy parameters take place; these variations depend on the type of connected load and the capacity of transformer substations.

Basic issues of the Smart Grid concept development in Ukraine [2]**:**

1. Development of strategic vision of the future power industry in Ukraine based on the concept of Smart Grid.
2. Redistribution of the basic requirements and operational properties of the domestic power engineering on the basis of the Smart Grid concept and their implementation principles.
3. Defining the major development trends for all parts of power system: generation, transmission and distribution, sales, consumption and dispatching.
4. Redistribution of the basic components, technologies, information and management solutions in all the above-mentioned spheres.
5. Ensuring coordination of modernization (aimed at overcoming the technological gap) and innovation development in the Ukrainian power industry.

Trends of electric power industry development that enjoy the priority progress [3]:

– Optimal integration of generating and storage capacities of diverse physical nature in an electric power system.

– Countering of negative impacts.

– Motivating active behaviour of the end-user. Providing access for an 'active consumer' and the distributed generation on the electric power markets.

– Ensuring the energy supply reliability and electric power quality in various price ranges.

– Transformation of the system-centric approach into customer-centric one.

– Self-healing in case of disturbances, including emergency ones.

– Asset management optimization.

Development trends for smart electric grids of the Ukraine's Unified Power System:

– Transition to the distributed generation.

– The transition from rigid dispatch scheduling and regulation to arranging coordinated operation of all network objects.

– Implementation of new technologies and power facilities that ensure manoeuvrability and controllability of an electric power system and its objects.

– Constructing of smart metering, monitoring, diagnosis and control systems covering the distributed generation as well as the electricity transmission, distribution and consumption.

– Development of a new generation of operational applications (SCADA\EMS\NMS) targeted at new power devices.

– Formation of a highly efficient integrated information and computing structure being a core of the electric power system.

Prospects for Smart Grid implementation in the Unified Power System of Ukraine

Major benefits of renewable energy sources [4]:

– cost reduction of traditional fossil fuel resources;

– reduction of Ukraine's dependence on fossil fuels importation;

– environmental compliance due to reduction of the negative impact on the environment.

Problematic aspects of the renewable energy implementation in the Unified Power System of Ukraine:

– inadequacy of Ukraine's legal framework;

– insufficient technical standards base and state standards for renewable energy power plants' design and connection to electric grids of the Ukrainian Unified Power System;

– the need to include capacities of renewable energy power plants in the daily dispatch load schedule of load on mandatory basis.

Problematic aspects of the renewable energy implementation in the Unified Power System of Ukraine:

– rapid and uncontrolled capacities increase of renewable energy power plants;

– the state-owned enterprise national electric company “UKRENERGO” does not posses a tool to restrict technical specifications issue and construction ofrenewable energy power plants; consequently, technical specifications for the connection of wind power farms accounting for 2062 MWe have already been issued and approved; solar power farms – 570 MWe; applications to obtain technical specifications account for about 14000 MWe, that comprises 40% of the Ukrainian Unified Power System consumption;

– reduction of cycling capacities alongside with the increase of basic capacities in the general balance of the Unified Power System of Ukraine. The need for extra spare capacity in the event of power fluctuations on solar power farms and wind power plants;

– deterioration of the quality of electricity in the power supply regions with functioning solar power plants;

– the need for extra measures aimed at reactive power neutralization and voltage regulation.

European countries experience:

1) implementation of significant capacities at renewable energy power plants (Denmark, Germany, Spain, etc.);

2) the UCTE system accident in 2006 was partially caused by significant power flows from regions with renewable energy power plants functioning;

3) the need to maintain appropriate spare capacity in the event of the power variation occurring on renewable energy power plants;

4) implementation of modern complexes to forecast the operation of renewable energy power plants, Smart Grid implementation.

1.3 Priority areas of development of intelligent control systems

A new technological revolution is taking place in the world, which is unfolding on the basis of the integration of these technologies into almost all spheres of economy and social life. A new type of society is being formed (Society 5.0), whose production chains, logistics, and social infrastructure will be based on artificial intelligence (AI). Armed with intellectual technologies, the intensity and effectiveness of their implementation become a criterion for the development of national economies. Accordingly, the attractiveness of countries and regions, the concentration of skilled labor, high-tech production facilities, material and financial resources, educational institutions, infrastructure and cultural facilities in them will depend on the degree of implementation of AI.

Different countries see similar opportunities for the use of artificial intelligence. Their plans, concepts and strategies most often emphasize that healthcare, technology, agriculture and manufacturing are the sectors with the greatest potential for AI transformation. The governments of these countries take into account the potential of this technology to strengthen their competitive positions in the main areas of social development.

Risk prevention concepts are developed, attention is paid to creating a regulatory framework for AI systems, exploring their impact on social inequality and the need for increased transparency related to AI systems.

These guiding documents emphasize the need to comply with the norms of international humanitarian law, ensure information security and confidential use of data related to the design, deployment and application of AI systems. The governments of these countries create conditions to support innovations in the field of AI.

For all the similarity of general tasks, principles and methods of achieving similar goals, foreign approaches cannot be effectively implemented in Ukraine.

The specifics of the current state and the unique conditions of our country determine the formation of alternative ways of AI development, taking into account the leading world practices.

The concept of the development of the field of artificial intelligence in Ukraine defines the purpose, basic principles and tasks of the development of artificial intelligence technologies in Ukraine as a priority direction in the field of scientific and technological research, taking into account modern trends and features of the development of Ukraine in the perspective of 2030.

The following key terms and abbreviations are used in this Concept:

– information technology – a purposeful, organized set of information processes using computing equipment that provides high data processing speed, fast information search, data dissemination, access to information sources regardless of their location;

– artificial intelligence (AI) is the property of systems to correctly interpret external data in accordance with the set goal, learn from such data and use the results of learning to achieve the set goals, including the collection and use of new data, through interaction with the environment. Such a property of systems is implemented through algorithms and methods, the work of which is possible thanks to equipment for computing and data collection, communication with other systems, interaction and influence on the surrounding world;

– artificial intelligence technologies – information technologies using artificial intelligence;

– the field of artificial intelligence – the sphere of social relations that arise in the process of applying artificial intelligence technologies with the use of specific methods and means of computer technology.

Investments in the development of AI technologies in the world are constantly growing. According to international experts, the amount of investment in AI in 2021 will reach 57.6 billion dollars (Deloitte study op. cit. 2017 Deloitte State of Cognitive Survey), while profits from the use of AI in certain sectors of the world economy, according to McKinsey Global Institute analysis will be from 3.5 to 5.8 trillion dollars [1].

In the world, AI technologies are actively used in various spheres of social life. In particular, with the help of AI technologies, medical diagnoses are established, unmanned driving of vehicles is carried out, financial instruments are traded on stock exchanges, large volumes of data are analyzed, images are recognized and generated, household robots are created, as well as highly accurate autonomous weapons.

Fundamental AI technologies are designed to contribute to the transformation of the economy, the labor market, state institutions and society as a whole. The use of AI technologies will provide significant opportunities for increasing production efficiency, reducing costs, and improving the quality of goods and services. The growth of data volumes, the development of new types of sensors and the decrease in the cost of computing power create the prerequisites for the further development of AI technologies.

In order to use the possibilities of AI technologies, most of the leading countries have developed national and supranational strategies in this area. Similar documents were approved by the European Commission, as well as in the USA, Canada, France, Great Britain, Germany, China, Japan, South Korea, Sweden, etc.

In the North Atlantic Treaty Organization (NATO), considerable attention is paid to the technologies of artificial intelligence and the practical aspects of their use from the point of view of the development of national and joint capabilities, as well as comprehensive consideration of possible problems and challenges associated with the mass distribution of relevant technologies in the world.

Ukraine, which is a member of the Special Committee on Artificial Intelligence under the Council of Europe (AD HOC COMMITTEE ON ARTIFICIAL INTELLIGENCE), in October 2019 joined the principles of the Organization for Economic Cooperation and Development (OECD) on artificial intelligence (OECD, Recommendation of the Council on Artificial Intelligence, OECD/LEGAL/0449).

Today, research in the field of information technologies is being conducted in Ukraine. The achievements of Ukrainian scientists in the creation of computer architectures and in system analysis, modeling, optimization, and creation of AI are known in the world. Ukraine has reached a certain level of concentration of knowledge-intensive industries. In Ukraine, there is a network of instrument-making and electronic industry enterprises, which are represented in almost all large industrial centers, a significant number of organizations are engaged in the development of software products, there are specialized research institutes, design bureaus.

The main principles of the development and use of AI technologies, the observance of which is mandatory for the implementation of this Concept, and which fully correspond to the OECD principles on artificial intelligence, are the following:

– AI should benefit people and the planet, promoting inclusive growth, sustainable development and well-being;

– AI systems are developed and used only under the condition of observing the rule of law, fundamental rights and freedoms of man and citizen, democratic values, and their use must be provided with appropriate guarantees, in particular, the possibility of unhindered human intervention in the process of functioning of the AI system;

– ensuring transparency and responsible disclosure of information about AI systems;

– AI systems must function reliably and safely throughout their life cycle, and assessment and management of potential risks must be carried out on an ongoing basis;

– organizations and individuals who develop, implement or use AI systems are responsible for their proper functioning in accordance with the above principles.

According to the analysis of the labor market in Ukraine and abroad, artificial intelligence has not become a factor in the increase in unemployment due to the dismissal of millions of workers due to the introduction of the latest technologies, as predicted by skeptics. On the contrary, the spread of AI contributes to the creation of many new jobs and higher-skilled specialties. This phenomenon is particularly characteristic of the labor market in the field of information technologies.

The technological level of the domestic production of computer equipment and its elemental base does not allow us to consider in the near future the possibility of full-fledged competition of Ukrainian products on the market of hardware solutions of AI technologies. At the same time, the available potential of scientists and their achievements is not properly utilized. The number of scientists participating in international projects is increasing, which indicates the active use of our scientific potential by other countries. Joint international projects in Ukraine arise mainly chaotically, without consideration of their expediency for the state and without proper coordination from a single center. Participation in such projects, mostly small, scatters the efforts of Ukrainian scientists and distracts them from setting and solving tasks of national importance.

Currently, the use of artificial intelligence in Ukraine is limited mainly to leading organizations in the fields of industry, information and communication and financial technologies, based on foreign developments. Often, such developments are created in Ukraine, but the intellectual property rights to them belong to foreign companies. The AI R&D software market is growing every year, with more and more vendors offering different AI solutions for business. Ukraine currently (according to LinkedIn) has more than 2,000 institutions and software development companies specializing in the field of AI. Among them are the globally recognized companies Grammarly, Reface, Ring Ukraine (SQUAD).

According to the State Statistics Service of Ukraine, revenues from the export of services in the field of telecommunications, computer and information services (where AI technologies are primarily used) collectively reach almost 30% of the export of services in the structure of foreign trade in services, which significantly exceeds imports.

Given the rapid integration of AI into information technology (IT), a shortage of specialists in this field is predicted. A significant share of AI specialists is involved in the creation of IT products for customers of the foreign market, which inhibits Ukraine's ability to create its own high-tech developments.

Currently, only basic and fragmentary developments of AI have been created and implemented in the world, and world science is only on the threshold of creating a full-fledged artificial intelligence that has the necessary attributes of a human.

Ukraine lags behind the leading countries in the pace and volume of implementation of such developments, but it has the necessary potential of fundamental development to make a breakthrough in the creation of completely new world-class technologies in the field of AI.

At the same time, the lack of appropriate targeted funding and a conceptual vision of the development of the field of AI leads to inefficient use of resources, loss of personnel potential, and ultimately to the outflow of specialists and promising scientists who leave for countries with more favorable conditions for scientific research.

Many authors who have dealt with the problem of artificial intelligence believe that the achievement of medium-level successes in this field will affect the daily life of all segments of the population around the world. Until now, only computerized communication networks such as the mobile phone network and the Internet have been able to provide this kind of pervasive impact on society. It is quite possible to imagine that really useful personal assistants for the office or home will have a great positive impact on improving the quality of everyday life, although in the short term they may cause some economic troubles. In addition, the technological possibilities that open up at this level can also be used to create autonomous weapons, the appearance of which many consider undesirable. Along with the spread of achievements in the field of artificial intelligence, the efforts of scientists to use already developed AI technologies, as well as to invent new ones, especially for the field of education, are increasing.

The application of intellectual developments for learning and teaching acquires its own research direction with corresponding problems specific to this area. Scientific communities are being created that are engaged in the study of educational processes and the application of AI technologies to create computer-based learning systems.

A new step in computer education was the emergence of agent-oriented intelligent educational systems, which include the following agents: teacher interface, learning interface, access to knowledge, ontologies, agent-coordinator of interactions. Quite interesting solutions have been obtained today in the field of creating tools to support the development of web-intelligent educational systems, which can be applied in cases where pedagogical (didactic) principles of learning, invariant to the discipline, are used in the learning process control algorithms, i.e. we are talking about adaptive management of the learning process. This is due to the emergence of new opportunities for the computerization of learning processes, both through the use of various distance educational technologies, and through the further integration of models, methods and tools of expert systems with educational systems within the framework of a single architecture that combines interacting logic -linguistic, mathematical, simulation and some other types of models.

Despite all the advantages and successes, in the development of artificial intelligence and its further existence there are certain problems with possible negative consequences. Modern theoretical problems can be reduced to such groups:

1. The problem of presenting knowledge.

Problems of neural networks:

– multi-criteria decision-making;

– stochastic decision-making models;

– development of new representation models for highly specialized subject areas.

Problems of biomachines, that is, machines that have living beings as part of them or structurally imitate humans:

– multi-criteria decision-making;

– decision-making based on statistical models;

– coordination of work of several robots;

– problems of improving neural networks.

2. Development of computer linguistics:

– development of new, more reliable programming languages;

– development of a natural language-based work management language.

3. The problem of improving computer logic:

– development of new architectures (parallel machines, research in the field of integrated memory, decentralized machines, modeling of high-speed electrical connections);

– humanoid robots (flexible and portable members of robots; recognition by robots of persons authorized to control robots; development of robot mechanisms; numerical methods for optimization of calculations);

– methods of accessing information (multimedia systems; heuristic analysis of texts; automatic extraction of knowledge from the text);

– creation of "intellectual spaces" (intellectual learning environments and shells);

– machine learning (machine reading and understanding of texts; recovery of lost data elements; cleaning of data from noise);

– medical vision (automatic analysis of anatomical structures; image reading; machine geometry and spatial scenes);

– mobile robots.

4. The problem of improving computer linguistics:

– development of a work management language based on natural language;

– creation of natural language models;

– language comprehension;

– development of programming languages that allow to increase the reliability of the developed software.

Researchers often consider whether artificial intelligence can be developed. But it is also necessary to devote time to analyzing the question of whether it should be developed after all. S. Russell believes that if the consequences of the creation of artificial intelligence technology are more likely to be negative than positive, then people working in this field have a moral responsibility, which obliges them to direct their searches in other areas.

Artificial intelligence can become the source of some unprecedented problems, namely:

1. As a result of automation, the number of unemployed may increase. Until now, automation with the help of artificial intelligence technology has consistently created more jobs than it has eliminated, and also led to the emergence of more interesting and high-paying specialties. Now that the canonical AI program has become the "intelligent agent" designed to assist humans, job loss is becoming an even less likely outcome.

2. The amount of free time available to people may decrease (or increase). In an information economy characterized by the availability of broadband and the ease of copying intellectual property, the greatest reward comes from the ability to be slightly more successful than the competition; a 10% increase in work duration can lead to a 100% increase in income. Therefore, everyone feels a growing crisis, which forces a person to work more and more intensively.

3. People can lose the sense of their own uniqueness. In his book "Computer Power and Human Reason", Weizenbaum, the author of the Eliza program, pointed out some potential threats that with the development of artificial intelligence, people will be automatons, and this idea leads to a loss of autonomy or even humanity.

4. People may lose some of their privacy rights. The development of speech recognition technology and the existing threat of terrorism may lead to the widespread use of wiretapping tools and therefore to the loss of civil liberties. Many people agree that computerization leads to infringements on privacy rights. Yes, one of the senior executives of Sun Microsystems, Scott McNeely, even stated: “You don't have any personal life anyway. Forget about him."

5. The use of artificial intelligence systems can lead to the fact that people will become more irresponsible. For example, if expert systems ever reliably produce more accurate diagnoses than humans, doctors could become legally liable if they do not use the expert system's recommendations.

Issues related to the use of intelligent agents on the Internet are becoming important. For example, some progress has been made in terms of introducing restrictions on intelligent agents so that they cannot, say, damage other users' files. The problems become even more important when it comes to monetary transactions. Will it be possible for an intelligent agent to own assets and participate in electronic auctions on its own behalf? As in the case of human cloning technology, legislators have yet to include new situations in the legal field..

6. The success of artificial intelligence could be the beginning of the end of the human race. Almost any technology presents potential opportunities for harm when it falls into malicious hands. When it comes to artificial intelligence and robotics, a new problem arises that these malicious hands may belong to the technology itself. Warnings about the dangers posed by robots or robotic humanoid cyborgs out of control have become the subject of endless science fiction.

If we look at the problem from the robot's point of view, if they become conscious, treating them simply as a "machine" can be an immoral degradation of their dignity. Robots themselves must also act morally, so you need to program them with a theory by which they can judge what is good and what is bad.

1.4 Problems of implementation of sources of distributed generation

Renewable energy is designed to contribute to solving, first of all, two important problems - energy efficiency and environmental safety. In the modern domestic market of energy resources, alternative sources of energy are just starting to gradually develop [1].

The Ukrainian economy remains the second most energy-intensive country in the world in terms of energy intensity. In the last 5-10 years, the energy problem has acquired particularly threatening features for the further development of the national economy of Ukraine, in connection with this, complex work has begun to be carried out to develop a vision and strategy for the development of the energy sector [2].

The widespread introduction of renewable energy sources (RES) of distributed generation (DG), storage and other technologies will have a significant impact on the development of traditional models of energy markets and the formation of energy balances.

The main factors that negatively affect the operation of the UES (unified energy system) of Ukraine:

– physical wear and tear and moral aging more than 80% TPP and CHP power units;

– working out the estimated technical resource of the majority of power transmission lines and electrical substations with a voltage of 220 kV and above;

– approaching the end of the design period of operation of NPP power units;

– suboptimal structure of generating capacities;

– shortage of maneuvering (9.1% for the optimal level not lower than 15%) and regulating capacities (17% for the required 30% - 35%) in the energy system, insufficient provision of mobile reserves of the UES of Ukraine in the conditions of the introduction of renewable energy sources (RES), which have stochastic mode of operation;

– insufficient levels of static and dynamic stability of individual nodes of the power system, etc. Schematic solutions, configuration and purpose of combined systems are extremely diverse. The relevance and perspective of these systems is undoubted, because their implementation will solve the problem of covering the peaks of the electrical load schedule in power systems, optimize the modes of operation of power transmission lines, and improve the environmental situation in the areas where power facilities are being built.

The main directions of integration of renewable energy sources and distributed energy resources are the organization of active participation of consumers and the creation of new infrastructures, one example of which is the Micro Grid system built on the basis of DG nodes.

Classic networks are not designed to work with the complex tasks of managing energy flows, which will appear with the transition to DG. One of the effective directions of conflict-free development of decentralization should be considered the organization of structural associations from many local sources, which makes it possible to form sufficiently powerful sources of generation with unique properties that are able to act as an organized unit of generation.

An important factor is that the introduction of DG sources leads to a change in the traditional centralized structure of the power supply system (PSS) to a decentralized one, which in turn requires changes in the concepts of monitoring, management and balancing of the system. The PSS with DG elements needs to establish a connection between producers and consumers of electric energy to ensure controllability of all network elements.

Today, a new direction in the energy industry is rapidly developing: namely, intelligent energy (Smart Grid) [3].

The local Microgrid system includes, as a rule, several sources of generation and distribution substations, energy conservation complexes, power flow regulators, which allows the Microgrid to function both in autonomous mode and to be connected to the external power system. Microgrids cope well with the task of increasing the reliability of energy supply due to the prompt switching of consumers between the general energy system and local energy sources in the event of overloads and voltage surges. In the future, the advantages of microgrid technologies will be their easy and quick adaptation to consumers, in contrast to centralized energy supply systems.

Optimal from the point of view of the implementation of DG in the PG of Ukraine is the construction of local energy systems (LES) with a balanced energy supply from combined sources of DG with ensuring their reliable and stable operation. Moreover, the balance of the energy supply is ensured by two types of DG sources - renewable energy sources and DG sources that consume traditional energy resources. This is due to the fact that the first type of sources, despite the practically zero cost of the primary energy resource, can have a sharply changing nature of generation associated with changing weather conditions, while the second type of sources has the opposite advantages and problems.

Since 2014, the energy sector of Ukraine has been in a state of war, which is why the necessary decisions with the beginning of the active phase of the war were worked out earlier. However, a whole list of new and more threatening challenges was revealed, including nuclear terrorism of the russian federation immediately after the seizure of the Zaporizhzhia nuclear power plant, a very large amount of damage to critical infrastructure facilities – gas and electricity networks, the demand for energy products decreased due to population migration, significantly the level of payment for energy carriers fell.

Despite all these challenges, the energy sector of Ukraine is holding up, moreover, with the acquisition of the status of a candidate country in the EU, certain changes have taken place, new challenges have appeared for energy and the industry as a whole [15].

With the beginning of the war, a number of regulatory changes were introduced, which were necessary to stabilize the industry and solve critical problems. The process is still ongoing, as the 2022/2023 heating season is approaching, which, according to the forecasts of specialists and industry experts, will be the most difficult in all the years of Ukraine's independence.

As a result of russian aggression, the energy industry of Ukraine suffered losses of hundreds of billions of hryvnias, for example, on April 24, Russia destroyed the Kremenchug thermal power station with missiles. Poltava OVA reported that 180,000 residents of Kremenchuk may be left without heat and hot water in the next heating season. On May 12, when restoration work began at the enterprise, another rocket hit.

Before the start of the war, in February 2022, Ukraine's energy industry was one of the most powerful in Europe, and remains so even now, despite the damage. Thus, Ukraine is among the top 10 European countries in terms of installed power generation capacity, and among the top 3 gas producers. Ukraine has the largest underground gas storages in Europe on its balance sheet. It has extensive, reliable systems of transportation of oil and oil products, gas, power lines, which are interconnected with neighboring countries.

The share of carbon-neutral generation in Ukraine is one of the largest in Europe. Approximately 70% of electricity in Ukraine is produced by hydro, nuclear and renewable generation. Diversification of electricity production is the key to the country's energy security [27].

Ukraine got rid of energy dependence on the russian federation, despite the situation, the heating period 2021/2022 was passed stably and calmly, without restrictions. Coal supply sources were diversified in the following steps: 1.4 million tons of coal were delivered by sea (18 boats), another 8 boats were expected with 0.6 million tons of coal (50% of all imports).

Before the war, namely on February 23, 2022, there were 701,000 tons of coal in Ukrainian warehouses, which is twice as much as in 2021.

Measures were implemented to save coal through own coal mining, use of NPP and RES energy.

During 2021, Ukraine built 1.2 GW of new RES capacity, which significantly reduced the need for coal.

Ukraine supplied itself with gas resources by 67%, the rest was imported from EU countries, from various suppliers.

Huge underground gas storages, which Ukraine owns, are a guarantee of the country's energy security. Before the start of the war, there were 10.2 billion cubic meters of gas in storage. m of gas is an indicator that is sufficient to supply the Ukrainian consumer market until the end of the heating season, even without new imports.

GTS of Ukraine was the guarantor of ensuring capacity for the next gas import from EU countries.

The war had a very negative impact on Ukraine's energy industry.

The special strategic goals of the enemy have become precisely the objects of the energy sphere, this is due, first of all, to geopolitical and economic strategic importance. In the eighth month of the war, it should be stated that the energy sector has stability, it has coped with all critical situations, the workers of the industry demonstrate high professionalism [26].

Approximately 4% of the generating capacity of the energy sector was partially or completely destroyed as a result of the military aggression of the Russian Federation, 35% of the capacity is currently under temporary occupation.

Yes, the largest nuclear power plant in Europe operates in the energy system of Ukraine, while it is under the occupation of the enemy [15].

The production capacity of the ZNPP is 6,000 MW, which is 43% of the total capacity of all NPPs of Ukraine.

50% of thermal generation has been destroyed or is under occupation, 30% of solar generation, 90% of wind generation.

There was a 10-12% reduction in gas production, damaged and non-functioning refineries, the production of which provided 30% of oil production for Ukraine. There are very large logistical and other components of the supply of petroleum products.

As of June 2022, the direct losses suffered by the energy sector of Ukraine, the oil and gas sector is approximately 47 billion hryvnias ($1.7 billion).

Indirect losses in the energy sector are estimated by energy industry experts at 341.8 billion hryvnias. The sector of gas production, transit and distribution has losses in the amount of 61 billion hryvnias, the sector of oil production and oil refining – 66 billion hryvnias.

Power grids and substations were among the first to suffer from enemy fire. Their recovery became a priority. In some areas, this has already been dealt with. In other regions, the work is unfinished.

So, on May 18, the DTEK company announced that it had restored 100% of the electricity in the Kyiv region.

According to the general director of "DTEK Kyiv Regional Electric Networks" Vitaliy Shayda, restoration of networks of the region to the quality and reliability of pre-war times will require investments of UAH 1 billion. Over 300 million hryvnias. already invested (from the working capital of the company).

Another 600-700 million hryvnias should be invested in 2022-2023 during the second stage of works – restoration of reserve food sources.

Losses for September 2022 in the energy sector due to the military aggression of the Russian Federation in Ukraine are estimated at 2 billion dollars. Here, not only the value of the asset is taken into account, but also how much it could generate electricity and earn from its sale [26].

Luhansk TPP DTEK suffered the most since the beginning of the war. Also, in fact, the Okhtyrska thermal power plant was completely destroyed (there was a direct hit by two shells).

Losses in solar energy due to aggression. Since the beginning of the full-scale Russian invasion of Ukraine, more than 550 MW of domestic SPPs and solar power plants have been destroyed or damaged. According to the Ministry of Energy, as of July 2022, more than 30% of RES capacities have currently suspended electricity production due to the war: 90% of wind and 12% of solar, depending on the total number of installed capacities, respectively [39]. These figures from the ASUN are based on more than 50 surveyed owners of solar power plants whose installations have suffered damage since the beginning of the invasion. 68% of the destroyed objects were installed in the occupied territories or close to the line of hostilities; of the total number of damaged power plants, industrial roof-top SPPs make up 5.9%, industrial ground-based plants – 29.4%, domestic plants – 64.7%. Despite all the damage suffered, Ukraine is taking confident steps closer to energy independence and is exerting all possible forces, so that "green" energy could continue to exist and develop. The CEO of SolarWind Systems (Kyiv) noted that 88% of the 45,000 power plants of private Ukrainian SPPs were networked before the start of the war. As a result of the full-scale invasion of the Russian Federation, most of the settlements and districts lost power, and the owners of these SPPs had to face the disadvantages of the "green" tariff, because the installed panels are currently turned off [11]. Of course, there are methods to obtain autonomy by means of manual tools, but to obtain complete autonomy, special components are needed that cannot be purchased in ordinary stores. A number of owners are already upgrading their grid stations to standalone or hybrid with additional hybrid or standalone inverters and batteries. To reduce the modernization budget, there is an option to transfer part of the installed panels to a new inverter. Hybrid stations are more expensive to build, but they provide energy independence. An example can be the situation when the hybrid station helped the family of Oleksandr Ananyev, a resident of the Kyiv region, and his fellow villagers to survive the russian occupation. His village was under occupation for almost a month. According to EcoPolitics, solar power producers urged Ukrainians to install solar panels as soon as possible, because of this, global investments in SPPs will only grow. Cyber attacks on energy infrastructure At the beginning of the full-scale invasion of energy infrastructure objects, more than two hundred thousand cyber attacks were carried out, for the whole of 2021 there were about nine hundred thousand of them. The number of cyberattacks on the energy sector in the first forty-seven days of the war exceeded two hundred thousand, while for the whole of 2021 their number was nine hundred thousand. Recently, specialists recorded fifty attempts of DDoS attacks. Last year there were only two of them. If we talk about the ministry itself, then in the last week alone, about twenty thousand cyber security cases were recorded, which were aimed at disrupting the vulnerability of its infrastructure [35]. According to Energoreforma, taking these data into account, since the beginning of the Russian invasion, the number of cyber attacks on the energy infrastructure has increased 1.7 times. Thanks to the coordinated work of the teams of the Ministry and the rest of the state bodies, in particular the CERT-UA government team, these attacks were repelled. The infrastructure is intact as much as possible. At the same time, a greater number of attacks are carried out specifically on the electric power sector, namely, on NEC "Ukrenergo" and Oblenergo. Due to the fact that these attacks are caused by an aggressor country, there were attempts to prevent the connection of the Ukrainian energy system to the European grid, but despite everything, we did it, and this can be considered one of the biggest victories during the years of independence. Most recently, a major cyber attack on one of the largest regional energy companies of Ukraine was successfully repelled. If the resulting attack was successful, 1.5-2 million private consumers would lose electricity, not taking into account the industry.

Recovery should take place with the help of the Ukrainian Recovery Fund and the support of international partners. Otherwise, the OSR will be forced to use the funds of the investment program of the following years, which will slow down the reconstruction of substations and the development of networks. This will have a negative impact on plans to increase automation and reliability, and reduce accidents.

Mykolaivoblenergo has preliminarily assessed losses for the beginning of May. Without temporarily occupied territories, they amount to more than 350 million hryvnias, but currently fighting continues on the territory of the region, therefore, in general, no one is able to give an estimate of the scale of destruction.

During the recovery, the company would like to focus more attention on increased levels of automation of network management [42].

First of all, this is the development of smart grids. The components are known - automation of substations of 35 kV and more, transformer substations and distribution points of 20 kV, lines of 10 kV and more; introduction of automated systems of monitoring and control of power grids and development of the latest dispatch centers; formation of intelligent electric power accounting systems, etc.

The goals of automation are to reduce SAIDI (measured in minutes/year), i.e. the time consumers are without electricity. Average indicators in Ukraine in 2020 were 816 minutes, while in 2019 in Germany – 12 minutes, Romania – 179 minutes, Croatia – 193 minutes. Last year, stimulating tariff formation (RAB regulation) was introduced for the Ukrainian regional energy company. Its use should increase investments in networks by increasing their reliability. September of last year was marked for the Ministry of Energy by the developed idea of introducing "smart networks" in Ukraine by 2035, which aimed to improve the networks precisely in the direction of smart grid – highly automated systems.

However, both the pace of automation of networks and the ways of financing will have to be reviewed after the victory. It is no longer possible to form smart networks through RAB regulation.

The rest of the experts are of the same opinion: it is impossible to rebuild and develop the electricity grid only with the funds of tariffs. We need a different algorithm and other ways of investment, financing, lending, which would guarantee the volume, which today already amounts to hundreds of millions of dollars. It is necessary to rebuild and develop, first of all, with the involvement of Ukrainian industrial productions, Ukrainian construction and assembly, commissioning and design institutions [15].

There is a need to receive international assistance not only with equipment, but also with production licenses. We must have the right to provide services and form joint ventures. In this way, we will increase the utilization of our industry. In the same way, it is necessary to form algorithms for the electrification of cities and carry it out together with regional management and joint regional programs to unite our energy enterprises.

It is necessary to analyze the model of the creation of urban systems with the subsequent rejection of the central supply of heat carriers (in some cities and generally from the supply of heat carrier) in medium and small cities, in the case when three or four boiler plants of 5-10 MW are able to provide heat to entire districts.

It will be a long-term safety stage, when it is very difficult to damage the local infrastructure, and in case of damage, it is only necessary to replace the transformer substation – there will be no need to build a new CHP. Recovery question.

It is possible to do without multi-year construction of new infrastructure, renewal of heating networks, cauldrons. However, we will be talking about the capital repair of the building 1 connection to electricity.

The case in Kremenchug should serve as an example for conducting an analysis of the general situation with heat supply in Ukraine, the security systems of all housing and energy systems, in order to be able to prevent such large-scale communal problems.

Damage to electrical networks in houses with electric heating in most cases does not lead to critical results, for example, in the situation with heat or gas networks. Their repair is easier. Producers of "green" electricity are the most modern sector of Ukrainian energy development, which was on the verge of bankruptcy due to the invasion of the Russian Federation [46].

However, investors do not lose hope that they can not only compensate for losses, but also accelerate the pace of RES development.

The owners of the stations hope to receive assistance for the restoration/repair of the stations with the funds from the post-war reconstruction and reparations funds. They hope to connect RES producers to the programs of the Ukrainian Recovery Fund, to allocate funds from the energy recovery fund created by the Energy Community, which currently compiles lists of damaged energy infrastructure facilities. Very exceptional critical such assistance for stations in debt and which are severely damaged and unable to continue operations.

The owners of the stations have started restoration work in the vacated areas where possible. Along with the beginning of the full-scale russian invasion of Ukraine, countries began to declare plans to accelerate the transition from fossil fuels to RES, the demand for equipment is increasing. We expect that the future development of RES in the world and in Ukraine will not slow down, but rather increase. Ukraine needs to reduce dependence on fossil fuels, increase capacity for heat and electricity production from RES, "green" hydrogen, which can replace gas in the future [31].

There is a need to build energy storage systems.

Energy recovery is a broader task than the recovery tasks undertaken by individual organizations. Taking into account that from now on the risk of a re-invasion of the Russian Federation will always be there, the sphere will never come to the situation that was created before February 24, 2022.

During the massive invasion, there were risks that should not be neglected even after the victory. In order to eliminate them, Ukraine must re-plan the entire economy.

Decentralization as a solution to the problem of great vulnerability of cities.

The disadvantage of today's megalopolises is that no matter where you shoot, you will end up somewhere. This does not necessarily have to be a planned goal. It can be a system of electricity, heat, gas supply, the damage of which can endanger the future existence of the city during the winter. The probability of risks depends on the size of the city. For this, it is desirable that the entire infrastructure be decentralized, so that in the event of a problem, it would be possible to localize and solve it. The days of monster factories are coming to an end: they will illustrate their own vulnerability, primarily in the 150-200 km zone from the border with the Russian Federation and Belarus (including Kyiv) [15].

A decentralized, protected economy is needed, which will be aimed at providing the needs of the country from the point of view of maximum defense. The state is obliged to have an extensive network of facilities that guarantees to provide the elementary needs of the army (helmets, cartridges, body armor, etc.). These enterprises should be located in the largest number of communities, so as not to concentrate production and business in monocities, so that a large number of communities are interested in their own development. Changing the structure of the economy and the structure of the life support of communities and cities Ukraine is not able to renew the old economy, which lagged behind civilized countries in terms of energy intensity by at least 2.5-3 times. It is necessary to create a safe, resource-efficient, decentralized economy, most focused on the security of the state. During decentralization, it is necessary to understand how much gas, water, and light need to be directed to one or another point, whether they contain alternative energy sources, or whether reserve fuel facilities are needed.

A unified conceptual approach to the further development of Ukraine from the direction of its infrastructure and economy of life support is necessary.

Such life support infrastructure must be developed and conditioned during development planning. Hence the problems of communications, roads, communications, etc. Ukraine should form the algorithm of a new order within the state and, accordingly, attract investors from this order. A state policy should be formed that would encourage such actions. Investors should have an understanding for what purpose they are doing it. Not because someone wants it, but because so many residents will live in this city, they will be involved there and it is necessary to provide for them.

Infrastructure requires fuel reserves, currently there are frequent calls to use biomass boilers instead of damaged heating plants. Ideas of this type are interesting, but the problem arises: where to get biomass in these points and who ensures its presence. The same straw can serve as an example. It will be publicly available if agriculture is developed, when it is sown and harvested on time, and the bale with straw does not burn at the first raid [19].

Supply of energy resources should be together with reserve fuel farms. If before that, reserve fuel farms were based on coal and fuel oil, now they can work on cyclically renewable resources, on biogas, on agricultural waste.

The first task is to encourage technical auditors who are able to inspect the houses in the areas where the damage occurred.

It is necessary to restore buildings and find out whether they are subject to restoration. The blast wave can only destroy windows, but if a bomb hits the foundation of a building, it can “collapse” at any time [40].

The EU is on track to meet its 2020 renewable energy target. In 2017, the EU achieved a RES share of 17.52% in gross final energy consumption, compared to a target of 20% for 2020 and above an indicative trajectory of 16% for 2017/2018. In addition, the EU as a whole is also slightly above the ambitious trajectory set by the Member States themselves in their National Renewable Energy Action Plans (NRAPs). In recent years, at the EU level, there has been a constant increase in the total share of RES and the sectoral share of renewable energy sources in electricity (RES-E), heating and cooling (RES-H&C) and, to a lesser extent, in transport (RES-T).

However, the rate of growth of the share of renewable energy sources has slowed since 2014. Compared to a share of 16.19% in 2014, average growth for the period 2014-2017 was just 0.44% per year, below the average annual growth of 0.83% that will be needed to reach 20% in 2020.

In terms of absolute consumption of renewable energy sources, the largest contribution is made by the heating and cooling sector, which in 2017 amounted to 102 million toe, renewable energy sources - 86.7 million toe, and the transport sector − 23.65 million t.e. The main RES in energy consumption were biomass for heating and cooling, hydropower and wind for electricity generation, and biofuels for transport. In the power industry, a significant paradigm shift towards renewable energy sources is taking place. One of the key factors was the decrease in the cost of electricity produced by solar panels and wind power plants, which for the period from 2009 to 2018 decreased by almost 75% and about 50% (depending on the market situation), respectively, as a result of lower capital costs, increased efficiency and improvement of the system of supply and holding tenders for the provision of support.

In Germany, market premiums paid for a 1.4 MW solar PV project were below the market cost of solar energy in summer 2018, and in Denmark, new wind projects were developed at a fixed feed-in tariff of €2.5/MW. Both in Germany and in the Netherlands, tenders for the construction of offshore wind farms with a capacity of 1,610 and 700 MW included applications for zero subsidies. Cost reduction is also one of the key factors in the growth of demand for RES from corporate consumers, especially if they sign a direct power purchase agreement with producers. During the period from 2015 to

2018, the volumes of electricity supplied from RES to corporate consumers increased fourfold, from 506 MW to 1,967 MW.

Investment is the leading factor in energy development. Investments in RES are increasingly driven by the market, and the share of government subsidies is declining. This was caused by a significant reduction in the cost of RES technologies, a reduction in subsidies based on more competitive support schemes and confirmed by the numerous results of zero or low cost auctions in a number of European countries [18].

According to preliminary estimates by the European Environment Agency (EEA), the share of RES in the gross final energy consumption in the EU doubled between 2005 and 2018, reaching 17.6% in 2017, and increasing to 18.0% in 2018. However, the growth of the RES share in final energy consumption has slowed down in recent years. The growth of energy consumption and the lack of progress in the transport sector jeopardize the chances of achieving both the RES targets and the 20% increase in energy efficiency at the EU level by 2020. In 2018, according to preliminary estimates of the EEA:

– recorded progress in achieving national targets for the use of RES in all EU countries, except Ireland, the Netherlands, Poland and France. Countries have met or exceeded their targets set under the RES Directive. In addition, 16 member states, except for Austria, Belgium, Germany, Ireland, Spain, Cyprus, the Netherlands, Malta, Poland, Portugal, Slovenia and France, have achieved or accelerated the fulfillment of their commitments;

– 12 countries (Bulgaria, Hungary, Denmark, Italy, Latvia, Lithuania, Romania, Finland, Croatia, the Czech Republic, Sweden and Estonia) have already fulfilled their own commitments made for 2020 in accordance with the RES Directive;

– RES accounts for 30.7% of gross final electricity consumption, 19.5% of energy consumption for heating and cooling, and 7.6% of transport fuel consumption [19].

The above conclusions indicate that the development of the market of renewable energy sources in the EU is rapid and is supported by the organization and member states.

Changes have been introduced in Ukraine in recent years, the main purpose of which is to stimulate the development of the RES market and maintain competitiveness for the sake of economic and energy development.

According to the information report on the main indicators of the development of the branches of the fuel and energy complex of Ukraine in October 2019, the volume of electricity production by power plants that are part of the United Energy System (UES) of Ukraine was 12,373.9 million kWh and decreased by 632 .1 million kWh, or by 4.9% compared to October 2018. At the same time, thermal power plants and thermal power plants produced 4,754.8 million kWh of electricity, which is 299.9 million kWh or 6.7% more than in October 2018.

In October 2019, the production of electricity by hydroelectric power stations and hydroaccumulation stations decreased by 158.1 million kWh, or by 24.8% compared to October 2018, and amounted to 478.8 million kWh. In October 2019, the production of electricity by alternative sources – power plants using wind, solar energy and energy from biomass compared to the indicator of 2018 increased by 176.0 million kWh or by 63.7% and amounted to 452.3 million kWh . In October 2019, electricity production by power plants of other types (block plants and other sources) compared to October 2018 increased by 25.8 million kWh, or by 18.7%, and amounted to 164.0 million kWh. In 10 months of 2019, the volume of electricity production by power plants included in the UES of Ukraine reached 126,706.1 million kWh, which is 2,228.9 million kWh or 1.7% less compared to the corresponding period of 2018 [36].

After the adoption of the Law of Ukraine "On the Electric Energy Market" [37] in 2017, the renewable energy sector is developing at a rapid pace. For the transition to RES, the government introduced "green" tariffs, which are compatible with EU preferential tariffs: a safe "green" tariff was provided until 2030 and is defined by the Law "On Electricity"; tariffs were set in euros - zero currency risk in hryvnias; the law guarantees the purchase of 100% of the energy produced from RES by the wholesale operator; the law specifies that a bonus for the use of Ukrainian equipment is provided at the level of 5-10% in addition to the existing incentive tariff; the electricity purchase agreement significantly protects the rights of investors and creditors; the National Energy Regulatory Commission is responsible for setting preferential tariffs, licensing RES, providing and distributing financial support to eligible parties.

Auctions are used to prevent monopoly in the Ukrainian electricity market from RES. A transparent tender is held through the electronic trading system ProZorro twice a year, in autumn and spring, and participation in the tender will be mandatory in 2020 for solar energy projects with a capacity of more than 1 MW and wind farms with a capacity of more than 5 MW. The first pilot auction should take place by the end of this year. The company that wins the tender receives government support for the next 20 years.

Ukraine is a European country with an area of 603,549 km². During the year, there are more than 290 sunny days here. Also, the land of the country is uniquely fertile: agricultural land occupies 70% of the territory, that is, the bioenergy potential is obvious. According to the report of the National Academy of Sciences and the Heinrich Bell Foundation "Ukraine's Transition to Renewable Energy by 2050", Ukraine can meet 91% of its energy needs by 2050 through the use of RES. Such a transition will be possible both economically and technically. According to experts, in the energy balance from RES, Ukraine can receive 45% - due to wind energy, 36% - from the sun, process up to 70% of biomass and bio-waste [38].

According to the State Agency for Energy Efficiency, Ukraine has a solar energy production potential of approximately 730 billion kWh. per year, but 34/2 billion kWh is technically possible. for a year. According to forecasts, 40/50% of private households will use solar panels on their roofs by 2030. This will increase the demand for using solar collectors for water heating. So private households will be provided with warm water throughout the summer and by about 15% in winter [39].

Ukraine has made progress in planning its future energy system and developing policy in the field of renewable energy sources. In the report of the International Renewable Energy Agency, it is determined that by 2030, the wider use of RES should reduce the energy system of Ukraine.

Some Ukrainian cities have also announced a complete transition to green energy by 2050. In 2018, the mayor of Zhytomyr announced a complete transition to alternative energy sources. The city authorities and the international non-governmental environmental organization 350.org are working together on this project. A memorandum on cooperation with 350.org was also signed by the mayors of Kamianets-Podilskyi and Chortkov. The simulation results of equivalent scenarios show that Ukraine has sufficient potential and can fully satisfy the demand for energy resources, even in conditions of high energy intensity of industry [40].

Ukraine has quite successfully implemented many tools to support the RES market. Green certificates, loans issued in foreign currency and laws that protect the rights of producers and stimulate the development of the sector indicate that the country is fully committed to the transition to renewable or "green" sources of energy.

As world and European experience shows, auctions are an effective modern tool of market regulation, which in the long term stimulate producers to innovative development and price reduction and reflect a market approach in the organization of relations with buyers and consumers. Taking into account the experience of the EU, Ukraine has already started to switch to the auction system, which should replace the system of green certificates.

From the experience of the EU, it can also be concluded that renewable energy sources contribute to the reduction of fuel import costs and improve trade and energy balances. For example, in 2010, the use of renewable energy in the production of electricity saved 10.2 billion euros by reducing the import of organic fuel, of which 2.2 billion euros were saved by the EU wind power industry. According to 2013 statistics, total CO2 emissions in the EU decreased by 362 million tons, and this indicator continues to grow every year.

Issues of environmental protection are gaining urgency. Ukraine ratified the "Paris Climate Agreement", as a result of which it agreed to reduce CO2 emissions into the atmosphere in order to prevent an increase in the overall temperature of the Earth and climate change. Therefore, the perspective direction of Ukraine's integration with the EU in the context of the implementation of the provisions of Annexes XXX and XXXI of the Association Agreement will be issues of environmental protection.

An example of how an EU member state can use RES in energy is Latvia. According to 2017 data, renewable energy sources accounted for 19.5% of the total energy used for heating and cooling in the EU. The leaders in the use of RES for heating or cooling were Sweden (69.1%), Finland (54.8%), Latvia (54.6%) and Estonia (51.6%) [41]. The example of Latvia is interesting because, like Ukraine, the country was part of the USSR, and after its collapse, it did everything possible to join the EU.

The EU remains a world leader in waste management and recycling. As S. Savchuk, the former head of the State Agency for Energy Efficiency and Energy Saving of Ukraine, noted: "The energy potential of solid household waste in Ukraine is quite high. 10 million tons of garbage are collected every year. In the process of their processing, it is possible to produce 3.5 million Gcal of thermal energy and 1.2 billion kWh of electricity, as well as to sort resource-valuable components - about 20% of the mass of garbage. The potential for gas replacement will be up to 1 billion m^3 per year. We are talking about huge funds that can be saved and left to work for the country's economy" [42]. Borrowing the experience of European countries will allow Ukraine to accelerate the transition to the principles of a resource-efficient, energy-saving, responsible, low-carbon, innovative, "green" economy.

The contribution of renewable energy sources to the total production of electricity in the world is almost 23%, while hydropower accounts for the lion's share – 16.6%. Among other RES, wind energy has the largest share – 3.1%, followed by biomass – 1.8%.

Thermal energy accounts for about half of the world's final energy consumption. More than a quarter of the thermal energy demand is provided by renewable sources, in particular, 17% is provided by traditional biomass, 7% by modern biomass and only 1% by other modern RES.

The International Renewable Energy Agency has developed a Roadmap to achieve a doubling of the share of renewable energy sources in global energy consumption in the period 2010-2030 (REmap 2030): from 18% RES in total final energy consumption (2010) to 36% (2030). At the same time, modern renewable energy sources should gradually replace the use of traditional biomass. Since in 2010 half of the 18% of RES accounted for traditional biomass, in 2030 the share of modern RES should more than triple (to 30%), leaving traditional biomass use with only 6%.

It is interesting to compare the REmap 2030 Roadmap with the forecast of the World Energy Council, which developed two scenarios for the development of global energy until 2050. Scenario 1 foresees a rather slow development of renewable energy - 20% of the total supply of primary energy in 2050, and a rather significant growth Compared to 2010, TSPE increased by 38% (from 546 EJ/year in 2010 to 879 EJ/year in 2050). This scenario seems unrealistic, since its RES target has already been achieved. Scenario 2 is more realistic. It provides for the predominant development of renewable energy and the growth of energy efficiency. Thanks to this, in 2050, the share of renewable energy sources should reach about 30% in TSPE and 50% in electricity production. At the same time, the total energy supply in the period 2010–2050 will increase by only 22%.

Projects to achieve 100% renewable energy consumption

Today, there are about 150 planned and already implemented projects for the complete transition to renewable energy in the world. They are divided into several categories: city, regional, state, housing and business projects. Among such projects for individual countries, cities and companies, the following can be distinguished:

– Denmark has set a goal of achieving 100% of heat and electricity production from renewable sources by 2035 and 100% of energy from RES in all sectors by 2050;

– Iceland has already achieved 100% of electricity production and 85% of heat energy from RES;

– Scotland: target of 100% electricity generation and 30% of total energy demand from RES by 2020;

– Maldives: the goal is 100% energy from RES by 2020;

– Since the beginning of 2015, Costa Rica has provided 100% of its electricity needs through RES. The goal is to achieve complete decarbonization by 2020;

– Saudi Arabia decided to completely abandon the use of fossil fuels by 2040 and replace them with renewable energy sources;

– The government of Uruguay has made an official statement that as of December 2015, 94.5% of the country's electricity needs are met by renewable sources. By 2017, it is planned to reduce carbon emissions into the atmosphere by 88% compared to the average indicators of 2009-2013 and achieve full decarbonization by 2030;

– Three US cities (Aspen, Burlington, Vermont) have already completely switched to renewable energy. The cities of San Francisco, Palo Alto, San Diego, Ithaca, Greensburg, Georgetown, and San Jose have also made it their goal to switch to RES and have already adopted relevant programs;

– Vancouver (Canada): in 2015, commitments were made to transition the city to 100% RES;

– Frankfurt (Germany): complete decarbonization of the city due to RES and alternative car fuel is planned by 2050;

– Copenhagen (Denmark): the goal is to achieve 100% heat and electricity production from renewable sources by 2035 and 100% energy from RES in all sectors by 2050. Complete decarbonization of the city is planned by 2025; Currently, 98% of the population receives heat energy from solid household waste and biomass;

– Munich (Germany): the goal is 100% electricity from RES in the housing stock by 2015 and for all consumers by 2025;

– Malmö (Sweden): the goal is 100% renewable electricity by 2020;

– Sydney (Australia): goal – 100% production of electricity, heat and cold from RES by 2030.

Such world-famous brands as IKEA, Johnson & Johnson, Nike, Procter & Gamble, Starbucks, Voya Financial and Walmart, Google, Apple, Microsoft, Facebook, Virgin Group, RWE, E.ON and others have joined the campaign to switch to renewable energy. They aim to use electricity exclusively from renewable sources in all sectors of their activity.

Today, smart and safe power grids are considered technologies that contribute to the transition of the system from traditional power grids to more sustainable and environmentally safe systems. However, there are significant contradictions in the scientific community regarding the implementation of such technologies as opportunities to ensure energy security and justice.

Given the consequences of the impact on the environment and guided by the policy of ensuring energy efficiency in the field of communication technologies, electricity distribution, energy systems began to change to more environmentally friendly ones. According to the report ("ETP Smart Grids", 2015), the Smart Grids platform is defined as an intelligent energy system that integrates the actions of all consumers and carries out energy generation and in the future effectively provides sustainable, economical and safe electricity supplies. Similar definitions of Smart Grids as intelligent energy systems are also considered in the report ("Top Markets Report", 2019). In this case, smart energy networks - Smart Grids are presented to energy consumers as smart energy systems that are capable of generating electricity themselves.

Farhangi H. (2017) defined Smart grid as new capacities that are able to provide electricity supply services with new capabilities, such as management, communication with energy consumers and integration of renewable energy sources. According to this approach, it is clear that the smart grid allows energy companies to more efficiently organize the work of energy supply and at the same time make capital expenditures due to energy savings to increase the operational efficiency of the use of renewable energy sources (Farhangi, 2017).

In our opinion, the use of Smart grid technology as smart and safe energy networks makes it possible to generate various types of energy into electricity at industrial facilities. At the same time, ensuring energy security, environmental sustainability and energy equality is of primary importance. The above three components form an energy trilemma, which is reflected in one of the indices. As an effective energy index, the trilemma was proposed by the World Energy Council and, according to the report ("Energy Transition Toolkit", 2018), is determined by the criteria of security, justice and sustainability.

At the international level, a balanced assessment of each country is carried out according to the energy trilemma index, as a result of which indicators are ranked relative to each other. At the same time, countries with the most developed and balanced values of the energy trilemma occupy higher positions. Long-term assessments show the relative improvements achieved by countries over time in the context of national governance systems and markets.

The United Kingdom has a balanced score on all dimensions of the trilemma. Great Britain effectively supports the components of the energy trilemma by forming various sources of primary energy supply. Thus, at the beginning of the twenty-first century, the country saw a sharp decline in coal supplies, which accounted for only 5% of the UK's energy supply (down from more than 20% of the total). The priority of the state is aimed at renewable energy sources, the capacity of which is constantly increasing. For example, in 2017, there was an increase in supplies from onshore and offshore wind - from 41 GW of supplies from renewable sources to 47 GW. Renewables currently account for 30% of the UK's total energy supply (Historical Trilemma Scores, n.d.).

Germany has been among the leaders of the energy trilemma for quite a long time. Despite the fact that there are relative changes in the indicators of fairness and sustainability, in general, according to the index of the energy trilemma, Germany has high values. This is primarily due to the transition from traditional sources to renewable energy sources. It is planned to increase the production of electricity from renewable sources by 65% by 2030. Striving to make the transition to more economical and efficient development, the decision to transform the electricity market from a system based on preferential tariffs to a bidding process for green energy producers was an important change in 2016 ("Historical Trilemma Scores", n.d.).

Thus, the share of renewable energy in the total energy production in Germany is 33.1%. In other words, in 2017, a third of the electricity in the Federal Republic of Germany was produced from wind, biomass, the sun, and hydroelectric power stations. In 2016, this indicator was 29%.

Renewable energy sources and their integration into the existing system remain a serious problem for Germany's energy policy, therefore the expansion of power grids and the development of appropriate storage facilities are the basis for the successful integration of renewable energy sources.

For a more balanced value of the energy trilemma index, the priority is to ensure energy security and environmental sustainability, which should be considered as electricity generation based on the use of renewable energy sources. Thus, according to the estimates of the World Bank and the data of the Organization for Economic Cooperation and Development (OECD), there are countries that have high indicators for the production and consumption of renewable energy sources.

For many countries, such as the USA, China, Brazil, Canada, Germany, energy conversion based on renewable energy sources is an important component of energy supply. Undoubtedly, the attractiveness of renewable energy sources is evident primarily due to their inexhaustibility, environmental friendliness, and independence from the price situation on world markets of traditional energy sources.

In addition, the UN Environment Program notes that alternative energy sources have provided 60% of the increase in energy potential in Europe and more than half in the USA. Global investment in renewable energy reached $279.8 billion in 2017, up 2% from 2016, even as wind and solar spending declined.

Investments in renewable energy in developed countries decreased by 19% in 2017, we note that investments decreased not only in the two leading countries - the USA and Japan, but also in the leading European countries - Germany and Great Britain. Thus, according to the German Association of Energy and Water Management, Germany plans to build and commission 76 power plants with a total capacity of 38,000 MW by 2020. In addition, in September 2017, the government of the coastal federal states, business associations and trade unions appealed to the government of the Federal Republic of Germany to allow the installation of wind turbines with a total capacity of 20 GW in the territorial waters of the country by 2030, with a further increase of the limit by 2035 by 30 GW.

According to a report by the Institute for Energy Economics and Financial Analysis, China is on track to become a leading international investor in renewable energy sources, which is why it has increasingly invested in "green" projects in other countries in recent years.

China has spent almost 45 billion US dollars on clean energy. Only solar panels were exported by China for 8 billion US dollars, which significantly exceeds the indicators of Germany and the United States of America (Chmeruk, 2018). Also, China plans to invest 361 billion US dollars in renewable energy sources by 2020. As part of this plan, it is expected to create 13 million jobs in the energy sector and increase the share of renewable sources in the total amount of electricity production to 15%, which is equivalent to 580 million tons of coal.

Also, a significant increase in investments in renewable energy sources provided developing countries, namely Mexico, Egypt, the United Arab Emirates and Argentina, with significant positive positions ("Renewables 2018 Global Status Report", 2018).

It is assumed that renewable energy in the UAE is a real opportunity to ensure the energy independence of the state. So, in 2015, construction of a solar power plant began in Dubai. The availability of such a large project, according to experts, will attract the attention of investors from around the world to national alternative energy in the UAE.

In addition, by 2030, 5% of all energy in the United Arab Emirates will come from solar panels. Today, the state finances large-scale projects from alternative energy sources around the world, actively lends to the construction and construction of renewable energy facilities in Iran, Mauritania, Argentina, Cuba and the Saint Vincent Islands (Chmeruk, 2018).

According to the results of 2017, global investments in the production of renewable energy, not including hydroelectric power plants, amounted to 279.8 billion US dollars. At the same time, the share of the total amount of investments in the development of solar energy amounted to 57%, about 160.8 billion dollars. USA, and increased by 18% compared to 2016.

This figure exceeds the amount of investments in gas and coal-fired power plants by about 103 billion US dollars. More than half of all solar power installations are in China. Also active countries that use solar batteries are Australia, Mexico and Sweden (UNEP, 2018).

UNEP experts in the report "Global trends of investment in renewable energy", which was prepared by the United Nations Environment Program, report a reduction in investment in renewable energy sources.

For example, in the USA, investments decreased by six percent - to 40.5 billion USD in 2017. At the same time, a slight decrease in investments in renewable energy sources was noted in the European markets. But, despite these facts, UNEP experts still point to the positive growth dynamics of investments in renewable energy sources in the medium term.

Thus, in the period from 2007 to 2017, projects from renewable energy sources on average constantly grew at a positive rate, which ensured an increase from 5.2% to 12.1% of the share of electricity produced using wind energy, solar batteries, waste , geothermal sources, sea waves and small water bodies.

As for the structure of investments, in 2017 in Europe, 73.4% of investments in the electric power industry were in renewable energy sources. Renewable energy is also projected to attract $7.8 trillion in investment by 2040. In Europe, renewable energy will cover 70% of needs by 2040, in the USA - 44% ("Global trends in renewable energy investment", 2018).

The use and distribution of renewable energy sources in the smart grid system has already provided about 6% of new electricity connections worldwide between 2012 and 2016.

In the developed countries of the world, Smart grid technologies play a key role in meeting the energy needs and ensuring the livelihood of millions of people living in rural and remote areas.

CHAPTER 2
MODERN CONFIGURATIONS OF CIRCUIT SOLUTIONS OF DISTRIBUTED GENERATION SOURCES IN THE ASPECT OF INTELLECTUALIZATION

2.1 General information on the features of connecting sources of distributed generation

The concretization of the concept of SmartGrid in relation to electric power systems of different technical levels initiated the appearance of such terms as StrongSmartGrid (SSG) – voltage networks above 110 kV, RegionalSmartGrid (RSG) – voltage from 3 to 110 kV, and MicroSmartGrid (MSG) – voltage 0.4 –3 kV, characteristic directly of the systems themselves and arising when they are combined, which determines the peculiarities of the construction of the equipment in the nodes of their connection and in the nodes of connection of loads. The practical solution of the listed tasks can be carried out on the basis of the use of power electronics and, in particular, on the basis of the wide implementation of converters of electrical energy parameters. Power electronics are organic elements of the considered systems, without which there is no need to talk about any construction and Smart Grid [18].

The choice of the type and structure of semiconductor converters, proposed for use in connecting different systems, should be carried out taking into account the nature of the change in the parameters of electrical energy, characteristic of one or another system. The main features of the SSG, RSG and MSG systems are the significant difference in the change of their electrical energy parameters over time. Relatively high stability of energy parameters is characteristic of SSG systems [18].

In RSG systems, there is some, and sometimes significant, but, as a rule, does not go beyond certain limits, change in energy parameters, caused by the type of connected loads and the power of transformer substations.

Among the main issues of the development of the Smart Grid concept in Ukraine [18], among others, it is possible to single out the definition of the main directions of development of generation, transmission and distribution, sales, consumption and innovative development of the Ukrainian electric power industry.

Meanwhile, among others, the directions of development of intelligent power grids of UES of Ukraine can be attributed [18]:

– Transition to distributed generation.

– Transition from rigid dispatch planning and regulation to the organization of coordinated work of all network objects.

– Introduction of new technologies and power devices that ensure maneuverability and control of the unified energy system (UES) and its facilities.

Problematic aspects of the introduction of renewable energy sources in the UES of Ukraine [18]:

– imperfection of the legislative framework of Ukraine;

– inadequacy of the regulatory and technical base and state standards regarding the design and connection of power plants operating on renewable energy sources (RES) to the electrical networks of the UES of Ukraine;

– extremely high tariffs for electricity produced by renewable energy power plants;

– the necessity of mandatory inclusion in the daily dispatch schedule of the power loads of power plants operating on RES.

Problematic aspects of the introduction of renewable energy sources in the UES of Ukraine:

– a rapid and uncontrolled process of increasing the capacities of power plants that use RES;

– the need to apply additional measures for reactive power compensation and voltage regulation.

The following facts are known from the experience of European countries [18]: a system accident in 2006, the cause of which was the presence of power flows from energy regions in which a significant number of RES-based power plants are installed; the need to maintain appropriate power reserves in case of a change in the capacity of power plants operating on RES; implementation of modern complexes for forecasting the operation of RES power plants, implementation of SMART GRID.

Currently, the issues of the implementation of SDGs are relevant, due to the fact that they use natural gas or RES and the increased efficiency [39-47, 49, 50, 57, 60, 80-85].

All this led to the rapid growth and development of small energy, which is based on the distribution of low-power electric generators in modern energy supply systems for energy consumers. Given the advantages of SDG compared to traditional power plants, its further development should be expected in Ukraine as well, since the important arguments presented are decisive in the modern field of energy supply [18].

In the practice of most countries of the world, it is customary to use the following definition: "Small installation for energy production" is an installation that uses biomass, secondary or renewable resources, including wind, solar and water resources, for the production of electricity with an installed capacity of no more than 80 MW [8].

Non-traditional and renewable energy sources include energy-generating installations that use the energy resources of rivers, reservoirs and industrial waste, wind energy, solar energy, compressed natural gas, biomass (including wood waste), sewage and solid household waste. Small energy sources include generating units in which energy conversion is carried out through fuel combustion processes, or without the use of combustion processes, in which energy production is based on the use of renewable energy sources. The latter are often called sources of "cold energy" or "green energy". In recent years, sources of small energy are classified as distributed generation [39-47, 49, 50, 57, 60, 80-85].

The combination of high efficiency of distributed generation and the use of cleaner types of fuel allows to greatly reduce the burden on the environment created by centralized energy systems.

Research by the Rocky Mountain Institute (USA) showed that placing small generators closer to consumers, as well as matching their capacities to consumer needs, has significant advantages over giant power plants, significantly increasing the value of these generators for the power system as a whole [39-47, 49, 50, 57, 60, 80-85].

Energy experts have come to the conclusion that if electricity supply companies do not take the initiative in promoting the development of DRG, then buyers supported by investors will. In the near future, the growth of small power generation will largely depend on the direction of restructuring of the power industry, the pace of closure of nuclear and coal power plants as a result of the requirements of new environmental standards [11].

The indicator of the present value of energy, or LCOE (English Levelized Cost of Energy) is calculated on the basis of market data and reflects the current cost of all costs for the production of one unit of energy. LCOE combines all types of costs and allows you to simplify the analysis of the cost of energy. It is used for primary comparison of the cost of energy produced with the help of different technologies [153]. In Ukraine, the generation of electricity from renewable energy sources enjoys state support in the form of "green" tariffs [39-47, 49, 50, 57, 60, 80-85].

From July 1, 2019, in accordance with the law "On the electric energy market", a new model of the electricity market came into operation in Ukraine. The basis of this model is competition and market tariff formation. It is expected that market indicators will reflect the fair value of electricity, which will be a signal for potential investors in the Ukrainian energy sector, including the RES sector [39-47, 49, 50, 57, 60, 80-85].

According to the analytical review "LCOE of renewable energy sources in Ukraine", LCOE calculations for RES in Ukraine for 2013-2019 showed that the Ukrainian market follows global trends. For all main RES technologies, the reduced cost of electricity decreased during the specified period [116].

Small-capacity wind farms, built 15-20 years ago and consisting of wind-electric installations with a unit capacity of 100 to 250 kW, were operated on working generator voltages. The figures show options for radial schemes of wind farms based on wind power plants with different types of electric generators [39-47, 49, 50, 57, 60, 80-85].

2.2 Aspects of the implementation of intelligent technologies in the energy industry

The development of the latest energy technologies significantly affects the strategic priorities of energy development. Separate technologies, at the same time, lead to changes in the conditions and principles of functioning not only of individual energy systems, but also of socio-cultural aspects of energy consumption.

Automation of technological processes, development of smart networks (Smart-Grids), artificial intelligence (Artificial intelligence) and innovative digital business platforms will allow effective management of energy supply and consumption modes. New technological solutions - a wide variety of generating capacities (for example, renewable energy sources or energy storage), energy-consuming installations (for example, household appliances, electric cars, etc.) will allow to balance the demand and supply of energy. Moreover, the use of artificial intelligence (AI) technologies becomes not only a way to reveal new opportunities in the organization of the energy supply process for consumers' needs, but also an effective tool for ensuring sustainable development and operational security of energy supply systems. On the other hand, the use of AI technologies, which contribute to the decentralization of the energy supply system and increase the flexibility of responding to the needs of consumers, significantly affects the functioning of existing centralized energy supply systems. This circumstance is a serious challenge and will require strategic decisions regarding the country's energy development priorities.

The aggression of the russian federation against Ukraine, which began on February 24, 2022, destroyed the planned process of gradual modernization of the country's energy assets. However, overcoming the consequences of an armed invasion can become a factor in the transformation of the country's entire energy sector. Ukraine, in the process of post-war recovery, should use the chance to rebuild the energy infrastructure immediately on the latest technological base, already adapted for the widespread use of AI.

In recent years, the pace of digitization of society's vital activities has significantly accelerated. Digital models, platforms, information processing algorithms have penetrated all spheres of economy and management. Thanks to innovative technologies and access to new types of data, new business processes and services appear on the market, costs are reduced and barriers for new participants to enter the market are reduced, the level of awareness of participants regarding the development of the situation and the price parameters of the necessary services is increasing.

Unlike traditional models of physical production of goods, digital business models are controlled by software and allow business entities to open new opportunities in promoting their products and increasing the efficiency of their activities.

Modern digital solutions, access to detailed and diverse data, combined with advanced capabilities for their analysis and processing, allow high-tech companies to provide customers with a new level of service, develop new functional capabilities of products, and create additional value for their services that were previously unavailable.

Digitization in the energy sector follows the general trends of technological development. The pace of penetration of digital technologies has significantly accelerated in recent years, which contributes to the emergence of new models of relationships in energy markets, the transformation of many traditional business models and the emergence of fundamentally new types of businesses in the field of providing energy and service needs of consumers.

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For energy market participants, digital tools and platforms provide more effective integration of various energy sources and types of consumers, contributing to better satisfaction of consumer needs and reliability of energy supply systems. At the same time, digitalization is creating new business opportunities and revenue streams for energy service providers, while helping consumers better understand their energy use and reduce their bills.

At the same time, the use of modern capabilities of various digital platforms for information processing is a kind of technological transition to a new quality of life in society. In general, this quality is associated with penetration to the level of practical application of artificial intelligence technologies.

Artificial intelligence (AI) is a relatively new technology of wide application of digital technologies, in particular, algorithms for processing large data sets to improve the processes of ensuring various aspects of the life of societies. Therefore, the application of this technology is still not standardized, moreover, there is still no clear definition of the term "artificial intelligence", the study of the possibilities of its application in various fields is ongoing.

For our research, we will analyze only the basic principles of the application of this new phenomenon of human life, first of all, considering its potential application in the field of energy.

The definition of AI in the legislation of Ukraine is contained, in particular, in the approved Concept of the Development of Artificial Intelligence in Ukraine (December 2020), where AI is: "an organized set of information technologies, with the use of which it is possible to perform complex complex tasks by using a system of scientific research methods and processing algorithms information obtained or independently created during work, as well as create and use own knowledge bases, decision-making models, algorithms for working with information and determine ways to achieve set tasks».

The European Commission in its proposals on the priority areas of AI development gives the following interpretation: "AI refers to systems that demonstrate intelligent behavior by analyzing the environment and performing actions - with a certain degree of autonomy - to achieve specific goals. AI-based systems can be purely software, operating in a virtual world (e.g. voice assistants, image analysis software, search engines, speech and facial recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications).

One of the most systematic definitions of AI is proposed in the analysis of the application of AI conducted by the OSCE: "An artificial intelligence system is a system that can, for a certain set of human-defined goals, make predictions, recommendations or decisions that affect the real or virtual environment».

These definitions allow us to understand the complex of opportunities and problems that arise in connection with the use of AI. Although the possible areas and methods of application of this technology can be very diverse, they can still be classified to simplify further analysis of the possibility of applying AI in practice.

In the application of AI, a number of usage options (templates) with different tasks can be distinguished, which can coexist in parallel within the framework of one AI system, namely:

Personalization is the algorithms of creating a "customer profile" (target characteristics), which can then be used to target the client's needs according to his needs (defined characteristics). The result, for example, in the field of selling goods/services, is usually a rating, based on which recommendation systems are developed for viewing information, choosing a product when purchasing, performing financial transactions, performing a personalized set of physical exercises, etc.

Interaction and communication are algorithms for ensuring interaction and exchange of information between machines and people using various methods, including voice, text, video or graphic forms. The results come in the form of chatbots, voice assistants, sentiment and intent analysis models etc.

Pattern and anomaly detection are algorithms for identifying patterns in data and comparing them to known patterns to assess whether they fit an existing pattern or whether deviations or anomalies are observed. Machine learning is used to identify such data sets. It is used, for example, to detect fraud, human errors, etc.

Recognition is algorithms that use machine learning and other cognitive approaches to detect and identify the required object or data (information) in the form of an image, video, audio, text or other unstructured data format, followed by classification of such data.

Achieving goals are algorithms focused on achieving goals through the use of machine learning and other cognitive approaches of computer systems. Such algorithms provide an opportunity to find an optimal solution to a problem, which can be achieved through an iterative process of trial and error learning. It is assumed that the cost function for which the decision is evaluated is given for the algorithm. Implemented in games, resource/logistics optimization tasks, iterative problem solving, real-time bidding and auctions, scenario modeling.

Forecasting and decision support are information processing algorithms that include descriptive analytics, predictive and projective analytics, predicting future values for data, predicting population behavior, determining and choosing the best approach, optimizing operations, etc. Forecasting typically uses data about past and existing behaviors to predict future outcomes, usually to help a person make decisions.

The above usage options can be applied separately or combined to solve individual tasks in automated AI systems.

Autonomous systems are physical and virtual software and hardware systems that are able to perform tasks, interact with the environment and achieve a goal with varying degrees of human participation. In particular, there is a distinction between augmented intelligence, where the joint work of people and machines is realized and a person is included in the decision-making cycle, and autonomous intelligence, where a person is not included in the cycle of the information processing and decision-making system. In general, there are four variations of the degree of autonomy of the AI system:

– Lack of autonomy (also known as "human support"): the system cannot act on its own recommendations or results of information processing. The human makes decisions, while using or ignoring the recommendations or results of the AI system at will;

– Low-level autonomy (known as "human-in-the-loop"): the system evaluates the input and acts on its recommendations or results if the human agrees;

– Mid-level autonomy (known as "human-on-the-loop"): the system evaluates the input and acts on its recommendations or results unless a human vetoes it;

– High-level autonomy (known as "human-out-of-the-loop"): the system evaluates input data and acts on its recommendations or results without human intervention.

For the adequate and effective operation of AI systems, significant amounts of information classified in a convenient, usable form are required. Relevant databases (Big data) are formed in various ways by both machines and people and are divided into:

– databases collected by people - are formed when a person needs to observe and collect information that requires subjective evaluation, in particular, when the object of research is not described by formalized models (for example, the mental state of a person) or when there is partial formalization, but certain the stages of the computational process are performed by humans;

– databases collected by automated sensors, devices that automatically monitor and record data, including cameras, microphones, thermometers, laboratory instruments and other sensors, such as Internet of Things (IoT) devices, and perform automatic recording information from online resources, mobile phones, GPS devices, activity bracelets, etc;

– databases collected by humans and automated sensors - some data is collected by humans together with automated tools.

It should be noted that the collection of large volumes of information and its processing by AI raises concerns about the human right to privacy and the adequate formation of dependencies between different data in order to avoid the inclusion of subjective preferences of algorithm authors (biases) in calculation algorithms.

In particular, the very application of human recognition systems and their biometric data (recognition of faces, voice, selection of information from various databases, etc.) raises concerns about human rights, as well as reliability and security in the event of cyber attacks and information theft. The same caveats apply to the system for detecting patterns and anomalies in behavior, especially the risks of illegal monitoring of individuals' activities. Personalization can have a positive impact on social structures and well-being, but it can also conflict with human values and the right of individuals to self-determination, as it tends to provide people with information according to a certain algorithm (for example, information that they have liked in the past or that people with a similar profile have liked).

AI systems for interaction support can affect the privacy of data use, which requires greater transparency and disclosure of information processing algorithms when interacting with a chatbot. Goal-oriented systems can learn from themselves through trial and error, but their data needs can grow exponentially. Furthermore, when the target specification is imprecise, these systems may deviate from their intended behavior.

The above AI application templates, methods of obtaining and processing information can be applied in the field of energy as well.

The conducted analysis demonstrates the positive aspects of the use of AI and the factors that significantly inhibit its implementation in the energy sector. In the coming years, however, the inevitable penetration of AI into various aspects of the activities of energy companies is expected. Digitization and the application of AI is a key way and tool to manage large and increasingly complex systems.

AI is a tool for the successful transformation of the energy sector, as it allows the integration of the latest and promising technological innovations in the energy sector and the resulting changes in the organization of the functioning of energy supply systems (decentralization of energy production and distribution and electrification of various technological processes).

Decentralization is driven by the increased deployment of small, geographically distributed generating capacities, such as solar and wind farms, which are connected to the local distribution network. Electrification of transport and buildings (heating and cooling), household consumption, includes a large number of new loads, such as electric transport, heat pumps and electric boilers, household works, etc. All of these new assets on both the supply and demand sides are complicating the energy sector, while making the application of AI for monitoring, management and control critical to the success of the energy transformation.

AI technologies can support the functioning of energy supply systems, taking into account the existing trends of technological development and transformation of energy market organization models in several ways, including better monitoring, operation and maintenance of energy assets; more advanced system operations and real-time control; introduction of new models of energy markets and business models, etc.

Of course, on its own, no single technology is the solution to all problems, but as part of the collective toolkit, AI creates a qualitative technological change that allows us to cope with the challenges of functioning of increasingly complex energy systems.

Implementation of the energy transition, expanding the use of RES, increasing the flexibility of energy systems and energy demand requires significant investments in the modernization of the energy infrastructure. Business models based on the use of digital technologies enable this modernization in cheaper and more efficient ways.

The growing interest of venture capital investors and large corporations in digital energy startups indicates high expectations for growth in this sector.

2.3 Introduction of distributed electricity sources during their implementation in the airfields and airports conditions

The importance of air transport in the world economy is constantly growing, which contributes to both technological development and the latest developments in the aviation industry, as well as globalization and ever closer business and cultural ties between different countries [100].

Air transport has a positive impact on the development of tourism business and international trade. Today, more than 52% of international tourist travel is carried out by air. The developed aviation industry contributes to increasing the investment attractiveness of the country and expanding opportunities for international companies to operate in its territory. Air transport also provides extremely fast delivery of valuable and perishable goods to the destination, which leads to its widespread use by large leading international logistics companies [20, 30].

Due to the relatively small capacity of dispersed power sources, they cannot fully meet the energy needs of powerful aerodrome facilities and airports. Its role is to complement centralized energy, using mainly local energy resources of regions, airfields and airports that may have a different set of small energy sources [40-60].

Cost-effective and more attractive is the option of decentralized power supply to airfields and airports from its own autonomous energy source (AES) with high efficiency and maneuverability. Such a source will provide adjacent enterprises with heat and electricity, the cost of production of which will be lower than the price of the power system, and increase energy security due to the possibility of mine operation even in case of force majeure in the power system. But each such option requires a detailed feasibility study and choice of type and capacity of AES.

Ukraine has powerful wind energy resources: the annual technical wind energy potential is 30 billion kWh. Operation of low-speed multi-bladed wind turbines, with increased torque, are effective, practically, on the whole territory of Ukraine [50].

Average wind speeds of 3–4 m / s are observed in the central parts of the forest-steppe and steppe zone, Chernihiv Polissya, the northern part of the Poltava-Romen forest-steppe region of the Dnieper lowland and the foothills of the Crimean mountains. In Ukraine there is no wind speed less than 3 m / s. In spring, average wind speeds of 4–5 m / s prevail in most parts of Ukraine, and 3–4 m / s in summer. In autumn, wind speeds in the range of 3–4 m / s are observed in almost the entire forest-steppe zone. The steppe zone is characterized by wind speeds of 4–5 m / s.

As you know, a common feature of the relief of Ukraine is the alternation of hills and lowlands. The vast majority of orographic formations in Ukraine (Volyn, Podil, Prydniprovska and Donetsk uplands, Prydniprovska lowland and Ukrainian Carpathians) are oriented from northwest to southeast according to the direction of the main geostructural elements.

The construction of wind farms should be in these regions, given the significant shortage of its own generating capacity. Preference should be given to the construction of wind farms in the adjacent water areas, which have a particularly high wind energy potential.

The availability of solar energy resources for practical use is determined by the following indicators: a) the amount of solar radiation that reaches the surface of various types of solar energy equipment; b) technical parameters of solar systems that convert the energy of sunlight into electrical and thermal. Based on this, for the needs of solar energy, cartographic atlases of solar energy resources have been developed, which reflect the technical energy potential (values of energy production by different types of solar systems).

Namely, the objects of airfields and airports, which are in Ukraine hundreds of hectares, for all its parameters can and should become a landfill for AES complexes, which in fact should become mini- or micro power plants in the structure of power supply systems of airfields and airports of Ukraine [20].

The proposed scheme of power supply of aerodromes and airports using a neurocontroller includes a sensor unit, a switch, a neurocontroller and two sources of electricity (network and autonomous alternative energy source).

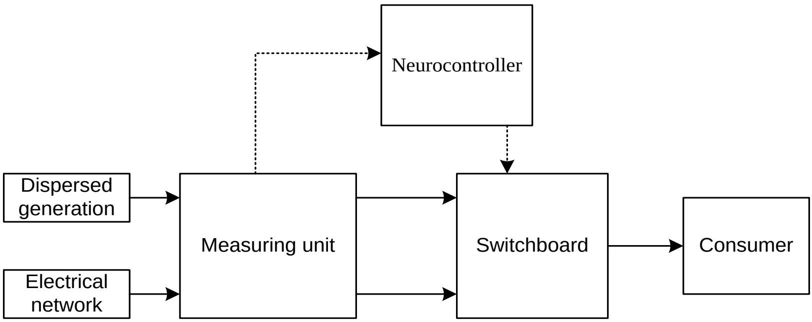


Figure 2.1 – Block diagram of the power supply system using a neurocontroller

The sensor unit determines the voltage, frequency and current directly in the power supply networks independently of each other, and transmits data to the neurocontroller.

The neurocontroller analyzes the energy parameters received from the sensor unit and sends a control signal to the switch.

The switch is multi-position and depending on the control signal from the neurocontroller has the ability to connect the consumer to one of the power sources, disconnect the consumer from the power source and perform the function of automatic switching on the reserve.

The advantage of the neurocontroller is that it can simultaneously receive signals from all sensors of the measuring unit and simultaneously analyze them in real time, because when implementing this scheme by conventional controllers, simultaneously analyze signals from sensors of the measuring unit in real time is not possible.

Thus, it is relevant and appropriate to introduce dispersed sources of electricity in their implementation in airfields and airports.

2.4 An approach to the reconfiguration of the airfield power supply system using distributed energy sources

The experience of hostilities on the territory of Ukraine shows that state and civil aviation needs a wide network of modern airfields. Civil small aviation is also promising as a business project. All these factors contribute to drawing attention to the network of airfields. One of the significant issues in this aspect is the power supply of airfields, which are located, sometimes, far from centralized power generation systems, or, taking into account the conditions of operation and location, need additional sources of power supply [1-20].

Analysis of the achievements of modern energy shows that decentralized energy systems using sources of distributed generation can be an extremely profitable area for capital investments, if it is possible to place sources of energy generation near consumers. Usually, energy transmission costs reach 30% of the cost of its production [1].

Existing methods for designing the power supply system for remote consumers are mainly considered as an alternative to centralized power supply, power supply due to electricity generation based on renewable energy sources (RES), or due to the use of boiler houses, diesel generators.

Meanwhile, developing the potential of RES is a technically difficult task at present, which is associated with the low density of energy flow from RES and their dependence on natural conditions. The cost of obtaining energy, although it decreases annually, remains much higher than that of traditional energy resources, and the necessary radical technical solutions do not yet exist.

The technological combination of RES energy and hydrocarbon fuel energy in one system has significant technical and economic advantages. This advantage lies in high energy efficiency, unattainable in existing energy supply systems, in the ease of integration with additional generating capacities based on RTE with any degree of substitution.

Combining the sources of distributed generation (SDG) and the network for parallel operation will give a synergistic effect - the appearance of new properties that were not present in the component parts, which is manifested, in particular, in the reduction of the irregularity of the total load schedule of the combined systems, the reduction of its unevenness in the daily , weekly and seasonal sections, reducing the dependence of the electric current frequency on power balance fluctuations [2].

In previous studies, the authors justify the positive effect of the introduction of SDG in the conditions of airfields, namely modularity, reliability, local management, reduction of negative impact on the environment and short start-up period [3, 4].

Thus, an urgent scientific and practical task is the development of a method for determining the potential of distributed energy sources in the conditions of airfields, taking into account the specifics of their functioning.

Energy of airfields includes processes: production, conversion, transportation, distribution, energy consumption, maintenance of these processes and development of control objects. Management of the specified processes is carried out by implementing a set of functions of collecting, transforming and transmitting primary information; forecasting the states of energy facilities (EF); development of management decisions; formation and transmission of control influences on the control object, which form control contours. But it constantly needs improvement.

The airfield electricity consumption control subsystem is not the largest, but is directly related to the operation of aircraft, on which the effective functioning of the airfield as a whole and the safety of aircraft operation largely depend. Therefore, special attention is paid to these objects during the development of an automatic power supply control system, since the purpose of this subsystem is primarily reliable and economical power supply of airfields [5, 6].

The paper proposes an approach to the construction of systems for automated control of airfield electricity consumption, which is based on the integration of distributed generation into the power supply system, in the form of a set of interdependent structures. As a result, it is necessary and relevant to use the latest technologies for switching electrical networks with the possibility of forecasting their energy parameters [20-30].

When integrating SDG with the network, it is necessary to solve issues related to the stable operation of the station, which excludes generator overload, under the condition of operational reliability. All this requires the creation of mechanical and electrical devices for automatic adjustment of the SDG. Therefore, it is proposed to connect the network to the consumer through an automated distribution device designed to regulate the consumer's power supply in automatic mode. Thus, under the condition of sufficient power supply to the consumer from SDG, the power system works in autonomous mode. In the event of an emergency or SDG failure, the automatic distribution device automatically connects the consumer to the network. In the case when, for a number of reasons, there is insufficient generation of SDG electric energy, the automatic distribution device automatically connects the network to the consumer's power supply system as an additional source of electric energy. Thus, the network is an additional source of electrical energy [19].

Such a regulation system increases the reliability of the consumer's electricity supply and the modularity of the system as a whole. Since, as necessary, the number of batteries is regulated.

To determine the potential of renewable energy sources (RES), which are part of the SDG in the conditions of airfields, it is necessary to have as complete and clear data as possible on the electricity supply (ES) and the electricity consumption of the load (EC) by the electrical equipment (EQ) of the airfields during the day, as well as the availability of data about the consumption of electrical energy (EE) in the electrical network (EN) ES and EC [30-40].

Having calculated EE costs in EN before using RES, which are part of SDG in the conditions of airfields and EE costs in EN after the introduction of RES, which are part of SDG in airfield conditions and comparing them, then when the inequality (yes) is fulfilled, proceed to the next stage, and if it is not performed (no), then they return to the beginning of the EN cost analysis.

They analyze in detail the parameters of various types of RES, their EE generation modes, the cost of operating equipment, the possible cost of placement, selected types of SDG, in the conditions of airfields, as well as possible payback periods, in the conditions of airfields, that is, they calculate the optimal payback period and the payback period is estimated. If the inequality is fulfilled (yes), then proceed to the analysis of the level of influence of the selected types of SDG for implementation in the conditions of airfields, on the ecology of the surrounding environment and the production process [112].

Thus, in the conditions of airfields, it is relevant and possible to introduce decentralized power supply systems based on renewable energy sources into the general structure. The proposed approach will make it possible to effectively introduce distributed generation into the power supply structures of airfields.

CHAPTER 3
MATHEMATICAL METHODS AND MODELS OF FORECASTING AND STATISTICS IN THE CONTEXT OF RESEARCH INTO THE MODES OF OPERATION OF DISTRIBUTED GENERATION SOURCES

3.1 Predictive models in the context of studies of sources of distributed generation

The terms "forecast" and "prediction" refer to future (unknown) events. Interest in the future arises from the practical need of the present. There are phenomena whose future we do not know, but they are important for the decisions we make in the present. Therefore, there is a need to predict these phenomena.

During the functioning of the object, certain events occur, the object assumes various states that significantly affect its use by a person, the functions it performs. These are primarily operational and non-operational states, failure and recovery events [40-50].

Today, forecasting is included in almost all fields of science and economic activity, because the development of the economy determines the growth rates of other elements of the social system. At the same time, the technical and economic component is one of the most important and difficult areas of the forecast.

The study is devoted to the theoretical and practical issues of forecasting the "electricity supply – electricity consumption – production" system, which is currently relevant and requires a solution. Currently, there is a certain range of research, but they are of a disparate nature, therefore there is a need for the formation of a systemic approach in the study of the "electricity supply - electricity consumption – production" system.

The state of any object can be described by a set, a set of variable states.

$x = \{x_1, x_2, x_3, ..., x_n\}$, which can acquire certain values and change over time $x_i(t)$. Proper performance of its functions by the object is possible under the condition that all variable states describing it acquire values that lie in a certain (allowable) area. In electrical engineering, variable states are usually called mode parameters or mode parameters. The border of this area can change over time and is described by the equation

$$D_0(x, t) = 0. \qquad (3.1)$$

If the value of the state variables of the object in this field, ie. it is ensured that it can perform its functions, that is, that the object is in a working condition; if outside the permissible area, then in the disabled.

Fig. 3.1 shows the change over time of one of the main state variables of the electric generator - voltage. The range of permissible values of this state variable is given here. It can be seen that by the moment t_0 the voltage value was in the permissible range. The generator was in working condition. After the moment t_0, the voltage value exceeded the limit of permissible values and the generator was in an inoperable state.

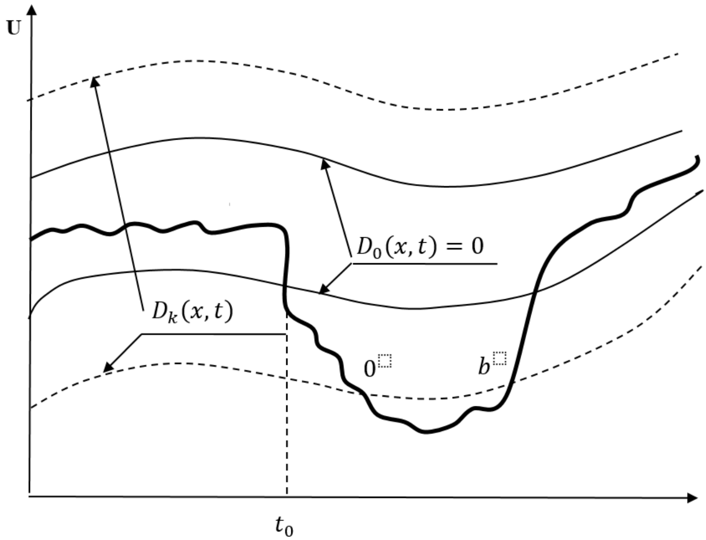


Figure 3.1 – Grafic variables of the electric generator - voltage

In some cases, we can talk about a partially functional state, when the object can perform its functions not completely, but partially. For example, fig. 3.1 with dashed lines shows the limits of the permissible area $D_k(x,t) = 0$ of generator operation, but with reduced voltage quality (usually for a limited time interval). When the voltage drops below this limit, the generator is turned off. Thus, the problem of forecasting the uninterrupted operation of the equipment arises.

The development of modeling, analysis, planning and forecasting in modern conditions is associated with a consistent increase in the level of their formalization. The basis for this process was laid, in particular, by progress in the field of applied mathematics, mathematical statistics, optimization methods, approximation theory, econometrics, prognostics etc..

Two types of data are used when building a simulation:

1) data characterizing a set of various objects at a certain point in time;

2) data characterizing one object over a series of consecutive moments of time.

Models built on data of the first type are called spatial models. Models built taking into account the second type of data are called time series models.

A time series (series of dynamics) is a set of values of any indicator for several consecutive moments or periods of time. Each level of the time series is formed under the influence of a large number of factors, which can be conditionally divided into three groups:

1) factors forming the trend of the series;
2) factors forming cyclic fluctuations of the string;
3) accidental factors.

Let's consider the influence of each factor on the time series separately.

Series in which the levels fluctuate around a constant mean are called stationary. Series characterizing technical systems are usually non-stationary. Most of them are characterized by a systematic change in levels with irregular fluctuations, when peaks and valleys alternate with different intensities. For example, cycles are repeated with different durations and different amplitudes of oscillations.

Most of the time series of the corresponding indicators have a trend that characterizes the cumulative long-term influence of many factors on the dynamics of the studied indicator. All these factors, taken separately, can have a multidirectional impact on the studied indicator. However, collectively they form its rising or falling trend. In fig. 3.2 shows a hypothetical time series containing an increasing trend.

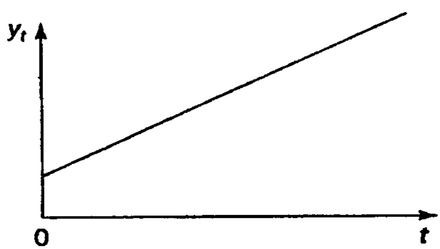


Figure 3.2 – Time series containing an increasing trend

Also, the studied indicator may be subject to cyclical fluctuations. These fluctuations may be seasonal in nature, as activity related to the operation of electrical equipment depends on the time of year. In the presence of large arrays of data over long periods of time, cyclical fluctuations associated with the general dynamics can be detected. Fig. 3.3 presents a hypothetical time series containing only a seasonal component.

Figure 3.3 – Time series containing a seasonal component

Some time series do not contain a trend and a cyclical component, and each subsequent level of them is formed as a sum of the average level of the series and some (positive or negative) random component. An example of a series containing only a random component is shown in Fig. 3.4.

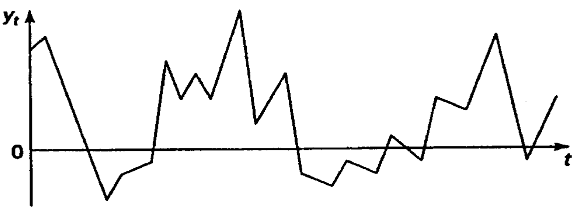


Figure 3.4 – Time series containing a random component

It is obvious that the real data do not follow completely and completely from the models described above. Most often, they contain all three components. Each of their levels is formed under the influence of a trend, seasonal fluctuations and a random component.

Most often, the actual level of the time series can be the sum or product of trend, cyclic and random components. The model in which the time series is represented as the sum of the listed components is called the additive model of the time series. The model in which the time series is represented as a product of the listed components is called a multiplicative time series model. The main task of the study of a separate time series is to identify and provide a quantitative expression of each of the above components in order to use the obtained information to forecast future values of the series or when building models of the relationship of two or more time series.

If there are trends and cyclical fluctuations in the time series, the values of each subsequent level of the series depend on the previous ones. The correlation dependence between successive levels of a time series is called autocorrelation of the levels of the series.

It can be quantitatively measured using the linear correlation coefficient between the levels of the original time series and the levels of this series shifted by several time steps.

The formula for calculating the autocorrelation coefficient looks like this

$$r_1 = \frac{\sum_{t=2}^{n}(y_t-\bar{y}_1)(y_{t-1}-\bar{y}_2)}{\sqrt{\sum_{t=2}^{n}(y_t-\bar{y}_1)^2 \sum_{t=2}^{n}(y_{t-1}-\bar{y}_2)^2}}, \quad (3.2)$$

where

$$\bar{y}_1 = \frac{1}{n-1}\sum_{t=2}^{n} y_t \, , \bar{y}_2 = \frac{1}{n-1}\sum_{t=2}^{n} y_{t-1}. \quad (3.3)$$

This value is called the autocorrelation coefficient of the first-order levels of the series, because it measures the dependence between adjacent levels of the series.

Similarly, the autocorrelation coefficients of the second and higher orders can be determined. Thus, the second-order autocorrelation coefficient characterizes the closeness of the connection between levels and is determined by the formula:

$$r_2 = \frac{\sum_{t=3}^{n}(y_t-\bar{y}_3)(y_{t-2}-\bar{y}_4)}{\sqrt{\sum_{t=3}^{n}(y_t-\bar{y}_3)^2 \sum_{t=3}^{n}(y_{t-2}-\bar{y}_4)^2}}, \quad (3.4)$$

where

$$\bar{y}_3 = \frac{1}{n-2}\sum_{t=3}^{n} y_t \, , \bar{y}_4 = \frac{1}{n-2}\sum_{t=3}^{n} y_{t-2}. \quad (3.5)$$

The number of periods used to calculate the autocorrelation coefficient is called the lag. As the lag increases, the number of pairs of values used to calculate the autocorrelation coefficient decreases. It is considered expedient to use the rule to ensure the statistical reliability of autocorrelation coefficients - the maximum lag should be no more $n/2$.

Properties of the autocorrelation coefficient.

1. It is constructed by analogy with the linear correlation coefficient and thus characterizes only the closeness of the linear relationship between the current and previous levels of the series. Therefore, based on the

autocorrelation coefficient, it is possible to draw conclusions about the presence of a linear (or close to linear) trend. For some time series with a strong nonlinear trend (for example, a parabola of the second order or an exponential), the autocorrelation coefficient.

2. Based on the sign of the autocorrelation coefficient, it is not possible to draw a conclusion about an increasing or decreasing trend in the levels of the series. Most time series of economic data contain positive autocorrelation levels, but may also have a downward trend.

The sequence of autocorrelation coefficients of the first, second, etc. levels. orders is called the autocorrelation function of the time series. The graph of the dependence of its values on the value of the lag (of the order of the autocorrelation coefficient) is called a correlogram.

The analysis of the autocorrelation function and the correlogram allows you to determine the lag in which the autocorrelation is the highest, therefore, the lag in which the connection between the current and previous levels of the series is the closest, that is, with the help of the analysis of the autocorrelation function and the correlogram, you can reveal the structure of the series.

If the autocorrelation coefficient of the first order turned out to be the highest, the studied series contains only a trend. If the autocorrelation coefficient of the order turned out to be the highest, then the series contains cyclic fluctuations with periodicity of time moments. If none of the autocorrelation coefficients is significant, one of two assumptions can be made about the structure of this series: either the series does not contain a trend and cyclical fluctuations, or it contains a strong non-linear trend that requires additional analysis. Therefore, it is advisable to use the autocorrelation coefficient of levels and the autocorrelation function to detect the presence or absence of a trend component and a cyclical (seasonal) component in a time series.

A common method of modeling the trend of a time series is the construction of an analytical function that characterizes the dependence of levels on time, or the trend. This method is called analytical time series alignment.

Since the dependence on time can take different forms, different types of functions can be used to formalize it. The following functions are most often used to build trends:

Linear trend:

$$\hat{y}_t = a + b \cdot t; \tag{3.6}$$

hyperbola:

$$\hat{y}_t = a + \frac{b}{t}; \quad (3.7)$$

exponential trend:

$$\hat{y}_t = e^{a+bt} \text{ (або } \hat{y}_t = a \cdot b^t\text{)}; \quad (3.8)$$

power function:

$$\hat{y}_t = a \cdot t^b; \quad (3.9)$$

polynomials of different degrees:

$$\hat{y}_t = a + b_1 \cdot t + b_2 \cdot t^2 + \ldots + b_m \cdot t^m. \quad (3.10)$$

The parameters of each of the trends listed above can be determined by the usual method of least squares, using time t=1,2,...,n as the independent variable, and the actual levels of the time series $\hat{y}_t$ and $\hat{y}_{t-1}$ as the dependent variable. For non-linear trends, the standard procedure of their linearization is performed beforehand.

There are several ways to determine the type of trend. The most common methods include qualitative analysis of the researched process, construction and visual analysis of a graph of the dependence of levels on time. Autocorrelation coefficients of the series levels can also be used for these purposes. The type of trend can be determined by comparing the first-order autocorrelation coefficients calculated from the original and transformed levels of the series. If the time series has a linear trend, then its neighboring levels are closely correlated. In this case, the autocorrelation coefficient of the first order of the levels of the original series should be high. If the time series contains a non-linear trend, for example in the form of an exponential, the first-order autocorrelation coefficient based on the logarithms of the levels of the original series will be higher than the corresponding coefficient calculated from the levels of the series. The stronger the non-linear trend in the studied time series, the more the values of the specified coefficients will differ.

The selection of the best equation in the case when the series contains a non-linear trend can be carried out by sorting through the main forms of the trend, calculating for each equation the adjusted coefficient of determination and the average error of approximation. This method is easily implemented during computer data processing.

A fairly common and simple method of analyzing dynamics is series smoothing. Its essence is to replace the actual levels of y with averages at certain intervals. The variation of the averages compared to the variation of the levels of the primary series is much smaller, and therefore the nature of the dynamics is more clearly manifested. The smoothing procedure is called filtering, and the operators with the help of which it is carried out are called filters. In practice, mostly linear filters are used, among which the simplest one is a moving average with a smoothing interval t<n. Intervals are gradually shifted by one element

$$y_1, y_2, \ldots, y_m; \tag{3.11}$$

$$y_2, y_3, \ldots, y_{m+1}; \tag{3.12}$$

$$y_3, y_4, \ldots, y_{m+2} \text{ etc.} \tag{3.13}$$

For each of them, the average $\bar{y}$ is determined, which falls on the middle of the interval. If m is an odd number, i.e. $m = 2p+ 1$, and the weights of the members of the series within the interval are the same

$$a_r = \frac{1}{(2p+1)}, \tag{3.14}$$

where

$$\overline{y_t} = \frac{1}{(2p+1)} \cdot \sum_{t-p}^{t+p} y_t, \tag{3.15}$$

where y_i is the actual value of the level at the i-th moment; and i the ordinal number of the level in the interval.

When t is even, the middle of the interval is between two time points, and then an additional centering procedure is performed (averaging each pair of values).

A moving average with the same weights ar when smoothing a dynamic series cancels out not only random but also periodic fluctuations characteristic of a specific process. Assuming the presence of such fluctuations, a weighted moving average is used, that is, each level within the smoothing interval is given a certain weight. There are different ways of forming the weight function. In some cases, the weights correspond to terms of the binomial expansion $\left(\frac{1}{2}+\frac{1}{2}\right)^{2p}$, with m=3, say $a_r = \frac{1}{4}, \frac{1}{2}, \frac{1}{4}$. In other cases, a certain polynomial is added to the data of the smoothing interval, for example, the parabola $\overline{y_t} = a + b_i + c_i^2$, where $i = -p, \ldots, p$. Then the weight function is as follows for m=5 $a_r = \frac{1}{35}(-3,\ 12,\ 17,\ 12,\ -3)$; for m=7 $a_r = \frac{1}{21}(-2,\ 3,\ 6,\ 7,\ 6,\ 3,\ -2)$ etc.

As can be seen from the formulas, the weights are symmetrical with respect to the center of the smoothing interval, their sum, taking into account the factor taken out in brackets, is equal to $\sum a_r = 1$.

The main advantage of the moving average is the clarity and ease of interpretation of the trend. However, it should not be forgotten that the series of moving averages is shorter than the primary series by 2p levels, and therefore information about the extreme members of the series is lost. And the wider the smoothing interval, the greater the loss, especially of new information. In addition, having a common basis of calculation, moving averages are dependent, which when smoothing significant fluctuations, even in the absence of cycles in the primary series, may indicate the cyclicity of the process (the Slutsky effect).

In symmetric filters, old and new information are balanced, and in forecasting, new information is more important. In this case, asymmetric filters are used. The simplest of them is the moving average, which replaces not the central, but the last member of the series (*adaptive average*):

$$\overline{y_t} = \overline{y_{t-1}} + \frac{y_t - y_{t-m}}{m}. \quad (3.16)$$

In the given formula, the first element characterizes the inertia of development, the second - adapts the average to new conditions. Thus, the average $\overline{y}$ seems to be updated with each step. The degree of renewal is determined by a constant weight – $\frac{1}{m}$.

The use of moving averages in technical analysis in comparison with the traditional approach to their calculation has certain features that must be clearly defined and taken into account when interpreting the obtained results.

In the practice of technical analysis, three main types of moving averages are used - simple, weighted and exponential. The first difference, which applies to all three types, is that the calculated moving averages do not refer to the central point in time (series level) of the averaging period, but to the last one. This is due to the main task of calculating moving averages by stock market analysts with short-term forecasting. The displacement of the obtained moving averages relative to the center of averaging, on the one hand, is a kind of extrapolation of the received trend of the dynamics to the future, and on the other hand, it is a forced technique that allows you to have the necessary calculation levels at the end of the dynamic series for comparing them with the actual dynamics. At the same time, the assumption is made that the observed trend will persist, at least during the studied period. Thus, the moving average not only reproduces the main development trend, but also, to some extent, extrapolates it.

When considering the possibilities of using a moving average to study trends in the securities market, a simplified version of its formula is often used, which does not reflect the calculation technique or algorithm.

The following options for writing the formulas of moving averages of various types, on the one hand, reflect the calculation methodology in a formalized form, and on the other hand, are based on the conventional notations adopted in technical analysis

It should be noted that assigning averages to the end of the averaging period removes the problem of their temporal binding when there is an even number of levels in this period. As you know, in the classic version of the calculation, the average, determined by an even number of levels, is brought to the middle between the two central levels. To attribute it to a specific moment or period, special techniques are used – centering or weighting. When applying the calculated averages to the end of the averaging period, the parity or odd number of averaged levels is no longer significant. Therefore, there is no need for further additional transformations.

One of the significant disadvantages of a simple moving average is that it reacts twice to those levels that are different in size from the others, which can signal a possible trend change. The first time it happens, when such a level, which is significantly distinguished from the general series, falls into the averaging period, and the second time – when this level goes beyond this period. In the first case, the reaction of the moving average is quite justified, since such a level that violates the established trend can really be the beginning of a new emerging trend or a significant correction of an old trend. If this did not happen, and this anomalous level became only a random deviation from the general trend, then the reaction of the moving average to its exit from the averaging period does not give the analyst any useful information, since the trading signal received in this case will always be false. According to the figurative expression of A. Elder, a professional stock trader and the author of a number of books on technical analysis, a simple moving average is similar to a watchdog that barks twice - when someone approaches the house and when they move away from it, and the owner does not know when exactly to react to bark.

The main purpose of weighting levels in the study of the dynamics of complex technical processes and phenomena is to describe the main trend of development, when it is assumed that this trend is non-linear. There is a point of view that the simple moving average method gives good results for dynamic series with a linear development trend. If the trend is non-linear, each so-called active section (corresponding to the averaging period) must be smoothed using a polynomial, the parameters of which are estimated by the method of least squares. If you use the time countdown from the conditional zero and combine the beginning of the countdown each time with the middle of the smoothing interval, the weighted moving average for each time period t will correspond to the parameter a0.

It should be noted that when using a number of dynamics of polynomials of different measures to approximate the obtained weights will always be symmetrical relative to the central level of the averaging period.

It seems to us that the use of such a weighting procedure is not always unconditionally appropriate for a series of dynamics with a non-linear trend.

The quality of the obtained results strongly depends on the degree to which the trend, characteristic of the entire studied series, will be reproduced in each active area. So, if the entire investigated series as a whole is well approximated by a second-order polynomial, then it is quite likely that such a polynomial will be the most optimal function for smoothing each active part of this series. If the general trend of changes in the levels of the series is well described by a polynomial of a higher order, then it does not follow at all that such a polynomial will be an ideal approximating function for every active section. Moreover, if the trend line obtained for the entire time series has several inflection points, then with a high probability it can be stated that the change in levels in each active area will obey different laws. Based on this, we will suggest that weighting using polynomials higher than the 2nd order requires such preliminary analytical work that nullifies the feasibility of further use of such a relatively simple mechanical technique, which is a moving average.

Let's formulate the basic principles of trend analysis using moving averages.

The main task facing the analyst when studying the trend of the "electricity supply – electricity consumption - production" system is to receive signals that indicate moments of correction or changes in the direction of the trend. For this, the line of moving averages obtained in one way or another must be compared with the electricity supply – consumption schedule. As already noted above, the most informative is the schedule for a day.

Seasonal fluctuations are part of the trend. The simplest approach to modeling seasonal fluctuations is to calculate the values of the seasonal component using the moving average method and build an additive or multiplicative model of the time series.

The general appearance of the additive model is as follows:

$$Y = T + S + E. \tag{3.17}$$

This model assumes that each level of a time series can be represented as a sum of trend (T), seasonal (S) and random (E) components.

The general view of the multiplicative model looks like this

$$Y = T \cdot S \cdot E. \tag{3.18}$$

This model assumes that each level of a time series can be represented as a product of (T), seasonal (S) and random (E) components.

The choice of one of the two models forms the basis of the analysis of the structure of seasonal fluctuations. If the amplitude of fluctuations is approximately constant, an additive model of the time series is built, in which the values of the seasonal component are assumed to be constant for different cycles. If the amplitude of seasonal fluctuations increases or decreases, a multiplicative model of the time series is built, which sets the levels depending on the values of the seasonal component.

The construction of additive and multiplicative models is reduced to the calculation of T, S and E values for each level.

The process of building a model includes the following steps.

1) Alignment of the output series using the moving average method.

2) Calculation of the values of the seasonal component S.

Eliminating the seasonal component from the initial levels of the series and obtaining smoothed data (T+E) in the additive or (T·E) in the multiplicative model.

Analytical alignment of (T+E) or (T·E) levels and calculation of values using the obtained trend equation.

Calculation of the obtained values (T+E) or (T·E).

Calculation of absolute and/or relative errors. If the obtained error values do not contain autocorrelation, they can replace the original levels of the series and further use the time series of errors to analyze the relationship between the original series and other time series.

The quantitative representation of the dynamics of complex technical processes is unique. As a rule, the results integrate some balance ratios for some period of time (day, week, month, quarter, year), the indicator is calculated at the end of this period. Technical processes are not characterized by smooth analytical functions, the indicator is presented not as part of a continuous analytical curve, but as a separate point. The graphic representation of the dynamics becomes a set of discrete points, the mathematical one - a set of tuples of length two, where the first component of the tuple corresponds to the reference time, the second to the value of the indicator. Such functions are usually called "lattice". Lattice functions are difficult to work with, especially when determining extremum points, slopes, derivatives cannot be calculated

Analytical models are especially important for predicting the behavior of technical processes, as they help to understand process trends and take early measures to improve them. Forecasting has always been relevant and in demand. At all times, everywhere, in any kind of activity, one wanted to know the prospects of development, the more or less distant results of the ongoing transformations, and the accompanying direct and indirect consequences.

It should be noted that modern methods of forecasting in general and complex technical systems separately rely on methods and models of econometrics. The emergence of idempotent mathematics, which is a synergy of technical and economic methods, proved the effectiveness of the application of the econometrics methodology in the study and forecasting of technical processes in general and the processes of the power supply - power consumption - production system separately.

Econometrics, which appeared in 1930 (R. Frisch), required "to provide this or that theoretical concept with a numerically determined characteristic." In econometrics, the only apparatus for working with lattice functions was and remains the least squares apparatus. Arbitrarily choosing a model and comparing it to a lattice process gives us the sum of squares of the uncertainty, not a very good representation of how accurate or inaccurate it is, whether the proposed model is successful or not, or whether it reflects the trends of the process, especially if it is complex additive or multiplicative a combination of trendy and seasonal components. Many years of work with the method of least squares revealed not only its advantages, but also disadvantages, especially when dealing with time series, during their modeling, analysis and forecasting

When forecasting the system of electricity supply - electricity consumption - production (SEEV), the model becomes a continuation of the process in the reporting period and must very accurately depict its trends in the forecast horizon. Prognostication assumes obtaining quantitative estimates of SEEV states in the future with the help of mathematical and instrumental means of implementation. Working forecasting appeared in the 1950s and 1960s, when forecasts of the economic behavior of countries and continents began to be constructed. Let's list the famous "forecasts of the century": G. Landsberg, L. Fishman, J. Fisher "Resources in the future of America. Needs and possibilities of their satisfaction in 1960-2000"; J.F. Dewhorst, J.O. Coppock, P.L. Yeats and others. "Needs and resources of Europe" (1961) – a ten-year forecast of the economic development of Western European countries; collection (1962) "The future of Europe in numbers" (forecast until 1970, for Belgium until 1975)

A great contribution to the development of econometrics was made by foreign scientists, especially T. Anderson, R. Winn, K. Gergely, J. Johnston, K. Dougherty, E. Kane, M. J. Kendall, A. Klas, Y. Kolek, E. Malenvaux, O. Lange, D. Poirier, A. Stewart, G. Teil, G. Tintner, K. Holden, I. Shuyan; foreign scientists have also done a lot for the development of prognostics, first of all, these are N. Viner, V. V. Leontiev, as well as I. Bernard, J. F. Dewhorst, P. A. Yates, Zhe.-K. Kolly, J. O. Coppock, H. Landsberg, F. Lyon, J. Martino, R. Otnes, M. Pesaran, L. Slater, J. Fisher, L. Fishman, D. Hayes, A. Hosking, L. Enokson, E. Yanch

One of the most important goals for time series models of the "electricity supply - electricity consumption - production" system is to build a forecast. Traditional models of time series cannot take into account all the characteristics of certain time series and need to be refined and expanded. One of the characteristic features of the "electricity supply - electricity consumption - production" system is its inherent uncertainty, which changes over time. As a result, "clustering of volatility" is observed (the formal measure of volatility is dispersion or root mean square deviation). This means that periods can alternate when the indicator "electricity supply - electricity consumption - production" system behaves erratically and in relatively calm periods of time $\{\varepsilon_t\}_{t=-\infty}^{+\infty}$.

The ARCH model, that is, a model with autoregressive conditional heteroskedasticity (autoregressive conditional heteroskedasticity), which was proposed by R. Engl in 1982 for modeling volatility clustering. The ARCH process of the qth order is given by the following relations:

$$\varepsilon_t|\Omega_{t-1} \approx N(0, \sigma_t^2), \tag{3.19}$$

$$\sigma_t^2 = \omega + \gamma_1 \varepsilon_{t-1}^2 + \ldots + \gamma_q \varepsilon_{t-q}^2. \tag{3.20}$$

Here is the background history of the process ε_t, and σ_t^2 is the conditional variance based on the background story ε_t, $\sigma_t^2 = Var(\varepsilon_t \mid \Omega_{t-1}) = E(\varepsilon_t^2 \mid \Omega_{t-1})$.

The content of the ARCH model is that if the absolute value of εt turns out to be large, then this leads to an increase in the conditional variance in subsequent periods. In turn, with a high conditional dispersion, the appearance of larger (by absolute value) values of εt is more likely. On the contrary, if the values of εt for several periods are close to 0, then this leads to a decrease in the conditional variance in subsequent periods almost to the level of ω. In turn, with a low conditional dispersion, the appearance of small (by absolute value) values of εt is more likely. Thus, the ARCH process is characterized by the inertia of conditional dispersion (clustering of volatility).

When applying ARCH models to real data, it was found that the ARCH model does not give sufficiently long volatility clusters, but only generates a large number of outliers (these are atypical or rare values that significantly deviate from the distribution of other sample data, these data may reflect true properties of the investigated phenomenon (variable), but may be associated with measurement errors or anomalous phenomena, and therefore should not be included in the model).

For a correct description of the data, a rather large length of the lag q is required, which creates difficulties in the estimation. In particular, the condition of non-contradiction of coefficient estimates γ_j is most often violated. Therefore, Engle imposed a restriction on lag coefficients, which is expressed in the fact that they decrease linearly to zero. The lag weights are given by the ratio:

The GARCH model (generalized ARCH) proposed by T. Bollerslev is an alternative modification of the ARCH model, which allows for longer clusters with a small number of parameters. The GARCH model often allows to obtain a more "concise" description of temporal dependencies for the conditional mathematical expectation, compared to the ARCH model, if we are talking about the conditional variance.

In practice, the GARCH model is supplemented with some model that describes the behavior of the conditional or unconditional mean of the observed series. From the point of view of forecasting, the model combining ARCH with GARCH is promising. In this case, the ARCH model is used to model the behavior of the conditional mathematical expectation of the series, and the GARCH model is used to model the conditional variance.

The most important conclusion from the analysis of the ARCH model is that the observed changes in the dispersion (volatility) of the time series can be endogenous, that is, generated by a certain nonlinear model, and not by any external structural shifts.

Based on the model, a forecast for the MATLAV system is built. For this, the garchpred function is used. It calculates the minimum-mean-square-error (MMSE) of the conditional mean and conditional mean-squared deviation of returns {yt} for a user-selected bias period.

If there is an opportunity to choose a forecast model during the study of the "electricity supply - electricity consumption - production" system, then there are certain requirements for the formation of such specific models.

The choice of a model for analysis and forecasting is explained by the fact that deterministic methods are based on smooth cause-and-effect relationships, extrapolation of the behavior or development of objects in the future based on the trends of their behavior in the past and present. Management processes in the "electricity supply - electricity consumption - production" system are characterized by a certain stability, inertia, existing structure, and interrelationships. This inertia continues in the future, the statistics of the process are preserved, mathematically, the methods of interpolation and extrapolation consist in the representation and processing of the behavior of indicators as time series in the reporting period and in the horizon of the forecast.

Currently, there are a large number of different forecasting methods. Among them are methods that are not directly related to extrapolation, for example, morphological analysis, a tree of goals, methods of building scenarios, etc.

To choose the appropriate approximating function, you need to know the behavior class of the indicator, they can be seasonal (periodic) processes, exponential-type accumulation or decay processes, sufficiently smooth trend processes. The manager, as a rule, does not know this class. Therefore, the choice of a single (unified, universal) system of functions that approximate.

Such a system of universal functions should well interpolate (in the reporting period) and extrapolate (in the perspective period) all classes of typical processes "electricity supply - electricity consumption - production" system, automatically "adjusting" its fragments to their seasonality, asymptotics, exponentiality, etc. It should possess some mathematical properties of "internal optimality" of the representation of the process. The system should be constructive, allowing to obtain solutions simply, quickly and accurately, in some ways better than the latter, without requiring any additional ideas, transformations, assumptions and the like. The system of functions should be researched and applied by mathematicians so that the correctness and reliability of the results are guaranteed during transformations. Mathematical formulation of tasks, forecasting methods should make the most of the capabilities of computer mathematics systems with their computer implementation and visualization.

Complex endogenous and exogenous interaction of indicators (where indicators, as always, mean a system of parameters characterizing the state and development of the "electricity supply - electricity consumption - production" system) in modeled, analyzed and forecasted processes of the "electricity supply - electricity consumption - production" system requires the involvement of system analysis, theory of functions, statistics, discrete mathematics with approximation (interpolation and extrapolation) of lattice functions, econometrics, and prognostics to the study of the dynamics of indicators.

Regression constructions on systems of lattice functions from the criteria of agreement forced to use only the method of least squares. Replacing lattice functions with smooth splines (and their derivatives, "slopes", "moments") puts the entire analytical apparatus of mathematical theory in the hands of the economist. The low order of the components of the spline and its derivatives facilitates the interpretation of the model "electricity supply - electricity consumption - production" system and management based on it.

In modern forecasting, insufficient attention was paid to flexible technologies of modeling, analysis and forecasting of the "electricity supply - electricity consumption - production" system processes. Classical deterministic analysis and forecasting with the selection of the most relevant polynomial process or group of polynomials (in the form of a combined model) should be supplemented by a universal analysis and forecasting apparatus with seemingly contradictory properties (low degree, high accuracy, optimal automatic "stitching" of fragments, work with multivalued functions, the use of an analytical apparatus, obtaining comprehensive information about the process in the form of phase portraits and parametric dependencies, a smooth transition from the reporting period to the prospective one, etc.), this would expand the circle of well-modeled, analyzed and forecasted processes.

Splines help to more accurately model, analyze and forecast the behavior of indicators of the "electricity supply - electricity consumption - production" system in conditions of instability of economic activity.

Splines entered the theory of approximation quite recently, but they entered rapidly, and immediately took their place in it, as if they were destined for them in advance.

Splines differ from ordinary functions in that they consist of fragments of functions of the same type, connected in a special way. Their main advantage is good approximation properties with high computational efficiency. Unlike functions familiar from elementary mathematics, which take values from minus to plus infinity, splines are local. This does not mean at all that you cannot construct a spline with infinite boundaries. But the spline is easy to express in terms of a linear combination of local basis splines. The locality of the basic splines means that the inequality is zero only in a limited area. Such bases are more realistic in describing real processes than they are unlimited. Attention to such bases has increased greatly in the last decade due to the development of wavelet methods. Wavelet methods also use local bases, but unlike splines, no attention is paid to docking conditions. Thus, basic splines can be considered one of the varieties of wavelets.

The method of least squares with the spline model does not fundamentally differ from the one used for classical models. However, a number of features of spline bases make it possible to get rid of the problems described above and to efficiently organize the computational process. We will use the approach with the interpolation model. Let's apply the Hermitian cubic spline. It guarantees the continuity of the values and the first derivative. The value of the first derivative must be specified, but practically it is expressed through the central differences of neighboring nodes. Thus, the first derivative approximately repeats the derivative of the original function. The difference from the cubic spline of the minimum defect (the most studied in theory) is that the continuity of the second derivative is not guaranteed (visually it is not noticeable), but the first derivative is not subject to the continuity of the second derivative. In addition, the weighting coefficients of the basic splines (estimated parameters of the method of least squares) are the values of the spline at the docking points. The latter ensures the convenience of interpreting the result. The use of other splines does not fundamentally change what was stated, but it is necessary that the basic splines consist of four fragments.

It must be said that piecewise polynomial functions were used much earlier in private approximation tasks. It is enough to recall the broken Euler method, Lebesgue's proposed proof of the Weierstrass theorem on the approximation of a continuous function by polynomials, the piecewise-polypomyalp approximation of a static function in the works of S. M. Nikolskyi in the early 1950s on the best possible quadrature formulas. Splines appeared as extremals in the well-known works of J. Favar on the best possible approximation and in the works of A. N. Kolmogorov on exact inequalities for derivative norms (30s). However, for a long time, the classical theory of approximation did not see splines as an approximation device that could compete with algebraic or trigonometric polynomials, at least until it got closely involved with problems about its predecessors

However, the intrusion of splines into the theory of approximation occurred due to the task of function interpolation. Upon closer examination, it turned out that interpolation splines are not only predominantly polynomial from the point of view of computational convenience, but in a number of situations have the best possible approximate properties, providing the minimum possible error with a given dimension. When after that they began to try the spline apparatus on classical problems of the best possible approximation, it turned out that the methods for solving extreme problems developed at that time in the theory of approximation, based on the idea of duality, work in splines no worse, and sometimes even better, than in polynomials. Literally, within a few years, approximation tasks for splines were completely solved, which took decades to solve for polynomials. It should be noted, however, that in a number of fundamentally important tasks related to estimating the error of spline interpolation, it turned out to be possible to obtain an exact solution using only the internal specificity of splines.

Formulas of signals, in detail and precisely describing certain physical objects, fields and processes, can be very complex and not very suitable for practical use both, in the general case, in the mathematical analysis of physical data, and in purely applied tasks, especially in calculations of expected measurement results and mathematical modeling of physical processes. In addition, practical registration of physical data is performed, as a rule, with a certain error or with a certain level of noise, which in terms of values can be much higher than the theoretical error of signal prediction when calculating using complex, although very accurate formulas. It does not make much sense to design systems for processing and analyzing signals according to highly accurate formulas, if increasing the accuracy of calculations and the corresponding complication of systems does not give a tangible effect in increasing the accuracy of data processing. In all these conditions, the task of approximation arises - the representation of arbitrary complex functions f(x) by functions j(x) that are simple and convenient for practical use, so that the deviation of j(x) from f(x) in the domain of its task is the smallest according to a certain criterion of approximation . The functions j(x) were called approximation functions.

Mathematics very often operates with special mathematical functions for solving differential equations and integrals, which do not have analytical expressions and are represented by tabular numerical values yi for discrete values of independent variables xi. Experimental data can also be represented by similar tables {yi, xi}. Points in which discrete values of functions or data are defined are called nodal points. However, in practice, the values of these quantities may be needed at completely different points, different from nodal points, or with a different discretization step of the arguments. The task of calculating the values of the function that arises in the intervals between nodes is called the interpolation task, outside the family of nodal points forward or backward along the variables – the task of extrapolation or forecasting. The solution of these tasks is usually also performed using approximating functions.

Smoothing of statistical data or approximation of data taking into account their statistical parameters refers to regression tasks and is considered. As a rule, in regression analysis, averaging of data is carried out by the method of least squares (LSM).

All of the above tasks refer to the tasks of approximating signals and functions, which have a centuries-old history, in the process of which the classical mathematical methods of approximation, interpolation, extrapolation and regression of functions were formed. All modern mathematical systems (Mathcad, Matlab, Maple, etc.) have in their composition a universal apparatus for performing such operations, which gives the user the opportunity to implement sufficiently complex practical tasks on data processing without turning away from the theoretical details of their implementation.

The method of least squares (LSM) is the oldest, multifaceted and universal among those used in the practice of processing empirical data and signals. Specialists of different fields call the tasks solved with the use of MNC in different ways. This is regression analysis, parameter estimation, smoothing, filtering. As a result, regardless of the initial content of the task and the interpretation of the results, we have identical models and calculation algorithms for solving systems of linear equations.

The idea of using splines as a model in LSM cannot be called new. Most of the monographs on splines (especially of the practical direction) deal with this issue. However, the construction of splines by LSM is not widespread. This tool is also missing in statistical packages with regression analysis. There are a number of objective reasons for this, related to both the implementation and the features of using such a tool. The use of a spline as a model allows you to adequately describe processes of a complex form (having more than four to six extrema).

Let's consider the main assumptions that underlie the usual LSM. The signal is represented by discrete readings, $y_i = f_i + \xi_i$, which is the sum of readings of the non-random function $f_i = f(t_i)$ and random readings ξ_i. Random counts have zero mean $\mathrm{M}[\xi] = 0$ and are uncorrelated. $V[\xi] = \sigma^2$ Let's describe the readings y_i using some function g (A,t), which depends linearly on the vector of numerical parameters A of length r. The function g (A,t), is a linear combination of basis functions: $g\ (A,t) = \sum ajBj(t)$. We will demand that the values of A ensure the minimum value of the root mean square error of the deviation of the model function g (A,t) from the original readings:. $\sum_1^r (y_{i-} g(A,t_i))^2$ Minimization tasks in matrix form $(Y - XA)^T (Y - XA) \rightarrow min$ are reduced to a system of linear algebraic equations $A = (X^T X)^{-1} (X^T Y)$ of order r, called normal. Here, the matrix X (dimensions of n rows (number of readings) and r columns) contains readings of the basic functions in the columns: $X_{i,j} = B_j(t_i)$. If there are random components, the obtained values of the parameters will be random numbers $\hat{A}$ - estimates of the values of A (those that would be obtained in the absence of random readings ξ_i). The Gauss-Markov theorem asserts that if the above conditions are met, the estimates $\hat{A}$ are the most efficient (have the minimum variance) among all linear unbiased estimates: $M\left[\hat{\mathbf{A}}\right] = \mathbf{A}$, $V\left[\hat{\mathbf{A}}\right] \rightarrow \min$.

The linearity of the model with respect to the estimated parameters makes it possible to construct accurate confidence intervals for estimates of $\hat{A}$ if ξ_i have a normal distribution. The covariance matrix of estimates is equal to $\mathrm{V}[\hat{A}] = \sigma^2 (X^T X)^{-1}$ Since σis not known, we use the estimate $\tilde{\sigma}^2 = s^2$, where $s^2 = (Y - X\widehat{A})^T (Y - X\,\hat{A})/(n - r - 1)$. The probability confidence interval α for $\hat{\alpha}_j$ is $\pm \mathrm{t}(\alpha,\upsilon) s \sqrt{g_{j,j}}$, where $\mathrm{t}(\alpha,\upsilon)$ is the two-sided (α+1)/2 quantile of the Student distribution with the number of degrees of freedom $\nu = n\text{-}r\text{-}1$, $g_{j,j}$ is the diagonal element of the matrix $G=(X^TX)^{-1}$. For other distribution laws, these intervals will be asymptotic (more precisely, the larger). The efficiency of LSM also depends on the type of distribution law of the random component ξ_i). With the normal law of distribution, LSM is a private solution more than the general method of maximum likelihood estimation (MLE).

An important condition for the practical application of the method is its brutality in relation to the initial assumptions. Let's consider the consequences of their violation.

A non-zero mean of the random component leads to a shift in estimates. Practically, this is equivalent to adding a constant to a non-random function. The offset is easy to correct if the value is known or can be determined.

The non-stationary dispersion and correlation of random readings leads to suboptimal estimations.

The non-normality of the distribution law reduces the efficiency of LSM estimates compared to MLE. According to research results, the efficiency with a law close to uniform is about 73%. The efficiency depends most significantly on the contra-excess and decreases significantly for sharp-peaked distributions.

In general, it should be noted that LSM is quite resistant to violations of the initial statistical assumptions. In practice, these violations must be sufficiently obvious from the raw data for their impact to be noticeable.

It should be noted that, despite the availability of affordable and powerful computing equipment and software packages that allow quite simply to investigate the sensitivity of the method, it is very difficult to find numerical evaluations and experimental results of this kind in the literature. If there are doubts or questions about the impact of violations of the conditions, it is always possible to conduct a number of computational experiments with alleged violations to assess their impact.

Let's consider LSM from a slightly different point of view, in relation to interpolation tasks. Consider the solution of the interpolation problem. In the matrix form, we have **S=X A**, where **X** is a matrix, the columns of which contain readings of the basis functions. A- interpolation coefficients. For the Lagrange interpolation polynomial, the interpolation coefficients are equal to the values of the interpolated signal at the nodes. We will assume that the readings of a non-random function are the result of interpolation. Then LSM can be considered as an inverse problem with respect to interpolation. In the case of using the Lagrange interpolation polynomial, it is necessary to estimate the values at the interpolation nodes based on the known (with error) interpolated values. From this point of view, we can consider that the interpolation formula is actually a model in LSM.

The method of least squares is the most critical to the selection of basis functions. Therefore, we will consider in detail the issue of choosing the most suitable system of basic functions. Naturally, they should be linearly independent. But, in addition, they should provide a small error of approximation, have good computational properties, good statistical qualities of parameter estimation and their natural interpretation.

If other conditions are met, a poor approximation of f(t) is manifested by the presence of autocorrelation in the residuals, a shift in the estimates, and a gross error in the confidence intervals. To avoid this, it is better to choose a larger number of basis functions that make up r, hoping for a better approximation, even if this worsens the quality of statistical estimates. If f(t) is poorly approximated, the confidence intervals calculated under the assumption of good approximation will be biased and underestimated. The poor fit of the model g(A,t) to the function f(t) can be determined by analyzing the residuals of the approximation $e = Y - X\hat{A}$. Regression analysis packages contain functions for calculating autocorrelation functions for analysis of residuals, as well as a number of statistical criteria for assessing the presence of autocorrelation in residuals.

In practice, it is quite difficult to immediately choose the necessary system of basic functions. For this, elementary visual methods are used. Simply put, they try to find out the characteristic contours of known dependencies in a noisy signal: straight line, parabola, exponent, logistic curve, etc. When processing fast, changing processes with a random shape, the operator is unable to do this. Therefore, the signals are processed in short segments, in which the shape of the signal does not change too much. Practically, this means that in a short segment, most signals can be approximated quite well by polynomials of low degrees. However, to obtain statistically reliable estimates of model parameters, it is necessary to have the maximum possible number of degrees of freedom. It is desirable that the difference between the number of initial readings on the processing fragment and the length of the vector of model parameters should be several dozen. The requirement of low variability of the signal on the processing fragment prevents this.

Let's consider the main factors affecting the choice of basis functions.

The complexity of calculating the values of the basis functions. It is of fundamental importance in the full calculation of LSM in the case of processing fast-moving processes. In econometrics, this is a rather rare situation.

The statistical properties of LSM with a given basis are determined by the covariance matrix of estimates, $V = M[(\hat{A} - A)(\hat{A} - A)'$ which is equal to the variance of the random component of the matrix It is desirable to have the minimum values of the diagonal elements G . They decrease as the number of data increases. This reduction for the chosen basis has a limit called the Kramer-Rao limit. The most significant reduction of diagonal elements to the number of data on the order of several tens of counts. As a rule, a simpler model has better statistical properties.

Interpretation of the elements of the parameter vector. In some cases, this is important for the interpretation of the obtained results. Sometimes it is important that the evaluated parameters have the same meaning as the input data. Then it is advisable to use the Lagrange polynomial.

The next major problem of LSM is the computational properties of the method. Under certain conditions, small errors occurring both in the input data and in finite-precision calculations lead to larger errors in the result. The system of normal equations becomes close to degenerate. However, it will not work to estimate degeneracy using a determinant, as is done in analytical calculations. This is related to the relativity of the machine zero and the finite accuracy of calculations. Therefore, they use another indicator - the number of conditioning. Conditionality is a numerical measure of the effect of a deviation in the input data on the result. There are different indicators of conditioning. The absolute value of conditioning is equal to $\|C^{-1}\|$. This is how the norm of the matrix (a kind of its size) is denoted. It can be considered in different norms, it has no fundamental significance. The Euclidean norm is most often used. Absolute conditioning is an a priori assessment. It can be determined without solving the system of equations. But it is worth keeping in mind that more than 90% of the computing costs when solving a system of equations are spent on the circulation of the matrix.

Relative conditioning: $\|C^{-1}\|\|B\|/\|A\|$ is an a posteriori estimate determined after solving the system of equations. The standard conditioning number equal to $\|C^{-1}\|\|C\|$, which is denoted as cond (C), is most often used. Given that $\|C^{-1}\|\|C\| \geq \|C^{-1}C\| = \|I\| = 1$, we obtain the lower limit of the standard conditioning number equal to one. If cond(A)=1, we say that the matrix A is perfectly conditioned. For a degenerate matrix A - cond(A)=(If cond(A) is small (close to one), A is well conditioned, otherwise A is poorly conditioned.

From the perspective of a compromise of the listed requirements, algebraic polynomials of degree no higher than the fifth are most often stopped.

Undoubtedly, graphic analysis and visualization of decisions contributes to the study of the processes of the "electricity supply - electricity consumption - production" system in terms of forecasting. It should be noted that two factors contributed to the widespread use of graphic approaches in trend analysis. First of all, there is a lack of computing equipment that is suitable for operational day-to-day work and is capable of processing large data sets. Secondly, the complexity and weak adaptation of known methods of mathematical analysis to the study of the dynamics of the electricity supply-electricity consumption-production system. Therefore, graphs were almost the only tool that allows you to get an idea of the existing trends that are being formed. Gradually, some relationships were found in the location of trend lines and actual dynamics, the first graphic models and figures appeared.

The experience accumulated during this period was reflected in Edwards and Meiji's classic guide "Technical Analysis of Stock Trends", published in 1948. In it, the authors introduced the theory of analysis of support and resistance lines, shoulder model of trend reversal, models of triangles and rectangles. The most important concept of the statistical analysis of the dynamics in general, and the analysis of the dynamics of the "electricity supply - electricity consumption - production" system, in particular, is the concept of trend. The trend is the general direction of changes in the levels of the studied time series in a given time interval. No matter how chaotic the changes in electricity supply may seem, they are, nevertheless, the result of the interaction of many factors and, in the end, form certain trends.

Most often, standard econometric methods are used for short-term forecasting. In this case, the time series is represented as a function of a small number of significant factors and a random stochastic component, which summarizes the influence of all random factors. The technology of such a forecast usually includes three stages: in the first, the essential factors are determined, on which the quantitative characteristics of the "electricity supply - electricity consumption - production" system depend for our research (for this, standard methods of dispersion and correlation analysis are used), in the second, the obtained model is checked on normality and independence of the residuals (these properties of the residuals are necessary for the correct assessment of the confidence interval of the forecast), and on the third, an assessment of the quality of the forecast is made (usually the assessment of the variance of the forecast error is used as a quality criterion). In this area, quite a lot of models have been developed that use both external factors in relation to a number of factors (for example, indicators of the "electricity supply - electricity consumption - production" system) and past values of the time series or its derivatives (for example, ARMA, ARIMA, ARCH, GARCH, E-GARCH). However, the majority of similar models describe the processes unsatisfactorily. In addition, the justification of the use of such methods is questionable from the point of view of the currently accepted efficient market hypothesis. The main model of short-term behavior in such a market is the model of Brownian motion, first proposed by Louis Bachelier in relation to financial markets back in 1900 and then developed by Norbert Wiener. For this model, it can be rigorously shown that the best possible forecast of tomorrow's indicators is the simplest forecast: today's indicators of the "electricity supply - electricity consumption - production" system. As it turned out, the forecast quality of most econometric models is worse than the quality of such a simple forecast (the variance of the forecast error for econometric models turns out to be greater than the variance of price growth).

The value of the fractal characteristics of the series allows you to naturally determine whether the current local state of the numerical series is a random walk or a trend (flat). This fact is used for forecasting. Indeed, in the trend, you can use econometric methods, and in the state of random wandering, you can use previous data, or even abandon forecasting altogether. Let's evaluate the quality of a simple version of such a forecast.

Consider the number series. In each of the ranks, we will highlight areas for which μ_+≤0.5, that is, areas where a trend is observed. For each point of each section, we will build a forecast using linear regression on four previous points. Formally, it can be written as follows:

When $\mu_{+} \leq 0{,}5$, $\mu_{+} \leq 0{,}5 X(t+1) = a(t+1)b$ where the coefficients a and b are estimated by the set of points (t,X(t)),(t-1,X(t-1),(t-2mX(t-2)) i (t-3,X(t-3)).

If $\mu_{+} > 0{,}5$ the forecast is not made.

Considering the indisputable influence of factors in the formation of trends to determine the forecast, there is a need to consider an expert assessment of the influence of factors. Expert assessment is considered appropriate in the absence of numerical, statistical data regarding the "electricity supply - electricity consumption - production" system.

Obtaining information as a result of a questionnaire survey depends to a large extent on the quality of the completed questionnaires, the organization and conduct of the survey. Based on this, the following rules should be followed when filling out questionnaires:

– include in the survey all or at least the main factors that affect the investigated performance characteristic;

– use names of factors only generally accepted for the researched process;

– if possible, specify intervals for the factors;

– questionnaires should be small, concise and do not require a lot of time to read and fill in;

– form the questions in the questionnaire clearly and do not assume a double interpretation;

– to interview specialists (experts) who clearly imagine the researched process;

– to involve specialists of various related specialties in the survey;

– conduct the survey in such a way as to ensure the independence of the opinion of the interviewed specialist;

– the number of interviewed specialists should significantly exceed the number of factors included in the study.

When filling out the questionnaires, the method of a priori ranking is used, which requires the placement of factors in the order of decreasing degree of their influence on the performance indicator.

If a number of experts could not determine the degree of influence of some factors and gave them the same ranks, the ranks are transformed.

For this:

– the factors are placed in an ascending series, ranked by the values of the respective expert's ranks;

– factors are numbered using a continuous series of natural numbers (1,2,3,..., K, where K is the number of factors);

– the same ranks of factors for a certain expert are replaced by transformed ones, which represent the arithmetic mean of the corresponding numbers of the natural series;

– the rest of the factor ranks are replaced by the serial number of the factor in the ranked series.

The correctness of the determination of the ranks is controlled by comparing their sums invested by experts with each other, as well as by comparing the values obtained by the formula $\frac{1+K}{2} \cdot K$.

The results of transformations are summarized in the table. 3.1.

Table 3.1 – Transformed ranks

Experts	Ranks of factors included in the survey									Sum of ranks by experts $\sum b_{ij}$
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	

Some loss of information may occur during conversion of the original rank table. Taking this into account, the adequacy (correspondence) of the primary and transformed ranks is checked.

For this:

– determine Spearman's even rank coefficient using the following ratios:

1) for unconnected ranks:

$$\rho = 1 - \frac{6 * \sum_{i=1}^{K} (\alpha_i - \beta_i)^2}{K^3 - K}; \tag{3.21}$$

2) for connected ranks:

$$\rho = \frac{\frac{K^3 - K}{6} - (T_1 - T_2) - \sum_{i=1}^{K} (\alpha_i - \beta_i)^2}{\sqrt{\left(\frac{K^3 - K}{6} - 2T_1\right)\left(\frac{K^3 - K}{6} - 2T_2\right)}} \tag{3.22}$$

where α_i, β_i – are the ranks of the ith factor, determined by the sum of the initial and transformed ranks, respectively;

$$T_1 = \frac{1}{12} \sum_{j=1}^{l_1} \left(r_j^{\,3} - r_j\right); \tag{3.23}$$

$$T_2 = \frac{1}{12} \sum_{j=1}^{l_2} \left(r_j^{\,3} - r_j\right); \tag{3.24}$$

where r – is the number of the same ranks in the *j*-th group, which were obtained by combining the same ranks.;

l_1, l_2 – the number of groups of the same conditional ranks, respectively, in the original and transformed tables;

– analyze the value of Spearman's rank coefficient and draw conclusions.

At the same time, if:

$\rho < 0$ – the transformed table gives information opposite to the original table. Further analysis is not possible. It is necessary to find out about the reasons for this (few experts participated in the survey; the questionnaires were unclear; the experts did not know the process being analyzed; the influence of the factors was difficult to determine; an error was made during the conversion of ranks, etc.)..

$\rho = 0$ – the ranks of the initial table do not correspond to the transformed ones (independent of each other). Further analysis is not possible. Reasons for this must be linked (see previous for $\rho < 0$).

$\rho = 1$ – full correspondence between the original and transformed rank tables.

$\rho > 0, but\ \rho \neq 1$, Spearman's rank coefficient is considered:

a) insignificant, that is, we consider $\rho = 0$, if the calculated value is less than the critical value:

$$\rho_{calculated} < \rho_{critical} = \frac{\varphi(P)}{\sqrt{K-1}}\left\{1 - \frac{0{,}19}{K-1}[\varphi^2(P) - 3]\right\}, \quad (3.25)$$

where $\varphi(P)$ – s the value of the normalized Laplace function at the reliability level P, selected from special tables;

with probability P = 0,95; 0,954; 0,997; $\varphi(P)$ = 1,96; 2,0; 3,0;

K – is the number of factors included in the survey;

б) significant, if the calculated value is greater than the critical value:

$$\rho_{calculated} > \rho_{critical} = \frac{\varphi(P)}{\sqrt{K-1}}\left\{1 - \frac{0{,}19}{K-1}[\varphi^2(P) - 3]\right\}. \quad (3.26)$$

At the same time, the closer the calculated value of Spearman's rank coefficient ρ is to unity, the less information was lost in the process of converting ranks.

To reveal the degree of consistency of the opinions of experts (interviewed specialists) in assessing the question posed to them, we use the Kendell concordance coefficient, which is calculated:

1) for unbound ranks:

$$W = \frac{12\sum_{i=1}^{K}\Delta_i^2}{n^2(K^3 - K)}; \quad (3.27)$$

2) for connected ranks:

$$W = \frac{12\sum_{i=1}^{K}\Delta_i^2}{n^2(K^3 - K) - n\sum_{j=1}^{n}T_j}; \quad (3.28)$$

where n – is the number of experts interviewed;

$$\Delta_i = \sum_{j=1}^{n} b_{ij} \frac{1}{K}\sum_{i=1}^{K}\sum_{j=1}^{n} b_{ij} \quad (3.29)$$

b_{ij} – is the transformed rank of the i-th factor of the j-th expert;

$T_j = \sum_{r=1}^{b_j}(r_r^3 - r_r)$;

r_r – the number of groups of equal ranks of the j-th expert;

b_j p – the number of groups of equal ranks of the j-th expert;

Analyzing the value of the obtained Kendell concordance coefficient, we draw a conclusion.

If:

W=0 – there is complete agreement among experts in assessing the degree of influence of factors, i.e. there is an identity of opinions (ideas, views) of experts in assessing the degree of influence of a factor;

W = 0 – there is no consistency of experts' views;

$W \neq 0$ and $W \neq 1$ we check the significance of the calculated concordance coefficient using the X^2 criterion (X_i - quadrant).

At the same time, we define:

$$X^2_{calculated} = n(k-1)W. \qquad (3.30)$$

Then, having set the level of reliability (significance) for K-1 degrees of freedom, we search for X^2_{table} using special tables.

In the future, we will consider:

1) the concordance coefficient is significant, i.e. $W \neq 0$, if

$$X^2_{calculated} > X^2_{table} \qquad (3.31)$$

2) the concordance coefficient is not significant, i.e. $W = 0$, if

$$X^2_{calculated} < X^2_{table} \qquad (3.32)$$

If the calculated concordance coefficient is insignificant, then we conclude that there is no agreement of experts' opinions regarding the given task. We identify the reasons for inconsistency (complexity of the process, ambiguity of the questions, low level of experts' knowledge, small number of experts included in the survey, etc.).

If the concordance coefficient is significant, we draw conclusions about the degree of agreement of the experts based on its value. The closer the concordance coefficient is to unity, the greater the consistency of experts' opinions in assessing the delivered question. Using the table 3.2, we make a qualitative conclusion about the degree of agreement of experts.

Table 3.2 – Qualitative conclusion about the degree of agreement of experts

The value of the concordance W coefficient	0,1–0,3	0,3 – 0,5	0,5 – 0,7	0,7–0,9	>0,9
Characteristics of experts' agreement	Low	Medium	Noticeable	High	Very high

In the case of the significance of Kendell's concordance coefficient, that is, when there is an agreed opinion of experts in the assessment of the question about the degree of influence of the factors, we proceed to the analysis of the agreement of the opinions of experts on each factor separately.

For this purpose, the assumption of the uniformity of the distribution of ranks for each factor is checked using the Mises-Smirnov criterion (the ω^2 criterion), which compares the calculated value of the $n\omega^2$ criterion with the z_p criterion and draws conclusions.

If:

a) the distribution of the ranks of the factor does not contradict the uniform distribution, so the experts do not have an agreed opinion on this factor. This conclusion is written as an inequality:

$$n\omega^2 < z_p \quad (3.33)$$

Then they find out the reason for this (a sharp level of training of experts-ekopvrts, unclear questions in the questionnaire, the complexity of the process being studied, the complex and ambiguous nature of the influence of the factor, etc.), or conduct an additional survey;

b) the distribution of ranks corresponds to a uniform distribution, i.e. the experts have an agreed opinion about the degree of influence of the factor under analysis. This conclusion is written as an inequality:

$$n\omega^2 > z_p \quad (3.34)$$

In order to visualize the placement of factors according to the degree of influence, a graph-diagram of ranks is constructed.

On the abscissa axis, equal intervals are placed, on which the factors are placed in the order of increasing sums of their ranks, and on the ordinate axis, the sums of ranks are placed in the order of decreasing values (for example, Fig. 3.5).

The graph constructed for evaluating the factors was a bar chart in which the indicators are arranged in descending order. We check whether the decline is not random.

To do this, according to the agreement criterion X^2 (X_i - quadrant) the assumption about the uniformity of the distribution of rank sums is checked by calculating the value $X^2_{calculated} = \frac{1}{z}\sum_{i=1}^{n}\Delta_i^2$, $z = \frac{1}{k}\sum_{i=1}^{k}\sum_{j=1}^{n} b_{ij}$

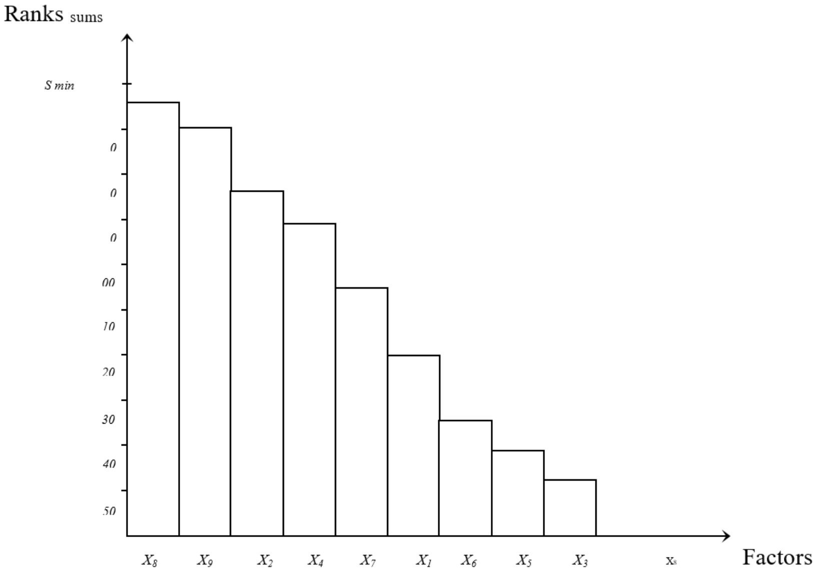


Figure 3.5 – Diagram ranging

Having set the level of reliability for *K-3* degrees of freedom, we look for X^2_{tabl}.

With:

1) if $X^2_{obzh} < X^2_{tabl}$, then the assumption of the uniformity of the distribution of the sums of the ranks for the factors is accepted, that is, of the randomness of the decrease of the values of the ranks; it is concluded that the level of a priori information (gathered with the help of a survey regarding the given task) is very low, and it is necessary to conduct a questionnaire survey at a higher level or to include all factors in the study, because, according to experts, all factors are important;

2) if $X^2_{obzh} > X^2_{tabl}$, then the assumption about the uniformity of the distribution of the sums of the ranks for the factors is rejected, that is, the decrease in the values of the ranks is not random, and a conclusion is made about the high level of a priori information about the dulling of the importance of the factors.

When the assumption of a uniform distribution of the rank sums for the factors is rejected, the assumption of the exponential nature of the decline of the values of the ranks according to the WE_0, criterion is checked, calculating the values of the WE_0 criterion:

$$WE_0 = \frac{\sum_{i=1}^{k} \Delta_i^2}{k^2 (s_{max} - z)^2} \quad (3.35)$$

where s_{max} – is the maximum sum of ranks for the factors.

Then the calculated value of WE_0 is compared, with 95% intervals *(WE_0^{H}; WE_0^{B})*.

When the calculated valueWE_0 did not fall into the tabular interval, i.e.

$$WE_0 \ \overline{\in} \ (WE_0^{H}; WE_0^{B}) \quad (3.36)$$

reject the assumption about the exponential nature of the decrease of values in the rank diagram.

When the calculated value of WE_0 falls into the table interval, i.e.

$$WE_0 \in (WE_0^{H}; WE_0^{B}) \quad (3.37)$$

assume the exponential nature of the decrease of values in the rank diagram.

In the case of the exponential nature of the decrease of the values in the rank diagram, there is an opportunity to divide (break down) the factors into groups according to the degree of their influence on the evaluated indicators.

To do this, by looking at the rank diagram, as well as the value of the sum of the ranks for each factor, visually choose the columns that are close in size or the sum of the factors of the rank diagram.

A detailed check of the difference of factors from each other is performed using the Student's *t*-test.

For this: .

1) the calculated value of $t_{calculated}$ s compared with t_{table}

With:

a) the difference between the average values is considered significant, i.e. the factors cannot be combined into a single group if

$$t_{calculated} > t_{table} \quad (3.38)$$

b) the difference between the average values is considered insignificant, that is, the factor can be combined into a single group if

$$t_{calculated} < t_{table} \quad (3.39)$$

When assembling groups, factors are included in the order of their importance, that is, starting with the factor with the lowest sum of ranks, as in the rank diagram.

After selecting groups of factors by the degree of influence, it is advisable to include them in groups in the study.

It should be remembered that the faster the value of the factor decreases in the rank diagram, the more clearly the division of factors into groups according to the degree of influence will be performed.

When a group of experts is identified, among which the consensus of opinion is high, we act as follows.

We determine the concordance coefficient *W* for all rank values.

We exclude one expert from consideration and determine the concordance coefficient W_1 for the remaining population.

In the following, we compare the calculated concordance coefficients W. If it turns out that $W_1 > W_2$, then the expert we excluded is removed from the population, and if it turns out that $W_1 <= W_2$, then the considered expert remains in the population.

After performing the specified procedure for all experts of the initial table, as a result, we will obtain a group of experts with a high consensus of opinion.

To identify a group of experts with a low degree of consensus:

1) determine the concordance coefficient for all experts *W*;

2) one expert is excluded from consideration and the concordance coefficient W_1 is determined for the remaining population..

If it turns out that $W_1 > W_2$, then this expert remains in the population, and if W1 < = W_2 , then the considered expert is removed from the population.

Having performed the above procedure for all experts of the initial table, we obtain a group of experts in which the agreement of opinions is low.

When assessing the consistency of the opinions of each expert with all the remaining experts:

1) we sequentially take the ranks of the relevant experts (1st, 2nd, etc.);

2) find the sum of ranks by factors for the remaining experts, i.e. by removing from the sum of the ranks of the analyzed expert;

3) for the sums of the ranks, we establish conditional ranks depending on their values: the smallest sum is the 1st rank, the next in value is the 2nd rank, etc.; in the case of the same amounts, we assign the same (connected) ranks, defined as the average of the serial numbers that have these amounts in the rank series;

4) we determine the value of the Spearman rank coefficient ρ for the ranks of the selected exgart α_i and the conditional ranks β_i, btained from the sums of the ranks, using the ratio for calculating ρ;

5) analyzing the value of the calculated Spearman coefficient ρ, we draw conclusions. At the same time, the negative value of the Spearman coefficient ($\rho < 0$) indicates the originality of the expert's opinion in assessing the problem (task); a positive value of the Spearman coefficient ($\rho > 0$) indicates the consistency of the expert's opinions with all other experts;

6) using table 3.3, we evaluate the degree of consistency or

originality of the opinion of each expert compared to all others, and also give a quantitative assessment of the level of competence of the expert compared to all other experts.

Table 3.3 – Originality of the opinion of each expert compared

Spearman coefficient value ρ	0,0-0,3	0,3-0,5	0,5-0,7	0,7-0,9	>0,9
Opinions agreement measure $\rho>0$	Low	Medium	Noticeable	High	Very high
Opinions difference measure $\rho<0$	Low	Medium	Noticeable	High	Very high
Assessment of competence	1	2	3	4	5

Note. If the opinions of an individual expert are original, the reason for the difference (novelty of the opinion) or the weak competence of experts in the process being assessed is clarified through additional analysis.

Thus, methodological approaches to the issue of building forecasts of the power supply-power consumption production system were systematically investigated and grouped. In the future, we will consider the practice of applying the above methods, which will provide an opportunity for researchers to use the proposed research in a practical experiment.

3.2 Statistical research methods in the context of the development of distributed generation sources

3.2.1 Statistical methods of electrical energy consumption research

Currently, the general methodology for the study of complex technical systems has significantly developed. According to the general definition, this class includes systems with relatively independent, autonomous behavior of subsystems with high internal activity and selectivity, purposeful functioning of the system in general. Such systems are open, in constant interaction with the environment and fundamentally capable of solving various tasks under various conditions. Currently, there is a question regarding the study of electric energy consumption for effective management.

An effective solution to the problem of effective management of electricity consumption depends on the amount of received and processed information. At the same time, a significant amount of initial data increases the dimensionality of the problem and creates difficulties with regard to operational calculations and high-quality decision-making. The processing of such information involves the use of statistical methods.

The active role of statistical evaluation is justified and related to the fact that at each stage of the development of technical systems there are not only positive, but also negative trends, factors of external influence, which are not enough just to identify and classify. In the process of conducting a statistical analysis, it becomes possible, based on the generalization of information, to develop an adequate idea of the state, vectors and dynamics of the development of the object, its determinants, and on this basis to develop management decisions, the implementation of which will allow limiting or completely preventing the negative impact, as well as strengthening the effect of favorable factors and conditions.

Different systems of statistical research used today have certain general characteristics (invariant composition of tasks, methods of collecting and analyzing information, etc.), which makes it possible to talk about statistical research as a certain integral scientific and practical phenomenon.

Statistical research must be considered as a system, the functioning of which includes a number of stages. They should include: the process of continuous observation, the study of phenomena and events, the formation of a management information base, control over the course and nature of object changes, and the assessment of deviations based on a system of criteria (benchmarks).

Statistical research should have certain properties. Among them: the presence of a clear target setting for the selection of the most important and necessary information; the use of a relatively constant set of tracking parameters and indicators and a stable respondent network; comparability of research results.

Statistical research as a system is a set of interconnected elements. Among them: its object, target function, subject (specific aspects of object research, determined by the tasks), subject, which includes different groups of participants, methodological base, system of indicators, resource and organizational support.

Industry in general, and heavy industry in particular, determines the growth of consumption of energy resources, the main of which is electricity. Over the past ten to fifteen years, the growth of electricity consumption levels was: in ferrous metallurgy - $45.8, in non-ferrous metallurgy - $39.9. The existing trend will continue.

The effectiveness of the process of using electricity in electro-technical complexes and systems of underground mining enterprises in a qualitative aspect is characterized by its technical equipment, degree of productivity, suitability and other properties.

The modern period of electrification of production is characterized by a significant increase in the role of indicators of the technical and economic efficiency of the use of electricity.

As you know, reducing their energy intensity is an integral and decisive component of the efficiency of industrial enterprises. It is natural that the energy intensity of industrial enterprises is influenced by: natural and climatic factors, fixed and working capital, intangible assets, personnel activity. It is the energy intensity of enterprises that determines how effective the management's actions are in the field of distribution, direction, planning and analysis of all the available resources of the enterprise, which niche is and will be occupied by this enterprise in the market in the future, taking into account the influence of the competitive environment on it. An important place in this issue belongs to the impact on the dynamics of the components of the production process of current trends in the field of technology development, that is, taking into account the factor of scientific and technical progress. The apparatus of econometric methods of modeling complex production processes allows to investigate these processes, their interaction, to reveal the peculiarities of the structural relationship between these components. Therefore, the study of issues of formalization of production potential based on the use of modern approaches and methods of economic and mathematical modeling is an important and urgent issue for domestic iron ore enterprises.

1. Features of modeling production potential as a field of enterprise activity are represented by the apparatus of production functions developed by Cobb and Douglas, and improved by taking into account the factor of scientific and technical progress in the works of Tinbergen. The specifics and individual features of the technology of operation of iron ore enterprises in view of the energy intensity of the processes are covered in detail in the works of A. A. Dremin. Without diminishing the in-depth scientific analysis of the production potential of enterprises, we note that the issue has not been fully investigated and requires further study.

The practical basis for improving the efficiency of electricity consumption in enterprises is, among other things, the improvement of methods for calculating electrical loads, establishing scientifically based specific electricity consumption, increasing the accuracy of forecasting and the level of planning of electricity consumption indicators, reducing losses and saving electricity, etc. The rapid growth of energy consumption creates a danger of the imminent exhaustion of fossil energy resources. The risks associated with the development of the energy industry determine the increased interest in certain assessments of the future dynamics of the energy industry and the consequences of its development. It should be taken into account that energy security is currently the cornerstone of the policy of many countries. It is appropriate to note that by 2030, according to the Ministry of Fuel and Energy of Ukraine, the country plans to reduce the consumption of energy resources by 12%, including in metallurgy, which traditionally includes the iron ore industry, by 30%. In contrast to these "plans", we note that until 2019 such a trend in the levels of electricity consumption is not observed in reality. The level of electricity consumption in 2018 compared to 2013, electricity consumption in Ukraine practically did not decrease, including in metallurgy (including the mining industry) it did not decrease at all (≈24.5%).

When determining a comprehensive assessment of electricity consumption, the question arises about the change in consumption from each source of electricity in comparison with the previous period, as well as what are the reasons, namely: a change in technology; provision of resources, etc. Elaboration of these issues is the basis for the possibility of solving issues for the formation of a comprehensive assessment of electricity consumption

Efficient electricity consumption is a consequence of reducing energy intensity and should be based on optimal planning and forecasting of electricity consumption. Optimum planning and forecasting of electricity consumption is based on scientifically based regulation of electricity consumption for the main and auxiliary production processes. The rationing of electricity costs largely depends on the planned measures of electricity consumption at enterprises. The establishment of technical and economically justified planned measures of electricity consumption poses the task of determining the load modes of electricity receivers.

2. Analyzing the mentioned factors, it is possible to distinguish two main directions of ensuring optimal energy capacity, namely: the supply of physical volumes of energy resources in accordance with the needs of the economy, while reducing the influence of external factors on the stability of energy supply, and reducing the growth rate of the economy’s need for energy carriers while ensuring stable GDP growth by increasing the efficiency of the use of energy resources by the national economy. Moreover, these directions also contribute to strengthening the economic security of the state. Each of the above directions has its own priorities. In general, the implementation of the solution to the task of ensuring optimal energy efficiency, taking into

account the listed factors, involves two directions. Implementation of the first direction means ensuring: maximum use of available own energy resources, new energy conversion technologies, use of secondary energy resources; avoidance of monopoly dependence of energy supplies through diversification of energy import sources and transportation routes; modernization of fixed assets, primarily of fuel and energy complex (FEC) enterprises (the level of wear and tear of fixed assets of FEC is about 60%); development of a set of measures to ensure the vital activity of the economy in the event of unforeseen circumstances in the FEC or with supplies of FER. Implementation of the second direction should ensure: changing the structure of industrial production by reducing the specific weight of energy- and resource-intensive industries; comprehensive modernization and rearmament of economic complexes of Ukraine based on energy saving, implementation of the latest energy-saving technologies, modern telecommunications and computer networks; reduction of wasteful and unmanaged use of fuel and energy resources (FER) and secondary energy resources; expanding the use of alternative energy sources. The analysis of the priorities of both directions of ensuring the optimal energy intensity of iron ore enterprises points to energy saving as a key direction of efforts of the management apparatus. At the current stage, Ukraine faces the task of reducing the energy intensity of its economy and thus guaranteeing its security

This can be achieved in several ways. Extensive - increasing own production and imports from various suppliers - is the most acceptable for Ukraine, taking into account its economic condition. However, one cannot completely distance oneself from the introduction of alternative energy. By replacing outdated equipment with new ones, Ukraine can almost halve its heat and electricity costs.

In view of this, the main components of the formation of approaches to the comprehensive assessment of electricity consumption by iron ore enterprises can be formulated: theoretical justification of methodological provisions for monitoring the electricity consumption of energy-intensive components; modeling; optimization and forecasting; substantiation and determination of informative signs and indicators of energy efficiency using factor analysis, etc. This is especially important in conditions of limited volume of the data set.

The theoretical and methodological principles are the basis for evaluating the consumption of electrical energy both theoretically and in practical application.

It is considered appropriate to have a three-level hierarchy of electricity consumption. At the first level, an analysis of the external environment of electricity consumption is carried out, which allows obtaining information about the potential costs of maintaining and servicing the electricity supply system. The second level is intended for internal use, within which specific indicators of electricity consumption are evaluated, as well as an assessment of trends in the development of electricity consumption at the enterprise. The set of first and second level data allows for the evaluation of electricity consumption for the analysis of the main indicators of electricity supply, and also creates prerequisites for the implementation of management measures. At the third level, specific management recommendations are formed, which are based on an expert assessment of the value and dynamics of the main indicators of electricity supply and electricity consumption, as well as objective data on the state of electricity consumption obtained at the previous stages.

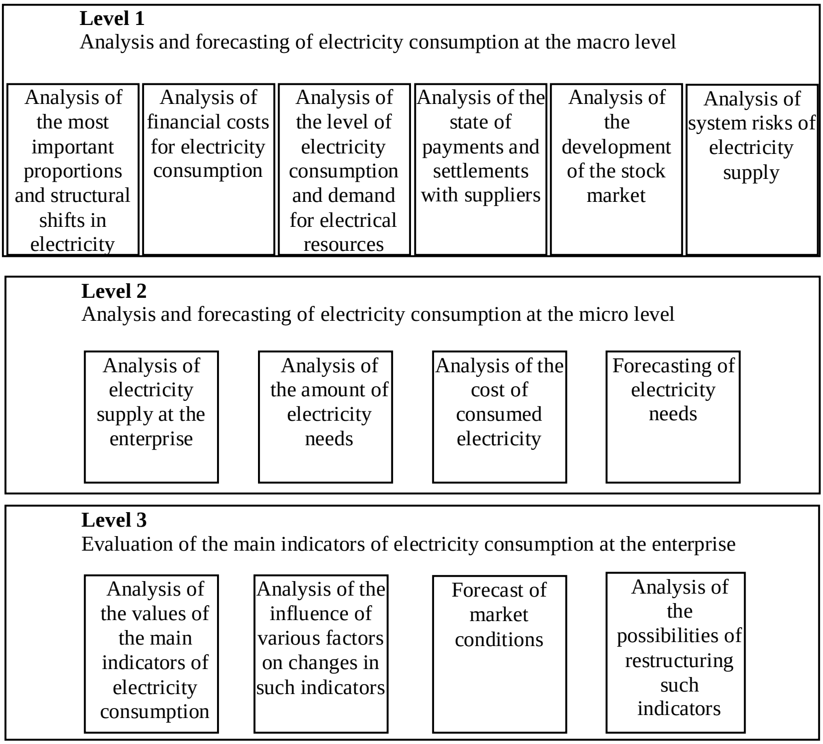


Figure 3.6 – System of main indicators of electricity consumption of enterprises

On the basis of the information obtained from the electricity consumption system, various management decisions can be made, including regarding the optimization of electricity consumption at enterprises. That is, such a system is an information base for planning and forecasting optimal values of the main indicators of electricity consumption. This determines the need to continue research in the field of creating fundamentally new methods and means of information integration.

Comparative analysis occupies a significant place among statistical methods. Based on the analysis of statistical information, data comparison, managers have the opportunity to make effective decisions regarding the consumption of electricity. Accordingly, in relation to the management processes of electricity consumption at enterprises of the iron ore industry, the levels of electricity consumption of the selected most energy-intensive components were studied, namely: skip lifting installations (SLI), crushing and sorting factory (CSF), water discharge installations, ventilation installations. Graphs (Fig. 3.6 - Fig. 3.11) were constructed based on the data obtained, which allows for a visual analysis of the components of the electricity balance.

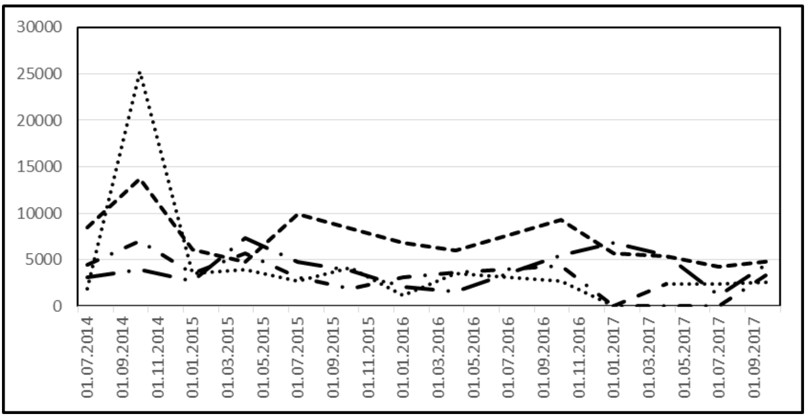


Figure 3.6 – Electricity consumption at the CSF of Kryvbas iron ore mines

Yes, Fig. 3.7 – electricity consumption of the Federal State Statistics Service – certifies the highest level of electricity consumption noted on Lenin mine in the period from September 1, 2014 to November 1, 2014. In the specified period, there is a significant increase for Zhovtneva mine.The period of the lowest consumption corresponds to: 01.05.2017 - 01.07.2017.

The electricity consumption of the SFS for Gvardiyska, Zhovtneva, and Rodina mines in the period from 01.01.2015 to 01.09.2017 is characterized by relative stability, in contrast to Lenin mine.

Figure 3.8 shows the power consumption of ebb devices. In contrast to the electricity consumption of the components of the Federal State Statistics Service, the levels of electricity consumption of water discharge devices are of much greater importance. For Rodina mine correspond to the period 01.07.2014 - 01.09.2014, and from 01.07.2017 to 01.09.2017. In general, electricity consumption by ebb devices for Rodina mine is characterized by significant unevenness, which may indicate technical problems in the operation of the devices. For Zhovtneva, Gvardiyska, Lenin mines electricity consumption can be characterized as relatively stable. The lowest consumption of electricity was recorded for Gvardiyska mine.

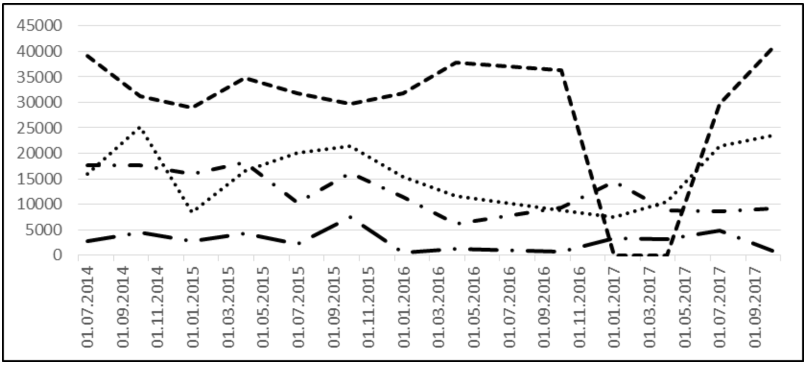


Figure 3.7 – Electricity consumption at water discharge facilities of Kryvbas iron ore mines

Fig. 3.8 corresponds to the description of electricity consumption by ventilation devices for iron ore enterprises of the Kryvyi Rih region. We can consider the consumption of electricity by ventilation devices for Rodina mine characterized by significant fluctuations. The highest values were recorded in the period from September 1, 2014 to March 1, 2015. Electricity consumption by ventilation devices is considered relatively stable. Lenin mine the lowest values of electricity consumption by ventilation devices were recorded for Zhovtneva mine in the period from September 1, 2014 to November 1, 2014.

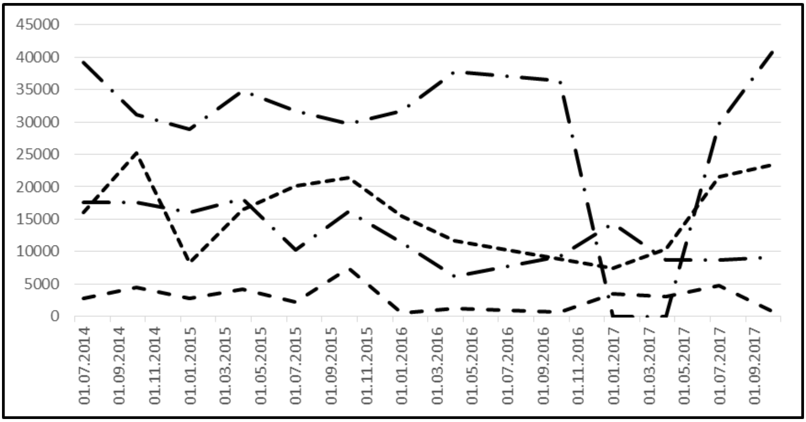


Figure 3.8 – Electricity consumption at ventilation installations of Kryvbas iron ore mines

We perform a visual analysis of the electricity consumption by the SLI devices in accordance with fig. 3.9. Lenin and Rodina mines, which have the lowest values of electricity consumption by SLI devices in the period from 01.01.2017 to 01.03.2017. The general characteristics of electricity consumption by the SLI devices for enterprises of the Kryvyi Rih region are relatively unstable.

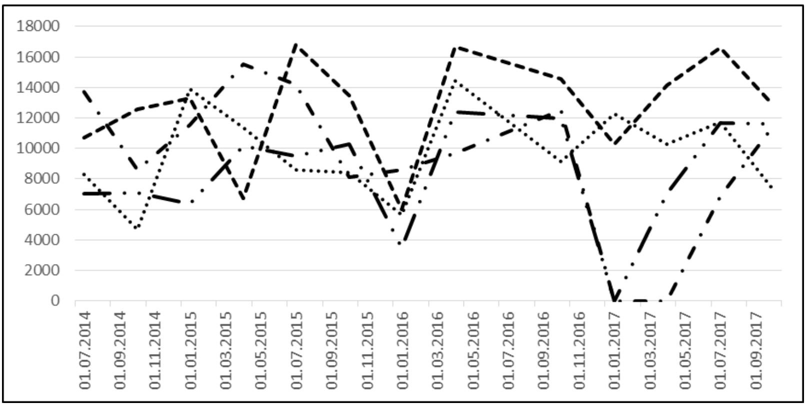


Figure 3.9 – Electricity consumption at the Kryvbas iron ore mines SLI

Thus, it can be argued that the period from 01.01.2017 to 01.03.2017 is considered problematic for Rodina mine - no power consumption for all analyzed devices. Drainage devices consume the most electricity. The lowest values of electricity consumption correspond to CSF devices. For the practical application of information and analytical information, we use appropriate quantitative methods.

It is generally known that observation is the main stage of statistical research. That is, tracking the consumption of electrical energy is the basis for the application of statistical research methods. It is important to track the consumption of electrical energy both to eliminate uncertainty when making management decisions and to obtain information for building an appropriate forecast.

As research shows, iron ore enterprises in general and with underground methods of iron ore raw material extraction in particular are powerful consumers of electricity. Table 3.4 presents statistical data on electricity consumption at individual iron ore mines. The data provided in Table 1 make it possible to conduct a comparative analysis. Such a scattering of statistical data indicates the need for additional analysis. Such analysis can be multifactor analysis, spline analysis, etc..

Table 3.4 – Indicators of electricity consumption and its cost by iron ore mines of Ukraine (December 2020)

Mines	Electricity consumption, thousand, kWh	Specific share of energy consumption, %	Volumes payment for consumption electricity, thousand UAH	Specific share of payment for electricity, %	Specific value, hryvnias/kWh
Zhovtneva mine (Kryvyi Rih city)	3871,095	14,40	3510,437	13,04	0,90683
Rodina mine (Kryvyi Rih city)	6014,121	22,38	5541,670	20,59	0,92144
Gvardiyskaya mine (Kryvyi Rih city)	3919,249	14,58	4263,806	15,84	1,08791
Ternivska mine (Kryvyi Rih city)	3522,988	13,11	3291,708	12,23	0,93435
Frunze mine (Kryvyi Rih city)	4104,824	15,27	4620,472	14,81	1,12562
Yuvileyna mine (Kryvyi Rih city)	5073,224	15,12	4793,081	14,62	0,94478
Artyoma mine (Kryvyi Rih city)	4576,334	16,78	4510,298	14,95	0,98557

Hihant-Hlyboka mine (Kryvyi Rih city)	3376,675	89,23	3844,850	88,45	1,13865
Ekspluataciyna mine (Dniprorudne city)	3567,732	14,94	3729,671	13,64	1,04539

Visual analysis allows us to draw a conclusion about the correlation of data on electricity consumption and cost.

Based on the information obtained from the electricity consumption tracking system, appropriate management decisions can be made. Therefore, the application of statistical research methodology should be applied in the study of electricity consumption. Accordingly, there are requirements for the application of such a methodology.

In fig. 3.10 presents the author's vision and identification of requirements for the formation of a system of statistical methodology for estimating the consumption of electrical energy.

The system of principles of statistical methodology in the study of electrical energy consumption should include two levels of research: methodological and practical. The methodological level should include the following principles: interrelationship of elements; minimum permissible accuracy; unity of design principles; increasing informativeness. The practical level should include: communication with the current accounting system; visibility (understandability, convenience); versatility; The (methodological) aspect of tracking is precision and unity.

Another important principle is the principle of simplification.

The next principle is the principle of increasing informativeness.

The most important principles of practical modeling of the statistical research system are identification and interpretation; the principle of interpretation; the principle of differentiation and coordination of economic interests; principle of invariance.

The combination of the principles of differentiation and coordination of interests, intersubjectivity, and invariance leads to the formulation of the principle of universality.

The most important requirements for an analytical information system are: comparability, complexity, systematicity, reasonableness, visibility.

The definition of interpolation indicators is indisputable when examining power consumption systems

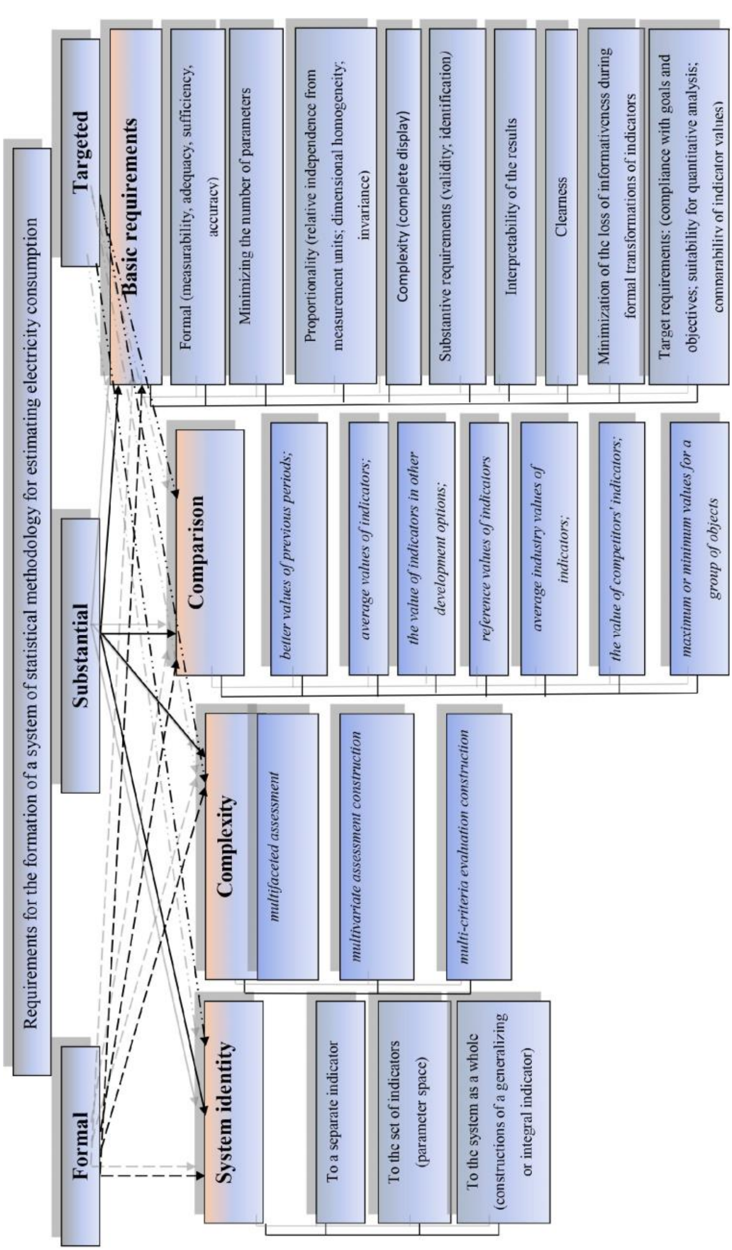


Figure. 3.10 – Identification of requirements for the formation of a system of statistical methodology for the assessment of electric energy consumption

Setting the interpolation task

Let a set of interpolation nodes or a grid on some segment [a, b] be given. In the simple case, the grid is uniform, that is, the distance between neighboring nodes is the same. In the future, we will also consider non-uniform grids.

1. The set of nodes $\left\langle \{ t_{n,} \right._{n=0}^{n=N}$, **t=(b-a)/N, t∈[a,b]**. For most of the statements below, the requirement that the grid is uniform is not necessary, almost all statements are easily proven for any grid, it is only important that there are no matches among the nodes.

2. The grid projection of the functionf(t) on [a, b], тобто таблиця $f_n = \left\{ f(t_n) \right\}_{n=0}^{N}$; i.e. the table this table is set by the grid restriction or restriction operator R [39].

The task is to reconstruct a continuous function from the table {fn}.

The number of parameters defining the spline is equal to the number of spline nodes. There is a dependence between the parameters of the function on the fragment and the coefficients of the polynomial-spline, which allows one to find others based on one coefficient, although the formulas can have a rather complicated form [38].

Contents of spline coefficients. As previously mentioned in the previous paragraph, the content of the spline parameters in the piecewise representation is determined by the type of function. With the polynomial representation, it is worth highlighting the case when the coefficients have the same physical meaning as the input data. That is, the coefficients are the values of the spline at the nodes. We will call this form Lagrangian, by analogy with the Lagrange polynomial. Note that the basic splines of this form are equal to one at the central node and zero at all others.

Taking into account the important economic aspect of electricity consumption, we consider it appropriate to consider statistical risk assessment.

This method is used to assess economic risks in cases where there is a significant amount of analytical and statistical information for a certain time regarding the effectiveness of the implementation of agreements on the consumption of electric energy, etc.

The essence of the statistical method of assessing the degree of risk is based on the theory of probability distribution of random variables. This means that, having sufficient information about the realization of certain risks in the past periods of electricity consumption, any business entity can estimate the probability of their realization in the future.

With the help of a statistical method, it is possible to assess the risk not only of a specific agreement, but also of the enterprise as a whole, when analyzing the dynamics of electricity consumption over a certain time.

The advantage of this method of assessing economic risks is simple mathematical calculations, and the obvious disadvantage is the need for a large amount of initial data, because the larger the array of statistical data, the greater the reliability of the assessment of the risk itself. Therefore, the statistical method cannot be used if there is no statistical information necessary for risk assessment.

Statistically, risk is assessed by calculating the fluctuation (variability) of a possible result. In practice, variance and standard deviation are used to characterize the degree of variability.

Dispersion is the mathematical expectation of the square of deviations of the possible values of a random variable from its mean value; or the weighted average of the squared deviations of the results from the expected ones. The formula for calculating the variance is as follows

$$D = \sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot P_i, \qquad (3.40)$$

where x_i - is the value that a random variable can take depending on specific conditions; x - the average expected value of a random variable; $P_1, P_2, \ldots, P_n$ – are the probability of possible values of a random variable.

The spread of the possible values of a random variable from its mean value can also be expected by the mean square deviation, which is the square root of the variance.

$$\sigma = \sqrt{\sum_{i=1}^{n_1} (x_i - \bar{x})^2 \cdot P_i} \qquad (3.41)$$

The economic meaning of the root mean square deviation from the point of view of risk theory is that it acts as a characteristic of a specific risk, which shows the maximum possible fluctuation of a value from its average expected value. This allows you to use the root mean square deviation as an indicator of the degree of risk in terms of the probability of its realization. At the same time, the larger the value of the root mean square deviation, the riskier is a certain management decision and, accordingly, the riskier the path of electricity consumption. The root mean square deviation is measured in the same units as the random variable being analyzed to determine risk.

As an example, you can consider two options for investing in a project related to electricity consumption worth UAH 100,000. for a period of one year: Project 1 provides for net costs of UAH 100,000, zero income during the year and payments at the end of the year, which will depend on the economic circumstances; project 2 is also worth UAH 100,000, but the distribution of payments differs from project 1.

Table 3.5 – Output data

Economic circumstances	Probability	Rate of return on investments, %	
		Project 1	Project 2
Deep recession	0,05	-3,0	-2,0
Medium recession	0,20	6,0	9,0
Slight growth	0,50	11,0	12,0
Medium growth	0,20	12,0	15,0
Strong growth	0,05	18,5	26,0

It is necessary to assess the risk of each project.

Calculations of the average expected rate of investment income for each of the projects, as well as the root mean square deviation as an absolute degree of risk are summarized in Table 3.6.

According to formula the standard deviation is equal to:

project 1: $\sigma = \sqrt{23{,}0} = 4{,}8\%$;

project 2: $\sigma = \sqrt{11{,}2} = 3{,}3\%$.

Therefore, project A has a wider margin of deviation from the expected amount of income.

You can graphically display the distribution of probability values of each of the projects. For this, first of all, it is necessary to assume that the distribution of values of probability values is normal. This means that half of the values in the distribution are smaller than the expected value, and half are larger. It is possible to have two normal distributions of probability values, but the closer the distribution line is to the expected value, the greater the confidence that the actual results are closer to the mean or expected value. Results closer to the expected value are more likely where the distribution is narrower.

Table 3.6 – Calculation of project characteristics

Economic circumstances	Probability (P_i)	Rate of income % (x_i)	Income % $(x_i \cdot p_i)$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$	$(x_i - \bar{x})^2 \cdot p_i$
1	2	3	4	5	6	7
Project 1 Deep recession	0,05	-5,0	-0,25	-15,6	243,4	12,2
Medium recession	0,20	6,0	1,2	-4,6	21,2	4,2
Slight growth	0,50	12,0	6,0	1,4	2,0	1,0

Medium growth	0,20	13,0	2,6	2,4	5,8	1,2
Strong growth	0,05	20,0	1,0	9,4	88,4	4,4
			10,6	D = 23,0		
Project 2 Deep recession	0,05	-2,0	-0,1	-12,6	158,8	7,9
Medium recession	0,20	9,0	1,8	-1,6	2,6	0,5
Slight growth	0,50	11,0	5,5	-0,4	0,2	0,1
Medium growth	0,20	13,0	2,6	2,4	5,8	1,2
Strong growth	0,05	16,0	0,8	5,4	29,2	1,5
			10,6 (x)		D = 11,2	

As can be seen from fig. 3.3, the distribution of probability values for projects 1 and 2 is normal, but the first project has a wider margin of deviation from the expected value. This means that the first project is riskier than the second.

The probability distributions of projects 1 and 2 have the same expected return value, but in the second project the distribution line is narrower, indicating less variability of return relative to the expected value, and therefore less risk.

Thus, in the given example, using a statistical method, risk is measured taking into account the variability of expected income. The more the income fluctuates, the higher the risk. This variability in the statistical method is measured using the root mean square deviation.

Dispersion and standard deviation are measures of absolute variability. In the quantitative analysis of risks, the coefficient of variation is also used, which is a relative measure of variability

The coefficient of variation is the ratio of the root mean square deviation of the results to the average (expected) value of the results.

The formula for calculating the coefficient of variation is as follows

$$\nu = \frac{\sigma}{\bar{x}} \cdot 100\% \,. \qquad (3.42)$$

The coefficient of variation is a relative value. Therefore, its size is not affected by the absolute values of the analyzed indicator. With the help of the coefficient of variation, it is possible to compare the variability of features expressed in different units of measurement. The coefficient of variation can vary from 0 to 100%. The larger the coefficient, the stronger the variability. There is the following qualitative assessment of different values of the coefficient of variation:

up to 10% - weak variability;
10-25% - moderate variability;
more than 25% - high variability.

3.2.2 Statistical methods of electrical energy generation research (Correlation, dispersion, factor and regression analysis, statistical hypotheses)

Analytical positive properties of regression models consist in the fact that, firstly, the factor that determines the reserves for increasing the efficiency of power consumption management is precisely determined; secondly, objects with a higher level of efficiency are revealed; thirdly, there is an opportunity to quantitatively measure the economic effect of the implementation of best practices, the implementation of organizational and technical measures.

Interpretation of regression models is carried out using the methods of the field of knowledge to which the studied phenomena belong. But any interpretation begins with a statistical evaluation of the regression equation as a whole and an estimate of the significance included in the model of the factor characteristics, that is, with finding out how they affect the value of the resulting characteristic. The larger the value of the regression coefficient, the more significant the effect of this feature on the model. In this case, the sign before the regression coefficient is of particular importance, which indicates the nature of the effect on the resulting characteristic. If the factor sign has a plus sign, then with the increase of this factor, the effective sign increases; if the factor sign has a minus sign, then with its increase, the effective sign decreases. Regression coefficients show the intensity of influence of factors on the performance indicator. Thus, the regression coefficients characterize the degree of significance of individual factors for increasing the level of the performance indicator. The specific values of the regression coefficients are determined based on empirical data according to the method of least squares.

The construction of regression models will allow to conduct a more detailed study of the energy-intensive components of iron ore enterprises.

Multiple correlation-regression analysis (MCRA) is used to identify the influence of the most significant factors on the result and to build an adequate mathematical model.

Commonly known stages of MCRA are as follows:

1. The least squares method (LSM) is used to estimate the parameters of the multiple regression equation. For linear equations:

$$y = a + b_1 \cdot x_1 + b_2 \cdot x_2 + \cdots + b_m \cdot x_m + \varepsilon, \qquad (3.43)$$

the following system of normal equations is constructed, the solution of which allows obtaining estimates of the regression parameters:

$$\begin{cases} \sum y = na + b_1 \sum x_1 + b_2 \sum x_2 + \cdots + b_m \sum x_m, \\ \sum yx_1 = a \sum x_1 + b_1 \sum x_1^2 + b_2 \sum x_1 x_2 + \cdots + b_m \sum x_m x_1, \\ \sum yx_m = a \sum x_m + b_1 \sum x_1 x_m + b_2 \sum x_2 x_m + \cdots + b_m \sum x_m^2 . \end{cases} \qquad (3.42)$$

In linear regression, the parameters at x characterize the average change in the result with a change in the corresponding factor by one unit with the unchanged value of other factors fixed at the average level.

2. Application of the method of least squares to the multiple regression equation on a standardized scale:

$$t_y = \beta_1 \cdot t_{x_1} + \beta_2 \cdot t_{x_2} + \cdots + b_m \cdot t_{x_m} + \varepsilon, \qquad (3.43)$$

where:

$t_y, t_{x_1} \ldots t_{x_m}$ – standardized variables calculated as

$$t_y = \frac{y - \bar{y}}{\sigma_y}, \qquad (3.44)$$

$$t_{x_i} = \frac{x_i - \bar{x}_i}{\sigma_{x_i}}, \qquad (3.45)$$

β_i – standardized regression coefficient;

$\bar{y}$ – the mean value of the dependent variable;

σ_y, σ_{xi} – mean square deviations of indicators;

$\bar{x}_i$ – average values of factor characteristics.

3. Comparing factors with each other, it is advisable to rank factors by the strength of their influence on the result. Applying LSM to the multiple regression equation on a standardized scale, we obtain a system of normal equations of the form:

$$\begin{cases} r_{yx_1} = \beta_1 + \beta_2 r_{x_1 x_2} + \beta_3 r_{x_1 x_3} + \cdots + \beta_m r_{x_1 x_m}, \\ r_{yx_2} = \beta_1 r_{x_1 x_2} + \beta_2 + \beta_3 r_{x_1 x_3} + \cdots + \beta_m r_{x_1 x_m}, \\ r_{yx_m} = \beta_1 r_{x_1 x_m} + \beta_2 r_{x_2 x_m} + \beta_3 r_{x_3 x_m} + \cdots + \beta_m . \end{cases} \qquad (3.46)$$

where r_{yx1} та r_{xixj} – pairwise and interfactor correlation coefficients.

The "pure" regression coefficients b_i are related to the standardized regression coefficients β_i in the following order:

$$b_i = \beta_i \cdot \frac{\sigma_y}{\sigma_{x_i}} \qquad (3.47)$$

4. The transition from the regression equation in the standardized scale to the regression equation in the natural scale of the variables, with the parameter a defined as:

$$a = \bar{y} - b_1 \cdot \bar{x}_1 - b_2 \cdot \bar{x}_2 - \cdots - b_m \cdot \bar{x}_m. \quad (3.48)$$

The considered meaning of the standardized regression coefficients allows them to be used when screening factors - factors with the smallest β_i value are excluded from the model.

5. Calculation of average coefficients of elasticity for linear regression are calculated according to the formula:

$$\overline{E_{yx_j}} = b_j \cdot \frac{\bar{x}_j}{\bar{y}}. \quad (3.49)$$

The coefficients show how many percent the result will change on average, if the corresponding factor changes by 1%. The average indicators of elasticity can be compared with each other and the factors can be ranked according to the strength of their influence on the result.

6. Determination of the density of the joint influence of factors on the result in relation to the evaluation of the multiple correlation index:

$$R_{yx_1x_2\ldots x_m} = \sqrt{1 - \frac{\sigma^2_{\text{уост}}}{\sigma^2_{\text{у}}}}. \quad (3.50)$$

The multiple correlation index value is between 0 and 1 and must be greater than or equal to the maximum pairwise correlation index:

$$R_{yx_1x_2\ldots x_m} \geq r_{yx_i} (i = \overline{1,m}). \quad (3.51)$$

7. Definition of the adjusted index of multiple determination, which contains a correction for the number of degrees of freedom and is calculated according to the formula.

$$\hat{R}^2 = 1 - (1 - R^2) \cdot \frac{(n-1)}{(n-m-1)}, \quad (3.52)$$

where n – number of observations;

m – number of factors.

8. The calculation of private coefficients (or indices) of correlation, which measure the influence on y of the factor x_i, with the elimination (exclusion of the influence) of other factors, can be determined by the formula:

$$r_{yx_1 \cdot x_1x_2\ldots x_{i-1}x_{i+1}\ldots x_m} = \sqrt{1 - \frac{1 - R^2_{yx_1x_2\ldots x_m}}{1 - R^2_{yx_1x_{j-1}x_{j+1}\ldots x_m}}}, \quad (3.53)$$

or by the recurrent formula:

$$r_{yx_1 \cdot x_1x_2\ldots x_{i-1}x_{i+1}\ldots x_m} = \frac{r_{yx_1 \cdot x_1x_2\ldots x_{i-1}x_{i+1}\ldots x_{m-1}} - r_{yx_m \cdot x_1x_2\ldots x_{m-1}} \cdot r_{x_1x_m \cdot x_1x_2\ldots x_{i-1}x_{i+1}\ldots x_{m-1}}}{\sqrt{(1 - r_{yx_m \cdot x_1x_2\ldots x_{m-1}}) \cdot (1 - r_{x_1x_m \cdot x_1x_2\ldots x_{i-1}x_{i+1}\ldots x_{m-1}})}}. \quad (3.54)$$

Private correlation coefficients determine the degree of closeness of the connection of each factor with the result in its pure form, without taking into account the influence of other factors.

9. The evaluation of the significance of the multiple regression equation is generally evaluated using Fisher's F-criterion

$$F = \frac{R^2}{1-R^2} \cdot \frac{n-m-1}{m}, \tag{3.55}$$

The private F-criterion evaluates the statistical significance of the presence of each of the factors in the equation. In general, for the factor *x*, the private F-criterion will be defined as:

$$F_{x_i} = \frac{R^2_{yx_1x_2\ldots x_m} - R^2_{yx_1x_{j-1}x_{j+1}\ldots x_m}}{1-R^2_{yx_1x_2\ldots x_m}} \cdot \frac{n-m-1}{m}. \tag{3.56}$$

The actual value of the private F-criterion is compared with the table value at the level of significance α and the number of degrees of freedom: k_1=1; k_2=n–m–1. If the actual value of F_{xi} exceeds F_{table} (α, k_1, k_2), then the additional inclusion of factor x_i in the model is statistically justified and the net regression coefficient b_i with factor xi is statistically significant.

10. The significance of pure regression coefficients is assessed using the Student's t-criterion. In this case, as in paired regression, a formula is used for each factor:

$$t_{b_i} = \frac{b_i}{m_{b_i}}. \tag{3.57}$$

For a multiple regression equation, the mean squared error of the regression coefficient can be determined by the formula:

$$m_{b_i} = \frac{\sigma_y \cdot \sqrt{1-R^2_{yx_1x_2\ldots x_m}}}{\sigma_{x_i} \cdot \sqrt{1-R^2_{x_1x_2\ldots x_m}}} \cdot \frac{n-m-1}{m}, \tag{3.58}$$

where $R^2_{x_1x_2\ldots x_m}$ – coefficient of determination for the dependence of factor x_i with all other factors.

11. On the basis of the calculated indicators of model adequacy, insignificant factor characteristics are determined and removed from further research. Thus, a new model is built, which includes significant factor characteristics, with new estimated regression parameters pre-calculated for it. On the basis of the new model, conclusions are formed about the influence of features on the resulting indicator.

Using the methodology of multivariate regression analysis, multivariate regression models were built (Table 3.7)

Table 3.7 – Multifactor models of iron ore enterprises of the Kryvyi Rih region

Enterprise	multivariate regression equation	R^2
Zhovtneva mine	$Y = 60421 + 0.37x1 - 0.9x2 - 0.35x3 - 0.66x4$	0.59
Gvardiyskaya mine	$Y = 134472.1 - 0.14x1 - 0.21x2 - 2.01x4$	0,29
Rodina mine	$Y = 61237.34 + 0.45x1 + 0.01x2 + 0.17x3 - 0.49x4$	0.87
Ternivska mine	$Y = 10719 - 0.21x1 + 2.35x2 + 0.18x3 - 2.32x4$	0,84

Where: X1 is the value of electricity consumption levels for SLI; X2 - the value of electricity consumption levels for ventilation; X3 - the value of electricity consumption levels for drainage; X4 - value of electricity consumption levels for CSF.

If there are three factors, then there is an opportunity to display the obtained results three-dimensionally.

R^2 – quantitative assessment of the obtained regression multiple equation. Let's say, for w Gvardiyska is 0.29, which indicates the inadequacy of the obtained equation. Obviously, there is a need to study incoming statistical data.

The multiple coefficient of determination, which determines the level of variation of the dependent variable at the expense of independent variables, is given as:

$$R^2 = \frac{\sigma_Y^2}{\sigma_{X_j}}, \ldots j = 1, m; \qquad (3.59)$$

$$R^2 = \frac{\hat{A}' X' Y}{Y' Y} \frac{n-1}{m-1}. \qquad (3.60)$$

Coefficient of determination without taking into account the number of degrees of freedom:

$$\bar{R}^2 = \frac{\hat{A}' X' Y}{Y' Y}. \qquad (3.61)$$

The correlation between them is taking shape:

$$R^2 = 1 - \left(\frac{n-1}{n-m}\right)(1 - \bar{R}^2). \qquad (3.62)$$

The multiple correlation coefficient $R = \sqrt{R^2}$ characterizes the closeness of the relationship between the dependent and independent variables. The multiple coefficient of determination and correlation satisfies the condition:

$$R^2 \in [0,1[; \ldots R \in]0,1]. \qquad (3.63)$$

The hypothesis about the presence or absence of a relationship between the dependent and independent variables can be tested using the F-criterion:

$$F = \frac{\sigma_P^2}{\sigma_u^2}. \quad (3.63)$$

The actual value of the F-criterion is compared with the tabular one at the degrees of freedom ***m-1*** and ***n-m*** and the selected level of significance. If $\boldsymbol{F_{fact}} > \boldsymbol{F_{table}}$, then the hypothesis about the significance (significance) of the relationship between the dependent and independent variables of the model is confirmed, otherwise it is rejected.

An alternative formula of the F-criterion due to the coefficient of determination takes shape

$$F = \frac{R^2/(m-1)}{(1-R^2)/(n-m)}. \quad (3.64)$$

The statistical significance of model parameter estimates can be determined based on the t- criterion:

$$t_j = \frac{\hat{a}_j}{\sqrt{\sigma_u^2 c_{jj}}}. \quad (3.65)$$

The value of the criterion t_j is compared with the tabular value at the selected level of significance α and ***n-m*** degrees of freedom. **If** $\boldsymbol{t_{fact}} > \boldsymbol{t_{table}}$, then the corresponding parameter of the econometric model is statistically significant.

Based on the t- criterion and standard error, confidence intervals for the parameters $\hat{a}_j$ are constructed *:*

$$a_j = \hat{a}_j \pm t_{(\alpha)}\sqrt{\sigma_u^2 c_{jj}}. \quad (3.66)$$

Prediction of the dependent variable based on the model given the dependent variables can be performed according to the following relationship:

$$\hat{Y}_{np} - t_{(\alpha)} S(\hat{Y}) \le Y \le \hat{Y}_{np} + t_{(\alpha)} S(\hat{Y}). \quad (3.67)$$

In this ratio $S(\hat{Y})$ is the standard error of the forecast:

$$S(\hat{Y}) = \sqrt{\sigma_u^2 X_p'(X'X)^{-1}X_p}, \quad (3.68)$$

where $\boldsymbol{X_p}$ – predictive values of independent variables; $\boldsymbol{X'_p}$ – matrix transposed to a matrix $\boldsymbol{X_p}$.

Autoregression and moving average model. A general model proposed by Box and Jenkins (1976) includes both autoregressive and moving average parameters. Namely, there are three types of model parameters: autoregression parameters (p), integrated parameters (d), moving average parameters (q). In the notation of Box and Jenkins, the model is written as ARIMA (p, d, q). For example, model (0, 1, 2) contains 0 (zero) autoregressive parameters (p) and 2 moving average parameters (q), which are calculated for the series after taking the difference with lag 1.

Identification. As before, the ARIMA model requires the series to be stationary, meaning that its mean is constant, and the sample variance and autocorrelation do not change over time. Therefore, it is absolutely necessary to take the differences of the series until it becomes stationary (logarithmic transformation is also often used to stabilize the variance). The number of differences that were taken to achieve stationarity is added by the parameter. Strong changes (strong jumps up or down) traditionally require taking the non-seasonal difference of the first order (lag = 1). Strong changes in slope require taking the difference of the second order. The seasonal component requires taking the appropriate seasonal difference (see below). If there is a complete decrease of the selective autocorrelation coefficients depending on the lag, the difference is usually taken in the first way. However, it should be remembered that for some time series it is necessary to take differences of a small order or not to take them at all. Note that a larger number of differences taken with a smaller number of coefficient estimates.

In this step (commonly referred to as model order identification, see below) you must also decide how many autoregressive parameters (p) and moving average (q) should be present in an efficient and parsimonious process model. (The parsimony of a model means that it has the least number of parameters and the largest number of degrees of freedom of all the models that are fit to the data). In practice, it is very rare that the number of parameters p or q is more than 2.

Assessment and prognosis. After identification, the next step (Evaluation) consists in estimating the parameters of the model. The obtained parameter estimates are used in the last stage (Forecast) in order to calculate new values of the series and build a confidence interval for the forecast. The evaluation process is carried out based on the transformed data (subject to the application of the difference operator). Before building a forecast, you need to perform the reverse operation (integrate data). Thus, the prediction of the methodology will be compared with the corresponding raw data. Data integration is indicated by the letter I in the general name of the model (ARIMA = autoregression integrated moving average).

Constant in ARIMA models. Additionally, ARIMA models can contain a constant whose interpretation depends on how the model is fitted. Namely, if there are no autoregression parameters in the model, then the constant is the average value of the series, if there are autoregression parameters, then the constant is a free term. If the difference of the series was taken, then the constant is the average or free term of the transformed series. For example, if the first difference (first-order difference) was taken, and there are no autoregression parameters in the model, then the constant is the average value of the transformed series and, therefore, the slope coefficient of the linear trend.

When calculating moving averages, each subsequent interval is formed on the basis of the previous one by replacing one level. Since the average $\bar{y}_j$ belongs to the middle of the interval, it is advisable to form intervals from an odd number of levels of the primary series. In the case of an even number of levels, an additional centering procedure is required (averaging each pair of values $\bar{y}_j$).

The series of moving averages is shorter than the primary one by (*m* – 1) levels, which requires careful attention to the choice of the width of the interval *m*. If the primary series of dynamics has a certain periodicity of oscillations, then the smoothing interval must be equal to or a multiple of the oscillation period.

For example, the width of the smoothing interval is *m* = 3. The primary series consists of seven levels, the series of moving averages consists of five, that is, it is two levels shorter (7 – 3 + 1).

Table 3.8 – Calculation of moving averages

Serial number of the year	y_t,	Moving average $\bar{y}_j$	Calculation $\bar{y}_j$
1	23,8	—	—
2	19,1	21,6	(23,8 + 19,1 + 21,9) : 3 = 21,6
3	21,9	22,2	21,6 + (25,6 – 23,8) : 3 = 22,2
4	25,6	24,0	22,2 + (24,5 – 19,1) : 3 = 24,0
5	24,5	26,2	24,0 + (28,5 – 21,9) : 3 = 26,2
6	28,5	26,9	26,2 + (27,7 – 25,6) : 3 = 26,9
7	27,7	—	—

The first value of the moving average is calculated as an arithmetic simple, each subsequent one can be determined based on the previous average and a correction term. Example:

$$\bar{y}_1 = \frac{23{,}8 + 19{,}1 + 21{,}9}{3} = 21{,}6 \quad ;$$

$$\bar{y}_2 = 21{,}6 + \frac{25{,}6 - 23{,}8}{3} = 22{,}2;$$

$$\bar{y}_3 = 22{,}2 + \frac{24{,}5 - 19{,}1}{3} = 24{,}0.$$

In the smoothed series of three-year moving averages, primary fluctuations have been eliminated and a systematic increase in its level is clearly visible.

The method of moving averages is also used for preliminary processing of highly fluctuating dynamic series; double smoothing is possible.

For now, we will show statistical studies on the application of spline technologies to determine interpolation points. Let us have data on the quantification of electric system usage values. it is necessary to solve the local problem of interpolation at the point X=1,57 for the following data.

Table 3.9 – Results of calculations coefficient

i	*X*	*Y*
0	-3	-0,141
1	-2	-0,909
2	-1	-0,841
3	0	0
4	1	0,841
5	2	0,909
6	3	0,141

The solution is based on the determination of moments in the formula:

1)

$$\varphi_i(t) = \frac{h^2}{6}\cdot m_{i-1}\cdot(i-t)^3 + \frac{h^2}{6}\cdot m_i\cdot(t-i+1)^3 + (Y_{i-1} - \frac{h^2}{6}\cdot m_{i-1})\cdot(i-t) + (Y_i - \frac{h^2}{6}\cdot m_i)\cdot(t-i+1)$$

Each node (except the extreme ones) corresponds to an equation:

$$m_{i-1} + 4m_i + m_{i+1} = 6\Delta^2 Y_{i-1}$$

$$m_0 = m_6 = 0$$

$$m_0 = m_6 = 0, \quad i = 1$$

2) We add 5 equations of the form:

$$m_0 + 4m_1 + m_2 = 5{,}016; \qquad i = 1;$$
$$m_1 + 4m_2 + m_3 = 4{,}638; \qquad i = 2;$$
$$m_2 + 4m_3 + m_4 = 0; \qquad i = 3;$$
$$m_3 + 4m_4 + m_5 = -4{,}638; \qquad i = 4;$$
$$m_4 + 4m_5 + m_6 = -5{,}016; \qquad i = 5.$$

Make a table:

Table 3.10 – Results of calculations coefficient

I	X	Y	ΔY	$\Delta^2 Y$	$6\Delta^2 Y$
0	-3	-0,141	-0,768	0,836	5,016
1	-2	-0,909	0,068	0,773	4,638
2	-1	-0,841	0,841	0	0
3	0	0	0,841	-0,773	-4,638
4	1	0,841	0,068	-0,836	-5,016
5	2	0,909	-0,768		
6	3	0,141			

3) We solve the system by the method of running, which is based on the solution of the following ratios:

$$m_i = \xi_i \cdot m_{i+1} + \eta_i; \tag{3.68}$$

$$\xi_0 = \eta_0 = 0; \tag{3.69}$$

$$\xi_i = -\frac{1}{\xi_{i-1} + 4}; \tag{3.70}$$

$$\eta_i = \frac{b_i - \eta_{i-1}}{\xi_{i-1} + 4}. \tag{3.71}$$

$$b_i = 6\Delta^2 Y; \tag{3.72}$$

Thus, we get:

$$m_1 = \xi_1 \cdot m_2 + \eta_1; \tag{3.73}$$

$$\xi_1 = -\frac{1}{0 + 4} = -0{,}25;$$

$$\xi_2 = -\frac{1}{-0{,}25 + 4} = -0{,}267;$$

$$\eta_1 = -\frac{5{,}016 - 0}{0 + 4} = 1{,}254;$$

$$\eta_2 = \frac{4{,}638 - 1{,}254}{-0{,}25 + 4} = 0{,}902;$$

$$m_5 = \xi_5 \cdot m_6 + \eta_5; \qquad (3.74)$$

$$m_5 = -0{,}268 \cdot 0 - 1{,}028 = -1{,}028;$$

$$m_4 = -0{,}268 \cdot (-1{,}028) - 1{,}178 = -0{,}902.$$

Make a table:

Table 3.11 – Results of calculations coefficient

i	ξ_i	η_i	m_i
1	-0,25	1,254	1,028
2	-0,267	0,902	0,902
3	-0,268	-0,248	0
4	-0,268	-1,178	-0,902
5	-0,268	-1,028	-1,028

The method is robust to rounding errors (that is, they do not accumulate) and can be applied to the solution of any tridiagonal matrices.

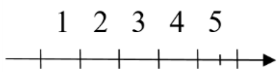
4) Enter the parameter t:

$$t = \frac{X - X_0}{h}, \qquad \text{where } h \text{ – shag}$$

$$h = 1; \quad X = 1{,}57; \quad X_0 = -3;$$

$$t = \frac{1{,}57 + 3}{1} = 4{,}57,$$

that is, the point is in the 5th interval. t = 4,57.



Spline $\varphi_5(t)$:

$$\varphi_5(t) = \frac{1}{6} \cdot (-0{,}902) \cdot 0{,}43^3 + \frac{1}{6} \cdot (-1{,}028) \cdot (4{,}57 - 5 + 1)^3 + (0{,}841 -$$

$$- \frac{1}{6} \cdot (-0{,}902)) \cdot 0{,}43 + (0{,}909 - \frac{1}{6} \cdot (-1{,}028) \cdot (4{,}57 - 5 + 1) = 0{,}998;$$

$$\varphi_5(t) = Y(1{,}57) = 0{,}998.$$

Thus, the application of spline statistical methodology allows to determine the necessary data for the definition and application of analytical methods of statistics.

The method of exponential smoothing also makes it possible to assess the degree of influence of the trend and/or cyclic component on the system response, but unlike the method of moving averages, it can also be used for short-term forecasts of the future trend one period ahead. That is why the method has a clear advantage over the previously considered one.

The name of the method comes from the fact that in fact, when it is applied, exponentially weighted moving averages are obtained over the entire time series; and it follows that the smoothed value at any point in the series is some function of all previous observed values. In the moving average method, the calculation does not take into account the influence of observations that lag more than **(L - 1) / 2** periods from the considered one. With exponential smoothing, all previous observations are taken into account – the previous one is taken into account with the maximum weight preceding it – with a little less, it is the "old" observation that affects the result with the minimum statistical weight. Calculating exponential smoothing manually requires an extremely large amount of monotonous work, and a clever algorithm implemented in software makes it easy and elegant to get the results you need.

The algorithm for calculating exponentially smoothed values at any point in the series i is based on three quantities: the observed value Yi at this point in the series, the calculated smoothed value for the previous point in the series Ei-1 and some predetermined smoothing coefficient W, constant throughout the series . It is clear that in the first point of the series there is no smoothed value for the previous point (there is no such point itself), and the smoothed value of E1 is considered to be the magnitude of the response observed at this point, Y1. A simple calculation rule applies to all the following points:

This is easily implemented in spreadsheets such as Quattro Pro or Excel. In the first row of the table with data related to the first point of the row, it is enough to duplicate the Yi value, in the second row enter the above expression, referring to the observed value from the same row of the table and the smoothed value from the previous row in the calculation formula. Next, the formula is simply copied to all other lines with the data of the time series, and further calculations are performed by the program.

A certain problem is the choice of the smoothing coefficient W, which greatly affects the results. Unfortunately, there is no objective criterion for its selection. With an equal degree of smoothing using the exponential smoothing method and the moving average coefficient W is connected to the interval L by the simple ratio W = 2 / (L + 1); in this way, smoothing according to the 5-point scheme is equivalent in its effect on the output data to exponential smoothing with a coefficient of W = 0.33. Although, in principle, W can take any value from the range 0 < W < 1, it is usually limited to the interval from 0.2 to 0.5. At high values of W, instantaneous current observations of the response are taken into account to a greater extent, and vice versa, at low values of W, the smoothed value is determined to a greater extent by the past development trend than by the current state of the system response.

Analysts of most firms use "their" traditional values of W when processing series. Thus, the analytical department of Kodak traditionally uses the value of 0.38, and at Ford Motors - 0.28 or 0.3. In general, dynamically developing firms and markets are characterized by higher W values than more conservative companies and stable markets; higher values are used for forecasts than for the analysis of previous trends. However, the reality is that the choice of the W coefficient was and will remain extremely subjective.

Example. Exponential smoothing and forecasting

.

Table 3.12 – Calculate the forecast based on the following information

Year		**Coefficient W**		
	ES value	**0.50**(1/2)	**0.33** (1/3)	**0.25** (1/4)
1970	5.3	5.300	5.300	5.300
1971	7.8	6.550	6.133	5.925
1972	7.8	7.175	6.689	6.394
1973	8.7	7.938	7.359	6.970
1974	6.7	7.319	7.140	6.903
1975	6.6	6.959	6.960	6.827
1976	8.6	7.780	7.506	7.270

1977	9.1	8.440	8.038	7.728
1978	9.5	8.970	8.525	8.171
1979	9.0	8.985	8.683	8.378
1980	7.1	8.042	8.156	8.059
1981	6.8	7.421	7.704	7.744
1982	6.2	6.811	7.202	7.358
1983	7.8	7.305	7.402	7.468
1984	8.3	7.803	7.701	7.676
1985	9.3	8.551	8.234	8.082
1986	8.6	8.576	8.356	8.212
1987	7.8	8.188	8.171	8.109
1988	8.1	8.144	8.147	8.107
1989	7.9	8.022	8.065	8.055
1990	7.5	7.761	7.877	7.916
1991	7.0	7.380	7.584	7.687
1992	7.2	7.290	7.456	7.565

Place the windows with the table processor and the browser so that it is convenient for you to work with them. If the resolution of the monitor is small, just switch between windows.

In cell **D7**, enter the same value as in cell **B7**. The easiest way to do this is to place the cursor on cell **D7,** type the plus **sign +** on the keyboard, then move the cursor to cell **B7** and press the **Enter** key.

Perform a similar operation with the cells **E7** i **F7**.

Enter in cell **D8** the formula **+D$5*B8+(1-D$5)*D7**.

Enter in cell **E8** the formula **+E$5*B8+(1-E$5)*E7**.

Enter in cell **F8** the formula **+F$5*B8+(1-F$5)*F7**.

Remarks The easiest way to do this is to enter a slightly modified formula in cell **D8** in the form **+D$5*$B8+(1-D$5)*D7**, and then copy it to cells **E8** and **F8**.

Copy the cell formulas from **D8, E8, F8** down the columns to the cell of the 29th row. You can use the buttons on the panel, the context menu, or the keyboard shortcuts **Ctrl–C Ctrl–V**.

It is possible to change the representation of numbers to a fixed format with 3 digits after the decimal point in the entire block of cells from **D7** to **F29**. Your table will then have the same representation as the table in the manual.

Call the plotting function.

As the **X**-axis, indicate the year by selecting all cells from **A7** to **A29**.

As the first series, specify all cells from **B7** to **B29**.

As the second series, specify all cells from **D7** to **D29**.

As the third series, specify all cells from **E7** to **E29**.

As the fourth series, specify all cells from **F7** to **F29**.

Always select the cell from the row corresponding to 1970, otherwise the relative position of the curves on the graph may change.

If the graph turned out to be three-dimensional, change the graph type to two-dimensional linear.

If necessary, change the color of the curves and cancel the conclusion of the markers on the graph.

Compare the appearance of your graph and your data with what is presented on the manual page. You can also round the calculated values in the same way as it is done in the manual.

Save the table with calculations in the directory you need or close the Quattro Pro system without saving the results.

These data can be presented in graphical form.

If you get a three-dimensional graph again, switch the display mode to two-dimensional and set the graph type to "Linear" or "**X – Y**". However, this graph clearly shows that in the last point the smoothed curves practically coincide. As usual, the blue bar represents the raw data, and the green, red and yellow bars represent smoothed values with coefficients of 0.5, 0.33 and 0.25.

The results of exponential smoothing can be used for short-term forecasts one step ahead on the time scale. Thus, for the presented data, it is possible to make a forecast of EE consumption for 1993. Since high values of the smoothing coefficient **W** are used in the forecasting, we can use the already calculated values for **W = 0.5.**

Calculation of the forecast is simple - the forecast value for 1 period ahead will be the smoothed value of the series in 1992, and in this way the forecast for 1993 is numerically equal to the smoothed value of 1992.

The analysis uses the smoothing constant a, the value of which determines the degree of influence on forecasts of errors in the previous forecast.

Note. For the smoothing constant, the most suitable values are from 0.2 to 0.3. These values show that the current forecast error is set at 20 to 30 percent of the previous forecast error. Higher values of the constant speed up the response, but may lead to unexpected outliers. Low values of the constant can lead to large gaps between predicted values

Thus, the considered approaches of statistical methodology enable scientists and practitioners-researchers to use advanced innovative approaches in their activities to make effective management decisions regarding the system of electricity supply - electricity consumption - production.

3.2.3 Statistical analysis of time series of the cost of electricity Boks-Jenkins method

The main content of this study is the construction of stochastic models for time series of product costs and the use of these models in forecasting. Note that in this study, we consider electrical energy as a product. If time varies discretely, then the time series is discrete. Observations of a discrete time series on the cost of electricity (EE) - Y , made at moments of time $t_1, t_2, ..., t_i, ..., t_N$, can be denoted by $u(t_1), u(t_2), ..., u(t_i), ..., u(t_N)$. If the observations are made at a fixed time interval Δt and is N of consecutive values of observations of the series, can be written $u_1, u_2, ...u_i, ...u_N$, denoting the observations made at equidistant moments of time $t_0 + \Delta t, t_0 + 2\Delta t, ..., t_0 + i \cdot \Delta t, ..., t_0 + N\Delta t$. In the future, the values t_0 and Δt are not important, but if it is necessary to accurately determine the observations, then it is necessary to specify their values. If we take time t_0 as the beginning, i.e. $t_0 = 0$, and Δt s the unit of time, i.e. $\Delta t = 1$, then u_i it can be considered as an observation of the cost of production at the i-th moment of time.

Their mathematical models are usually used to describe the behavior of physical objects. If a model based on physical laws can be obtained, such a model would be deterministic. At the same time, in practice, even such a model is not completely deterministic, since a number of unaccounted factors may participate in it. For such objects, it is not possible to offer a deterministic model that allows accurate calculation of the future behavior of the object. Nevertheless, it is possible to propose a model that allows you to calculate the probability that some future value will lie in a certain interval. Such a model is called stochastic. The time series models of electricity cost in the time domain are actually stochastic. An important class of stochastic models for describing time series are stationary models. They are based on the assumption that the process remains in equilibrium with respect to a constant average level, which is confirmed by studying the time series of the cost of production in the time domain.

One of the important applied tasks is to predict the future values of a time series based on its current and past values. The main feature in the development of stochastic time series models is the assumption of stationarity. A stationary stochastic time series is conveniently described by its mean, variance, and autocorrelation function. To estimate the average value of a discrete stochastic process, you can use the sample average

$$\bar{u} = \frac{1}{N}\sum_{i=1}^{N} u_i \quad , \qquad (3.75)$$

where $u_1, u_2, ..., u_N$ – time series values.

In turn, the variance of a discrete stochastic process is estimated using the sample variance

$$\sigma_u^2 = \frac{1}{N-1}\sum_{i=1}^{N} \left(u_i - \bar{u}\right)^2 \quad . \qquad (3.76)$$

To estimate the relationship between the values of the time series, autocorrelation is used with a lag k, equal to

$$\rho_k = \frac{1}{(N-1)\cdot\sigma_u^2}\sum_{i=1}^{N-k} \left(u_i - \bar{u}\right)\left(u_{i+k} - \bar{u}\right) \quad , \qquad (3.77)$$

where $k = 0, 1, 2, ..., K$.

In the study of discrete stochastic processes, which are the time series of the cost of products in the time area, there is a problem of forecasting. The use of i the time-series observations available to predict its value at a given time in the future $i+l$ is the basis of trading planning. And here there is a need for a forecast for an interval called a warning time [11]. Since observations are available in discrete equidistant moments of time, in the problem of forecasting the value of electricity Y value $u_i,\ldots,u_{i-1},u_{i-2},...,u_0$ in the current year and the value in previous years can be used ahead of $l=1,2,...$ $\hat{u}_i(l)$ time, denote by , made at the time the i forecast value u_{i+l} at a certain point $i+l$ in time in the future, that is, ahead l . $\hat{u}_i(l), l=1,2,...$ i A function that gives predictions for all future warning times at a time is called a predictive function at a time i . The goal is to obtain a predictive function, in which the mean of the square of the deviation of the true value from the predicted value $\left[u_{i+l}-\hat{u}_i(l)\right]^2$ was the least for each warning l . Before calculating the best forecast, it is also necessary to specify its accuracy so that the risk associated with predictive decisions can be assessed. The accuracy of the forecast is expressed by probabilistic boundaries on both sides of each predicted value. These limits can be defined for any convenient set of probabilities, for example, for 50% and 95%. The meaning of these limits is that the value of the time series that appears at the appropriate time, with the specified probability will lie within these limits..

It should be emphasized that stochastic models must be built for optimal forecasting. In the future, it is necessary to distinguish between a probabilistic (stochastic) model and an observed time series. The stochastic model for which exponentially weighted moving average forecasting is optimal belongs to a class of non-stationary processes called autoregressive-integrated moving average (ARIMA) processes. This broad class of processes provides a variety of both stationary and nonstationary models that adequately describe many time series encountered in practice. The considered approach to forecasting consists in initially finding an adequate stochastic model for the studied time series.

In the future, we will enter the designation of the offset operator back B , which is defined as

$$Bu_i = u_{i-1}. \tag{3.78}$$

Another important operator is a backward-shift difference operator ∇ that can be expressed through an operator (4)

$$\nabla u_i = u_i - u_{i-1} = \left(1-B\right)u_i. \tag{3.79}$$

Synthesized stochastic models take into account that in time series sequential values are strongly dependent. Therefore, it is advisable to consider them as generated by a sequence of independent impulses a_i . These pulses are the realization of random variables with normal distribution with zero mean and variance σ_a^2. The sequence $a_i, a_{i-1}, \cdots$ can be converted into a process u_i using a linear filter by calculating the weighted sum of previous observations, so that

$$u_i = \mu + a_i + \psi_1 a_{i-1} + ... = \mu + \psi(B) a_i, \tag{3.80}$$

where μ is the parameter that determines the level of the process,
$\psi(B) = 1 + \psi_1 B + \psi_2 B^2 + ...$ is a linear operator that transforms a_i into u_i.

The sequence $\psi_1, \psi_2, \cdots$ can be finite or infinite. If this sequence converges, the filter is stable, and the process (6) will be stationary.

Identify the most important classes of models. The autoregression model is an exceptionally useful stochastic model. In this model, the current value of the process is expressed as the final linear sum of the previous values of the process and a_i the momentum, that is

$$\tilde{u}_i = \phi_1 \tilde{u}_{i-1} + \phi_2 \tilde{u}_{i-2} + ... \phi_p \tilde{u}_{i-p} + a_i, \tag{3.81}$$

where $\tilde{u}_{i-j} = u_{i-j} - \mu$, ($j = 0, 1, ... p$) – deviation from μ.
Formula expresses the autoregressive (AR) process of order p.
If you define the autoregressive operator of order p as

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - ... - \phi_p B^p, \tag{3.82}$$

the autoregressive order model p can be written in the form

$$\phi(B) \tilde{u}_i = a_i. \tag{3.83}$$

It is necessary to emphasize, there is equality

$$\psi(B) = \phi^{-1}(B). \tag{3.84}$$

Autoregressive processes can be stationary or non-stationary. In order for the process to be stationary, it is necessary to choose $\phi(B)$ so that the scales in form a matching series.

Another type of model that is of great importance in describing time series is moving average processes. Let $\tilde{u}_i$ linearly depend on the final number of q the previous ones a_i, that is

$$\tilde{u}_i = a_i - \theta_1 a_{i-1} - \theta_2 a_{i-2} - ... - \theta_q a_{i-q}, \tag{3.85}$$

The process is called the moving average (MA) order process q . If you define the operator of the MA order q in the form

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - ... - \theta_q B^q, \qquad (3.86)$$

The model can be written in the form of a MA

$$\tilde{u}_i = \theta(B) a_i. \qquad (3.87)$$

To achieve greater flexibility in fitting models to time series, it is sometimes advisable to combine in one model of AR and MA. This leads to a combined ARIMA model

$$\tilde{u}_i = \phi_1 \tilde{u}_{i-1} + ... + \phi_p \tilde{u}_{i-p} + a_i - \theta_1 a_{i-1} - ... - \theta_q a_{i-q}, \qquad (3.88)$$

or

$$\phi(B) \tilde{u}_i = \theta(B) a_i. \qquad (3.89)$$

Many series exhibit a non-stationary character and, in particular, do not fluctuate relative to a fixed average. However, their properties can be in a certain way homogeneous. Such a series can be represented by a generalized autoregressive operator $\varphi(B)$, which can be written in the form

$$\varphi(B) = \phi(B)\left(1 - B\right)^d,$$

where $d = 1, 2, ...$

Then a generalized model that describes a homogeneous non-stationary process has the form

$$\phi(B) w_i = \theta(B) a_i, \qquad (3.90)$$

where $w_i = \nabla^d u_i$

Thus, d a homogeneous non-stationary process can be described by a model that requires the -a difference of the process to be stationary. A process defined is an effective model for describing stationary and non-stationary time series and is called an autoregressive integrated moving average (ARIMA) model of order (p, d, q) and is written as follows

$$w_i = \phi_1 w_{i-1} + ... + \phi_p w_{i-p} + a_i - \theta_1 a_{i-1} - ... - \theta_q a_{i-q}, \qquad (3.91)$$

where $w_i = \nabla^d u_i$.

The next step in constructing time series models is identification, which is applied to statistical data to identify the type of models that make sense to use in further research. A specific goal is to get an indication of what parameters values p, d, q are needed in the general linear ARIMA model and to estimate the values of these parameters. The task is to identify the appropriate subclass of models from the ARIMA model family

$$\phi(B)\nabla^d u_i = \theta_0 + \theta(B)a_i . \quad (3.92)$$

To do this, you must fulfill the following requirements:

– Take the difference ∇ from u_i as many times as necessary to ensure the stationary process for the summary of the studied process to the ARIMA

$$\phi(B)\nabla^d u_i = \theta_0 + \theta(B)a_i , \quad (3.93)$$

where $w_i = \nabla^d u_i$,

– Identify the resulting process of ARIMA.

The main tool for the implementation of these items is the autocorrelation function.

When identifying the order of difference, the nonstationary is indicated by the absence of a rapid decline in the autocorrelation function. It is assumed that the degree of difference required to obtain a stationary d will be achieved if the autocorrelation function of the time series (19) quickly fades away.

After finding the magnitude of the degree of difference d, it is necessary to study the general type of autocorrelation function to select the order of p, q ARIMA operators.

Consider the identification of the time series of the cost of electric energy (conditional unit), which is presented in Table 3.13.

Table 3.13 – Consider the identification

№, i	Years	Value u_i (c.u.)	The result ofelectricity cost simulation, $\bar{u}_i$
1	2000	125.3	127.8
2	2001	127.8	107.8
3	2002	107.8	138.7
4	2003	138.7	136.7
5	2004	136.7	142.6
6	2005	142.6	138.4
7	2006	138.4	129.1
8	2007	129.1	139.5
9	2008	139.5	139
10	2009	139	127.1

11	2010	127.1	136.8
12	2011	136.8	136.2
13	2012	136.2	137.8
14	2013	137.8	118.3
15	2014	118.3	129.3
16	2015	129.3	138.6
17	2016	138.6	137.8
18	2017	137.8	138.1
19	2018	138.1	147.9
20	2019	147.9	149.5
21	2020	149.5	175
22	2021	175	187.2

To switch from numbers to real time, you need to use the formula

$$t = 1999 + i, \ .$$

The analysis of the data in Table 3.13 indicates that the presented time series has non-stationary properties, since there is no fixed level of the product's cost during the observed time.

Table 3.14 – Consider the identification

Delay (k)	0	1	2	3	4	5	6
u	1	0.773	0.497	0.428	0.162	0.132	-0.072
∇u	1	-0.033	-0.094	0.21	-0.01	0.199	-0.081

For the investigated line of autocorrelation ∇u are small after the first delay.

This indicates that this time series can be described as a PPP process (0.1,1), i.e

$$\nabla u_i = a_i - \theta_1 a_{i-1}. \qquad (3.94)$$

Initial estimates for the PPP process (0.1,1) can be found by solving the equation relative θ_1

$$\rho_1 = \frac{-\theta_1}{1+\theta_1^2}, \qquad (3.95)$$

We have two solutions

$$\theta_1 = -0.5\rho_1^{-1} \pm \sqrt{0.25\rho_1^{-2} - 1} \ . \qquad (3.96)$$

Given that for the difference of a series $\rho_1 = -0.033$, according to the formula (20), we have

$$\theta_1 = -0.5 \cdot (-0.033)^{-1} \pm \sqrt{0.25(-0.033)^{-2} - 1} = 30.3,$$

$$\theta_1' = -0.5 \cdot (-0.033)^{-1} - \sqrt{0.25(-0.033)^{-2} - 1} = 0.033.$$

We accept $\theta_1' = 0.033$, given that this value lies within the interval of turnover $-1 < \theta_1 < 1$. So the formula (3.97) takes the form

$$\nabla u_i = a_i - 0.033 a_{i-1}. \quad (3.97)$$

Since the identification process led to a trial version of the model, the next step was to obtain effective parameter estimates. To do this, a target function was compiled, which allowed to clarify the initial assessment parameter θ_1

$$S(\theta_1) = \sum_{i=1}^{23} \left(w_i + \theta_1 \cdot a_{i-1} \right)^2, \quad (3.98)$$

where $w_i = \nabla u_i$.

Minimizing the function gave this parameter value

$$\hat{\theta}_1 = 0.236.$$

At the minimum value of the function is equal

$$S(\hat{\theta}_1) = 3172.$$

Thus, the function taking into account takes the form

$$\nabla u_i = a_i - 0.236 \cdot a_{i-1}, \quad (3.99)$$

or

$$u_i = u_{i-1} + a_i - 0.236 \cdot a_{i-1}. \quad (3.100)$$

A formula was used to calculate the values of the time series as it appears

$$v_i = 0.764 \cdot v_{i-1} + 0.236 \cdot u_{i-1}, \ (i = 1, 2, ..., 23)$$

where $v_0 = u_0$.

The cost ofelectricity as a weighted average of previous observations was made for 2022 for 4 years ahead of the formula

$$\hat{u}_i(l) = \lambda \cdot u_i + \lambda(1-\lambda) \cdot u_{i-1} + \lambda(1-\lambda)^2 \cdot u_{i-2} + \ldots, \quad (3.101)$$

where $\lambda = 1 - \hat{\theta}_0 = 1 - 0.236 = 0.764$.

Thus, for the PPP model (0.1,1), the forecast for all times in the future is an exponentially weighted moving average of the present and previous values u_i

To determine the probabilistic limits of predictions on random warning, use the error variance formula for the PPP model (0.1,1)

$$V(l) = s_a^2\left[1 + (l-1)\lambda^2\right], \tag{3.102}$$

where s_a^2 – is the estimation of the final dispersion.

The estimation of the final variance is determined, according to, by the formula

$$s_a^2 = \frac{S(\hat{\theta}_0)}{n} = \frac{3172}{23} = 137.9 \tag{3.103}$$

Then (1-ε)% probable limits $u_{i+l}(-)$ i $u_{i+l}(+)$ for u_{i+l} will have the form

$$u_{i+l}(\pm) = \hat{u}_i(l) \pm v_{\varepsilon/2} \cdot \sqrt{V(l)}, \tag{3.104}$$

or, with reference to,

$$u_{i+l}(\pm) = \hat{u}_i(l) \pm v_{\varepsilon/2} \cdot \sqrt{1 + (l-1)\lambda^2} \cdot s_a, \tag{3.105}$$

where $v_{\varepsilon/2}$ - is the quantyl level of the $1-\varepsilon/2$ standard normal distribution.

Given, 50% and 95% of the prediction limit for the $\hat{u}_i(l)$ written form.

50% limit:

$$\hat{u}_i(l) \pm 0.674 \cdot \left[1 + (l-1) \cdot 0.584\right] \cdot 11.7, \tag{3.106}$$

or $\hat{u}_i(l) \pm (3.28 + 4.61 \cdot l)$.

95% limit:

$$\hat{u}_i(l) \pm 1.96 \cdot \left[1 + (l-1) \cdot 0.584\right] \cdot 11.7, \tag{3.107}$$

or $\hat{u}_i(l) \pm (9.54 + 13.4 \cdot l)$.

of Boks-Jenkins.

Analytical trend function

To describe the statistical data of the cost of production, we approximate them using a trend line - an equation that describes the presented dependence. To find the analytical trend function, we will use Excel by constructing a trend line. A trend line in the form of a fourth-order polynomial was selected

$$u(i) = 0.0018 \cdot i^4 - 0.0501 \cdot i^3 + 0.2008 \cdot i^2 + 3.0235 \cdot i + 118.32, \quad (3.108)$$

where $i = 1, 2, ..., 23$.

The transition to real time is determined by formula.

The coefficient of determination was the value

$$R^2 = 0.8207.$$

The magnitude indicates a fairly good approximation of the trend line to statistical data. Figure 6 shows graphs of results of modeling the cost of products by building a trend line.

To find the probabilistic limits of forecasts, a matrix approach was used. For this, the regression equation as a fourth-order polynomial was presented in matrix form

$$U = I \cdot B. \quad (3.109)$$

$$U = \begin{pmatrix} 125.3 \\ 127.8 \\ 107.8 \\ 138.7 \\ 136.7 \\ 142.6 \\ 138.4 \\ 129.1 \\ 139.5 \\ 139 \\ 127.1 \\ 136.8 \\ 136.2 \\ 137.8 \\ 118.3 \\ 129.3 \\ 138.6 \\ 137.8 \\ 138.1 \\ 147.9 \\ 149.5 \\ 175 \\ 187.2 \end{pmatrix} \quad I = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 2 & 4 & 8 & 16 \\ 1 & 3 & 9 & 27 & 81 \\ 1 & 4 & 16 & 64 & 256 \\ 1 & 5 & 25 & 125 & 625 \\ 1 & 6 & 36 & 216 & 1296 \\ 1 & 7 & 49 & 343 & 2401 \\ 1 & 8 & 64 & 512 & 4096 \\ 1 & 9 & 81 & 729 & 6561 \\ 1 & 10 & 100 & 1000 & 10000 \\ 1 & 11 & 121 & 1331 & 14641 \\ 1 & 12 & 144 & 1728 & 20736 \\ 1 & 13 & 169 & 2197 & 28561 \\ 1 & 14 & 196 & 2744 & 38416 \\ 1 & 15 & 225 & 3375 & 50625 \\ 1 & 16 & 256 & 4096 & 65536 \\ 1 & 17 & 289 & 4913 & 83521 \\ 1 & 18 & 324 & 5832 & 104976 \\ 1 & 19 & 361 & 6859 & 130321 \\ 1 & 20 & 400 & 8000 & 160000 \\ 1 & 21 & 441 & 9261 & 194481 \\ 1 & 22 & 484 & 10648 & 234256 \\ 1 & 23 & 529 & 12167 & 279841 \end{pmatrix}$$

The parameter B was found by calculating the matrix formula as the solution of the equation

$$B = (I^T \cdot I)^{-1} \cdot I^T \cdot U = \begin{pmatrix} 118.33 \\ 3.02 \\ 0.201 \\ -0.05 \\ 0.0018 \end{pmatrix}.$$

The comparison with the coefficients of the fourth-order polynomial confirms the correctness of the result.

The predicted value of the cost ofelectricity is found by the formula

$$\hat{u}_n = i_n \cdot B, \tag{3.110}$$

where i_n – is the vector-column of future values of time,

$\hat{u}_n$ – the predicted value ofelectricity at the moment of time i_n.

The variance of the forecast (40) depends on the variance of the error and the vector i_n

$$s_{u_n}^2 = s^2 \cdot \left[1 + i_n (I^T \cdot I)^{-1} i_n^T\right]. \tag{3.111}$$

The variance of the error is calculated by the formula and is equal

$$s^2 = \left(U - I \cdot B\right)^T \left(U - I \cdot B\right) = 1055. \tag{3.112}$$

The point forecast should be supplemented with an interval forecast. For a given confidence level (1-α), the true value of the dependent variable will be in the interval

$$\hat{u}_n - t_{кр} \cdot s_{u_n} < u_n < \hat{u}_n + t_{кр} \cdot s_{u_n}, \tag{3.113}$$

where $t_{кр} = t\left(\alpha; n-m\right)$ (n – the sample volume m – the number of parameters in the regression equation) is a critical value found on the tables of the quantiles of the Steudent distribution.

We find α from the condition $P = 1-\alpha = 0.95$, that is, α =0.05. According to data $n-m = 23-5 = 18$ Іα =0.05 for the two-sided critical region from the table of distribution of the Steudent find

$$t_{кр} = t\left(0.05;18\right) = 2.1. \tag{3.114}$$

If $P = 1 - \alpha = 0.7$, then $\alpha = 0.3$. Then from the table of distribution of the Steudent we find

$$t_{кр} = t(0.3;18) = 0.534 \quad . \tag{3.115}$$

Table presents the results of calculating the forecast and the probabilistic limits of forecasts of arbitrary warnings at different trusting probabilities.

Table. 3.14 – Consider the identification

		α	0.05	0.05	0.3	0.3
№	Years	Forecast	The lower limit of the forecast	The upper limit of the forecast	The lower limit of the forecast	The upper limit of the forecast
23	2022	188.2	99.4	276.5	166	211
24	2023	211.2	94.5	327.7	181	241
25	2024	239.7	73	406.2	197	282
26	2025	274.7	34.1	515	213	336

Exponential smoothing

Exponential smoothing is a method of "smoothing" time series data that is often used for short-term forecasting. The basic idea is that time series data often has "random noise" associated with it, which results in peaks and troughs in the data, but by applying exponential smoothing, it is possible to smooth out these peaks and troughs to see the true underlying trend of the data. The basic formula for applying exponential smoothing is as follows:

$$\bar{u}_i = \lambda \cdot u_{i-1} + (1-\lambda) \cdot \bar{u}_{i-1} \ , \tag{3.116}$$

where $\bar{u}_i$ – is the predicted value for the current time period i,

λ – the value of the smoothing constant in the range from 0 to 1,

u_{i-1} – the actual value of the data for the previous period of time,

$\bar{u}_{i-1}$ – predicted value of the previous period of time $i-1$.

The magnitude of the smoothing constant determines the smoothing measure. The smaller the value λ, the more time series data are smoothed out.

The first period does not matter, since there is no previous period of time that could be used to calculate the predicted value.

To find the optimal value λ, a nonlinear least squares method was used, which consisted in minimizing the functionality according to the data given in Table 3.15,

$$S(\lambda)=\sum_{i=1}^{23}\left[u_i-\lambda\cdot u_{i-1}-(1-\lambda)\cdot\bar{u}_{i-1}\right]^2. \quad (3.117)$$

Table 3.15 – Consider the identification

№, i	Years	ES value u_i	Forecast value ofelectricity by exponential smoothing, $\bar{u}_i$
1	2000	125.3	128.4
2	2001	127.8	126.0
3	2002	107.8	127.4
4	2003	138.7	112.4
5	2004	136.7	132.5
6	2005	142.6	135.7
7	2006	138.4	141.0
8	2007	129.1	139.0
9	2008	139.5	131.4
10	2009	139	137.6
11	2010	127.1	138.7
12	2011	136.8	129.8
13	2012	136.2	135.2
14	2013	137.8	136.0
15	2014	118.3	137.4
16	2015	129.3	122.8
17	2016	138.6	127.8
18	2017	137.8	136.1
19	2018	138.1	137.4
20	2019	147.9	137.9
21	2020	149.5	145.6
22	2021	175	148.6
23	2022	187.2	168.8

As a result of minimizing the functionality by parameter λ , that is

$$S(\lambda)\to\min_{\lambda}, \quad (3.118)$$

given that $\bar{u}_0=u_1$, the value was obtained

$$\lambda_0=0.765. \quad (3.119)$$

At the same time, the minimum value of the functionality is equal

$$S(\lambda_0) = 3178 \quad .$$

To find the forecast ofelectricity value ofelectricity, the trend line on the smoothed value ofelectricity, the equation of which is given by the polynomial of the sixth order, was determined in advance

$$u(i) = 149.316 - 27.0529 \cdot i + 9.05378 \cdot i^2 - 1.2358 \cdot i^3 + 0.08236 \cdot i^4 - 2.6958 \cdot 10^{-3} \cdot i^5 + 3.506 \cdot 10^{-5} \cdot t^6 \quad (3.120)$$

The coefficient of determination at the same time amounted to an amount

$$R^2 = 0.797 \,,$$

the size of which indicates a fairly good approximation.

The point forecast of the cost of the productsU is calculated by substitution of i the required time value in the formula.

The variance of the trend line forecast depends on the variance of the error and the vector i_n

$$s_{u_n}^2 = s^2 \cdot \left[1 + i_n (I^T \cdot I)^{-1} i_n^T \right] . \qquad (3.121)$$

The variance of the error is calculated by the formula and is equal

$$s^2 = \frac{S(\lambda_0)}{23} = \frac{3178}{23} = 138.2 \qquad (3.122)$$

The point forecast found by the formula should be supplemented with an interval forecast. For a given level of confidence (1 $-\alpha$), the true value of the dependent variable will be in the interval

$$\hat{u}_n - t_{cr} \cdot s_{u_n} < u_n < \hat{u}_n + t_{cr} \cdot s_{u_n} \;, \qquad (3.123)$$

where $t_{кр} = t(\alpha; n-m)$ (n - the sample volume m - the number of parameters in the regression equation) is a critical value found on the tables of the quantiles of the Steudent distribution.

Table 3.16 presents the results of calculating the forecast and the probabilistic limits of forecasts of arbitrary warnings at different trusting probabilities.

Table. 3.16 – Results of calculating the forecast

		α	0.05	0.05	0.3	0.3
№, i	Years	Forecast	Lower limit forecast	Top prediction limit	Lower prediction limit	Top prediction limit
1	2022	167.3	133.6	200.9	158.7	175.8
2	2023	190.8	134.3	247.2	176.4	205.1

3	2024	227.5	122.9	332.1	200.9	254.1
4	2025	283.2	99.7	466.8	236.5	329.9

The moving average

The moving average method is still the most popular tool for technical analysis. He gained his popularity due to the ease of construction, calculation and interpretation of results. The essence of the method is in the calculation of averaged data for a certain period of time.

The moving average method is one of the empirical methods for smoothing and forecasting time series. The absolute values of a series of dynamics vary by the average arithmetic values of certain intervals. The choice of intervals is carried out by sliding method: The first levels are gradually removed, the following - are included. As a result, a dynamic smoothed series of values is obtained, which allows you to clearly trace the trend of changes in the parameter under study.

The main formula for applying a moving average is as follows:

$$\bar{u}_{N+i-1} = \frac{1}{N} \sum_{k=i}^{N+i-1} u_k \quad , \qquad (3.124)$$

where $\bar{u}_{N+i-1}$ - the projected value of the product value for the current time period i

N – the number of values of the product value, on which the averaging is performed,

u_k – the actual value of the product value at the moment of time k,

$i = 1, 2, ..., M - N + 1$,

M – the number of values of product cost.

To find the dependence of the smoothing error by the method of moving average from the N functional was used

$$S(N) = \sum_{j=1}^{M-N} \left[\sum_{l=j}^{N+j-1} \left(u_l - \frac{1}{N} \sum_{k=i}^{N+i-1} u_k \right)^2 \right]. \qquad (3.125)$$

Calculations on the formula (3.125) showed that with an increase in the number N increases the smoothing error by the method of moving average. Thus, the smallest smoothing error by the moving average method will be achieved when $N = 2$ and is the value

$$S(2) = 1242.$$

Table 6 presents the data of the cost of products and the results of smoothing by the method of moving average. In rice. 9 the results of modeling the cost of anti-aliasing products by the method of moving average are presented.

To find the forecast of the cost of products, the trend line on the smoothed value of the cost of products was determined in advance, the equation of which is given by the third-order polynomial

$$u(i) = 96.718 + 13.075 \cdot i - 1.2959 \cdot i^2 + 0.0382 \cdot i^3. \quad (3.126)$$

In this case, the coefficient of determination was the amount

$$R^2 = 0.885,$$

that indicates a pretty good approximation.

The point forecast of the value of electricity is calculated by substitution of i the required time value in the formula.

The variance of the trend line forecast depends on the variance of the error and the vector $\dot{i}_n$

$$s_{u_n}^2 = s^2 \cdot \left[1 + i_n (I^T \cdot I)^{-1} i_n^T\right]. \quad (3.127)$$

The variance of the error is calculated by the formula and is equal

$$s^2 = \frac{S(2)}{23} = \frac{1242}{23} = 54.$$

Table 3.17 – Results of forecast calculations

№, i	Years	ELECTRICITY value, u_i	Forecast value of ELECTRICITY by moving average ($N = 2$), $\bar{u}_i$
1	2000	125.3	
2	2001	127.8	126.6
3	2002	107.8	117.8
4	2003	138.7	123.3
5	2004	136.7	137.7
6	2005	142.6	139.7
7	2006	138.4	140.5
8	2007	129.1	133.8
9	2008	139.5	134.3

10	2009	139	139.3
11	2010	127.1	133.1
12	2011	136.8	132.0
13	2012	136.2	136.5
14	2013	137.8	137.0
15	2014	118.3	128.1
16	2015	129.3	123.8
17	2016	138.6	134.0
18	2017	137.8	138.2
19	2018	138.1	138.0
20	2019	147.9	143.0
21	2020	149.5	148.7
22	2021	175	162.3
23	2022	187.2	181.1

The point forecast found by the formula should be supplemented with an interval forecast. For a given level of confidence (1 – α), the true value of the dependent variable will be in the interval

$$\hat{u}_n - t_{кр} \cdot s_{u_n} < u_n < \hat{u}_n + t_{кр} \cdot s_{u_n} \quad , \qquad (3.128)$$

where $t_{кр} = t(\alpha; n-m)$ (n - the sample size, m - the number of parameters in the regression equation) – is the critical value found according to the tables of quantiles of the Student distribution..

Table 3.18 presents the results of forecast calculations according to formula and probability limits of the forecast with corresponding confidence probabilities according to formula.

Table 3.18 – Results of forecast calculations

		α	0.05	0.05	0.3	0.3
№	Years	Forecast	The lower limit of the forecast	The upper limit of the forecast	The lower limit of the forecast	The upper limit of the forecast
1	2022	176.7	37.3	316.1	141.3	212.1
2	2023	192.2	32.6	351.8	151.6	232.8
3	2024	210.5	20.5	400.5	162.2	258.8
4	2025	232	0.8	463.2	173.2	290.8

Comparison of electricity cost forecast errors

The quality of the electricity price forecast is determined not only by the forecast error, but also by the number of parameters included in the forecasting function model.

Analysis of the data shows that the smallest forecast error occurs for the analytical trend function. Along with this, the trend function has six parameters. If we take into account the number of parameters, then the best method will be the moving average, which has an error of 1242 with one parameter.

Table 3.19 – Results of forecast calculations

Type of forecast	Error	Number of parameters
Boks-Jenkins method	3172	1
Analytical trend function	1055	6
Exponential smoothing	3179	1
Moving average	1242	1

It has been established that in modern conditions of evaluating the effectiveness of economic research, a more thorough analysis of the dependence of the cost of electricity on time is necessary.

Based on the study of the real dependence of the cost of electricity on time, mathematical models of stochastic time series of the cost of electricity were built, which were used to forecast the cost of electricity.

The quality of the electricity price forecast is determined not only by the forecast error, but also by the number of parameters included in the forecasting function model.

Analysis of the data given in Table 3.19 shows that the smallest forecast error occurs for the analytical trend function. Along with this, the trend function has six parameters. If we take into account the number of parameters, then the best method will be the moving average, which has an error variance of 54 with one parameter.

CHAPTER 4
RESEARCH OF THE RELIABILITY OF THE ELECTRICAL SUPPLY SYSTEM OF AIRPORTS AND AERODROMES WITH USING NEURAL NETWORKS

In the conditions of airports and aerodromes (A&A), which has a very complex and branched structure, and technological processes are very complex and dependent on many factors, forecasting is a difficult and difficult task, provided that the forecast error is not exceeded by 4%. Therefore, in A&A conditions, it is expedient to use for the prediction of artificial neural networks (ANN), which suggest that there are significant links between individual factors.

The neurons of the weakly connected ANNs are placed at the vertices of the rectangular or hexagonal lattice, and each neuron will be bound to four neighbouring neurons (von Neumon’s area) or with six adjacent neurons (Gole's area), or with eight neighbouring neurons (Moore's area).

4.1 Analysis of mathematical description of neural networks

ANN concerning the type of activation functions that are part of the structure of the AN is divided:

1) homogeneous ANNs that consist of one type neurons with a single activation function;

2) heterogeneous ANNs that consist of neurons with different activation functions.

ANN, depending on the state in which neutrons are, divided into analogue and binary, and depending on the number of neurons that change their status at some time, divided into synchronous ANN when only one neuron changes its state; asynchronous, when its state changes several neutrons (a group of neurons).

The simplest ANN consists of a certain number of ANs, which are grouped into groups that form layers, neurons which are connected by weight links and input signals from other neurons, the previous layers.

As a result of the transformations of the input signals in the neurons of certain layers at the output of the ANN, the signal OUT.

Weights can be written as a matrix that has *m* lines and *n* columns:

$$W = \begin{vmatrix} \omega_{11}\ \omega_{12}\ \ldots \omega_{1n} \\ \omega_{21}\ \omega_{22}\ \ldots \omega_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \omega_{m1}\ \omega_{m2}\ \ldots \omega_{mn} \end{vmatrix}, \quad (4.1)$$

where m is the number of inputs, n is the number of ANN neurons.

Then the output vector, whose elements are outputs of OUT signals from the source neurons, are calculated as the matrix product of the matrix-string-input elements on the matrix of weight coefficients:

$$\vec{B} = \vec{X}\vec{W}, \quad (4.2)$$

Where $\vec{B}$ - vector row.

If the desired output from the i-th neuron is denoted by y_i, and the actual output from the i-th neuron is denoted $\hat{y}_i$, then the error for the k-th sample can be calculated using the formula:

$$\Delta E_k = \frac{1}{2}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2, \ i = \overrightarrow{1,n}. \quad (4.3)$$

then the total error for the entire election:

$$\Delta E_{\Sigma} = \sum_{k=1}^{n} E_k, \ k = \overrightarrow{1,m}. \quad (4.4)$$

The combined (total) input to this neuron determines its excitation (activity), that is, the total value of the weight bonds that affect the given neuron determines the real state of the neuron.

For one sample, with the linear function of activating the signal in the neuron, the error can be determined by the formula:

$$E = \frac{1}{2}(y_i - \hat{y})^2 = \frac{1}{2}(y_i - NET)^2. \quad (4.5)$$

Transforming this expression is obsessed with:

$$E = 0{,}5(y^2{}_i - 2y_i\hat{y} + \hat{y}^2) = 0{,}5\left[y^2{}_i - 2y_i(NET) + (NET)^2\right].$$

As $\hat{y} = (NET) = (x_1\omega_1 + x_2\omega_2)$ for two weights, then

$$E = 0{,}5\left[y^2{}_i - 2y_i(x_1\omega_1 + x_2\omega_2) + (x_1\omega_1 + x_2\omega_2)^2\right] =$$

$$= 0{,}5\left[y^2{}_i - 2y_i x_1\omega_1 - 2y_i x_2\omega_2 + (x_1\omega_1)^2 + 2x_1\omega_1 x_2\omega_2 + (x_2\omega_2)^2\right] =$$

$$= 0{,}5\left[y^2{}_i - 2y_i x_1\omega_1 - 2y_i x_2\omega_2 + x_1{}^2\omega_1{}^2 + 2x_1\omega_1 x_2\omega_2 + x_2{}^2\omega_2{}^2\right].$$

We find the dependence of the error E from ω_1.

$$E(\omega_1) = 0{,}5\left[x_1^{\,2}\omega_1^{\,2} + (2x_1x_2\omega_2 - 2y_ix_1)\omega_1 + (y_i - 2y_ix_2\omega_2 + \omega_2^2x_2^2)\right] =$$
$$= 0{,}5x_1^{\,2}\omega_1^{\,2} + (x_1x_2\omega_2 - y_ix_1)\omega_1 + (0{,}5y_i - y_ix_2\omega_2 + 0{,}5\omega_2^2x_2^2).$$

By ticking $0{,}5x^2{}_1 = a$, $x_1x_2\omega_2 - y_ix_1 = b$, $0{,}5y_i - y_ix_2\omega_2 + 0{,}5\omega_2^2x_2^2 = c$,

we get:

$$E(\omega_1) = a\omega_1^{\,2} + b\omega_1 + c. \tag{4.6}$$

So the dependence of the error E from ω_1 is parabolic, similarly, the dependence of the error E from ω_2 will also be parabolic. As $a = 0{,}5x^2{}_1 > 0$, then the branches of the parabola are directed upwards (in the positive direction of the axis E). This means that the dependency graph $E(\omega_1)$ has a local minimum, which coincides with the vertex of the parabola, which is a dependency graph $E(\omega_1)$.

Since the weight coefficients at the initial stage of the training of the NN gain some random values, the point that characterizes the initial position of the NN in the plane E, ω_1 may be at an arbitrary position and it is unlikely that it will be at the local minimum.

Consequently, in the process of learning, the ANN should make correction (change of values) of the weight coefficients so as to minimize the numerical value of the total error (E), that is $E \to E_{\min}$, so that this process must pass as soon as possible, that's mean for less number of iterations and epochs. If E will depend on the two variables (ω_1 i ω_2), then in the spatial Cartesian coordinate system (E, ω_1, ω_2) we obtain a volumetric figure of the rotation (paraboloid). That is, we observe a surface that determines the error value for various combinations of weight coefficients (ω_1 i ω_2), and a weight vector whose origin is at the origin, and the end at a point which is the projection of a local minimum of a paraboloid to a plane, indicates the direction of minimization of the error.

To correct the weights, one can apply the Wadow-Hoff or delta rule, which generally takes the following mathematical record:

$$\Delta\omega_{ij} = \eta\delta_j x_i,\ i = \overrightarrow{1,n},\ j = \overrightarrow{1,m}, \tag{4.7}$$

where $\delta_j = y_j - \hat{y}_j$ - the required output from the neutron *j*, and $\hat{y}_j$ - the actual (real) output from the *j*-neutron, x_i - the signal that came from the i-neutron, η - the coefficient of weight coefficient change (the rate of training), $\Delta\omega_{ij}$ - the magnitude of the change in the weight ratio between and j neutron.

In general, the delta rule can be written as:

$$\Delta\omega_{ij} = \eta\delta_j x_i = \eta(y_j - \hat{y}_j)x_i = \eta(y_j - \sum_{j=1}^{m} x_i\omega_{ij})x_i,\ i = 1, \overline{n},\ j = 1, \overline{m}. \quad (4.8)$$

The rate of change in error $\frac{\partial E}{\partial \hat{y}_j}$ relative to the change in the real output of the *j*-neutron is numerically equal:

$$\frac{\partial E}{\partial \hat{y}_i} = \hat{y}_j - y_j = -\delta j,\ j = \overrightarrow{1, m}, \quad (4.9)$$

and the rate of change in output $\hat{y}_j$ from the *j*-neutron from the change in weight coefficients $\Delta\omega_{ij}$ can be written as:

$$\frac{\partial \hat{y}_j}{\partial \omega_{ij}} = x_i,\ i = \overrightarrow{1, n},\ j = \overrightarrow{1, m}. \quad (4.10)$$

Then the rate of change in the error from the change in weight coefficients can be written:

$$\frac{\partial E}{\partial \omega_{ij}} = \frac{\partial E}{\partial \hat{y}_j}\frac{\partial \hat{y}_j}{\partial \omega_{ij}},\ i = \overrightarrow{1, n},\ j = \overrightarrow{1, m}, \quad (4.11)$$

$$-\frac{\partial E}{\partial \omega_{ij}} = -\delta_j x_i,\ i = \overrightarrow{1, n},\ j = \overrightarrow{1, m}, \quad (4.12)$$

$$\frac{\partial E}{\partial \omega_{ij}} = \delta_j x_i,\ i = \overrightarrow{1, n},\ j = \overrightarrow{1, m}, \quad (4.13)$$

where $\frac{\partial E}{\partial \omega_{ij}}$ – the derivative of the surface error, depending on the change in weight coefficients.

Then we can conclude that the changes in weight factors should occur in the direction opposite to the derivative of the error surface, that is, in the direction opposite to the direction of the gradient - in the direction of decrease, rather than increase.

The number of input neurons corresponds to a certain number of features that determine the dimension of the space from which all samples will be selected at the entrance to the ATM.

Depending on the nature of the solution to the problem of the distribution of samples into separate classes, according to certain features, based on the classification, the problems are divided into two types: linear and nonlinear. There are two ways to solve a nonlinear problem with ANN:

1) use an ANN, which will be based on two or more direct data split into classes;

2) change the look (content) of the data that is entered into the network.

Consider the response of the closed neurons to the input and output from the output layer of the ANN to the input data for the NN with two input, two hidden and one neuron of the output layer, using a threshold function with a numerical threshold value T = 0.4 at displacements $\Theta_{1(1)} = 1{,}2$ for one neuron, $\Theta_{1(1)} = 1{,}2$ for the second hidden layer neuron, $\Theta_{1(2)} = -0{,}2$ for the output layer; with matrixes of output coefficients $W_1 = \begin{vmatrix} 1{,}2 & 0{,}8 \\ -0{,}5 & -0{,}5 \\ -0{,}5 & -0{,}5 \end{vmatrix}$ for a hidden layer, $W_2 = \begin{vmatrix} -0{,}2 \\ 0{,}7 \\ -0{,}3 \end{vmatrix}$ - for the output layer, if the input neurons are signaled x_1 and x_2 whose directions are formed by the next tuple: $\{(1;1),(1;0),(0;1),(0;0)\}$

The results of the calculations presented are presented as Table 4.1.

Table 4.1 – Results of the calculations

№ n/n	x_1	x_2	$\Theta_{1(1)}$ 1,2	$\Theta_{2(1)}$ 0,8	$\sum_{i=1;j=1}^{i=2;j=2}{}_{(I)} x_i\omega_{ij}+\Theta_j$	$\sum_{i=1;j=1}^{i=2;j=2}{}_{(II)} x_i\omega_{ij}+\Theta_j$	NET$_I$	NET$_{II}$	$\Theta_{1(2)}$ -0,2	Σ_{III}	OUVT
1	1,0	1,0			0,2	-0,2	0	0		-0,2	0
2	1,0	0	$W_1 = \begin{vmatrix} -0{,}5 & -0{,}5 \\ -0{,}5 & -0{,}5 \end{vmatrix}$		0,7	0,3	1	0	$W_2 = \begin{bmatrix} 0{,}7 \\ -0{,}3 \end{bmatrix}$	0,5	1
3	0	1,0			0,7	0,3	1	0		0,5	1
4	0	0			1,2	0,8	1	1		0,2	0

Input values of the samples are transformed by the weight coefficients of the matrix and displacements and in the adjacent block (AdB) of the hidden layer neurons, and after activating the threshold function in the activation block (AcB) of the hidden layer neurons, we obtain the numerical values of the outputs from the hidden neurons of NET_I and NET_{II}. Then in the neuron of the output layer under the action of weight coefficients of the matrix W_2 and the bias Θ_3 and activation of the threshold function in the AcB of the source neuron, we obtain the initial numerical value of OUT for each sample of the input signals x_1, x_2.

4.2 Modeling the reliability of the power supply system of airports and aerodromes

The schematic diagram of the ANN discussed earlier can be illustrated as follows: the input neurons of the zero layer denote 1_0, 2_0, the hidden neurons of the first layer denote $1_{(1)}$, $2_{(1)}$, and the output neuron - symbol $1_{(2)}$, the weighting coefficients of the displacements for the hidden layer - $\Theta_{1(1)}$ and $\Theta_{2(1)}$, for the output layer - $\Theta_{1(2)}$, the input signals to 1_0 neurons through $x_1 = (1,1,0,0)$, and the input signals to 2_0 neurons – through $x_2 = (1,0,1,0)$, we will write the total output signal to the zero layer in the form of a tuple: $\{(x_1, x_2)\} = \{(1,0;1,0),(1,0;0),(0;1,0),(0;0)\}$, and the output signal $OUT = \{0;1;1;0\}$, - and the weight coefficients, respectively, ω_{ij} and γ_{jk}, the matrix which will be: $W_1 = \begin{vmatrix} \omega_{11} & \omega_{12} \\ \omega_{21} & \omega_{22} \end{vmatrix}$ and $W_2 = \begin{vmatrix} \gamma_{11} \\ \gamma_{21} \end{vmatrix}$.

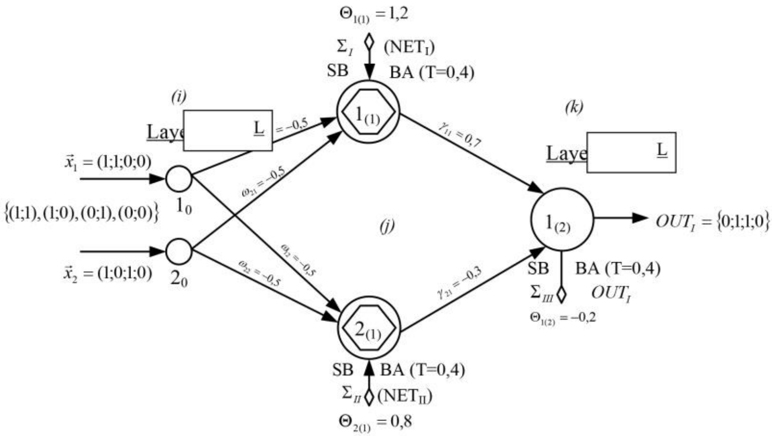


Figure 4.1 – Neiral system

$$\Sigma_I = \sum_{i=1;j=1}^{i=n;j=m} x_i \omega_{ij} + \Theta_{1j} ; \tag{4.14}$$

where $i = \overrightarrow{1,n}$, $j = \overrightarrow{1,m}$;

$$\Sigma_{II} = \sum_{i=1;j=1}^{i=n;j=m} x_i \omega_{ij} + \Theta_{2j} ; \tag{4.15}$$

where $i = \overrightarrow{1,n}$, $j = \overrightarrow{1,m}$;

$$\Sigma_{III} = \sum_{k=1;j=1}^{k=s;j=m} Y_j \gamma_{kj} + \Theta_k ; \; k = \overrightarrow{1,s}; \; j = \overrightarrow{1,m} . \tag{4.16}$$

In this case, n = 2, m = 2, s = 1, where *n* is the number of neurons of the zero layer, *m* is the number of entrances to the hidden layer neurons from the neurons of the zero layer (the neurons of the first hidden layer), *s* is the number of neurons in the initial layer (another layer); ω_{ij} – weight coefficient from the i-th layer (input) to the j-th hidden layer neuron. Then ω_{12} - weigh the coupling factor from the first neuron of the zero layer (inbound) to the second neuron of the hidden layer (the first layer), similarly to other weighting coefficients. γ_{jk} - the weighting factor of the j-th neuron of the hidden layer (the first layer) to the k th neuron of the output layer (the second layer).

Σ_I - the sum of the weight bonds that belong to the first hidden layer neuron, Σ_{II} is the sum of the weight bonds that belong to the second hidden layer neuron, Σ_{III} - the sum of the weight bonds that are part of the exit neuron (the second layer). $NET_I=Y_I$ is the exit signal from the first hidden layer neuron, after activating the threshold function (T = 0.4 - numeric value of the threshold), NET_{II} - signal from the second neuron of the hidden layer (layer 2), OUT - the numerical value of the output signal from the first the neuron of the output layer (second layer), after activating the threshold function (T = 0.4 - the numeric value of the threshold of the activation function). $\{(1,0;1,0),(1,0;0),(0;1,0),(0;0)\}$ - tuple of input signals to a zero layer (input layer), $\{1,1,0,0\}$ -cortex of output signals from the second layer (the output layer).

$\Theta_{1(1)}$, $\Theta_{2(1)}$, $\Theta_{1(2)}$ - weighted coefficients of displacement of the first and second neurons of the hidden layer (the first layer) and the first neuron of the output layer (second layer). $\vec{x}_1 = (1,0;1,0;0;0)$ - vector of input values to the first neuron (1_0) of the input layer (zero layer), $\vec{x}_2 = (1,0;0;1,0;0)$ - vector of input values to the second neuron (2_0) of the input layer (zero layer).

Schematically depicted ANN in Scheme 4 for different input vectors will be obtained at the output corresponding to each of them, namely (Table 3):

1) (1,0; 1,0) at the input, and at the output OUT = 0;
2) At the input (1,0; 0), and at the output OUT = 1;
3) On the input (0; 1.0), and on the output OUT = 1;
4) On the input (0; 0), and on the output OUT = 0.

Consequently, each input vector (x_1, x_2) at the output of the ANN corresponds to a certain numeric value OUT.

Threshold function

$$F(NET) = \begin{cases} 0, & if \quad NET < \mathrm{T} \\ 1, & if \quad NET \geq \mathrm{T} \end{cases}, \tag{4.17}$$

is an example of a nonlinear activation function.

An example of a linear function is

$$F(NET) = \beta(NET), \tag{4.18}$$

the area of values of which $F(NET) \in (-\infty;+\infty)$, in the presence of which in AcB, the exit from the neuron will be equal to the value of the entrance to this neuron, if $\beta = 1$. Then we can conclude that a multilayered neural network with a linear activation function can solve only those problems that can solve single-layer neural networks. Only incoming and outgoing neurons can be solved. Then we can draw the following conclusion that for multilayer NN it is necessary to use nonlinear activation functions, this is a logistic function

$$F(NET) = \left[1 + \exp\left(-\alpha \cdot NET\right)\right]^{-1}, \qquad (4.19)$$

or other nonlinear functions. The best option is logistic, since it is continuous throughout the definition domain $(-\infty;+\infty)$, differentiated and monotonically increasing for all NETs $(-\infty;+\infty)$ (in the range of values (0; 1)).

Consequently, each element and the set of input values *x* are connected by a weighted value $x_i \omega_{ij}$ with each AN, while in the AdB neuron we find the weight of the inputs to the given neuron that enters the AcB, after activation in which, the output of the output layer will output the NET signal. Output vector $\vec{L}$ of NN, components of which are OUT outputs from the neurons of the output layer, numerically equal to the product of the matrix $\vec{X}$ - the vector string of input signals on the matrix W is the matrix of weight coefficients, that is:

$$\overline{L} = \overline{XW}, \qquad (4.20)$$

where $\vec{L}$ is the matrix line.

Multilayer NNs have much more possibilities in solving practical and applied problems; they represent a set of layers, such that the output from one layer will be input to the next layer, and the increase of computed capacities (capacities) compared to single-layer NN, is possible only if there is nonlinear activation function between layers.

If there is no nonlinear activation function in multilayer NN, then the calculation of the numerical value of the output layer is found as the product of the input vector X on the first weight matrix W_1, and then on the next weight matrix W_2. That is

$$OUT = (\vec{X}\vec{W}_1)\vec{W}_2, \qquad (4.21)$$

but as a result of the fact that the product of the matrices is associative, then

$$OUT = (\vec{X}\vec{W}_1)\vec{W}_2 = \vec{X}(\vec{W}_1\vec{W}_2)\,. \tag{4.19}$$

That is, essentially, the transition from a multilayer NN to a single-layered NN, that is, a two-layer NN is equivalent to one hidden layer with a weight matrix, equal to the product of two weight matrices ($W_{заг} = W_1W_2$).

Then

$$OUT = (\vec{X}\vec{W}_1)\vec{W}_2 = \vec{X}(\vec{W}_1\vec{W}_2) = \vec{X}(\vec{W}_{заг})\,. \tag{4.22}$$

Consequently, any multilayered NN with a linear activation function can be replaced by an equivalent single-layer NM with a weight matrix:

$$W_{заг} = W_1W_2\,. \tag{4.23}$$

The NMs discussed earlier refer to the direct propagation of the input signal or the network with direct bonds, that is, from the input layer to the output layer of the signal from the NN, that is, from the previous layer to the next and in order. But the possibilities of such NN are limited, they do not have memory, that is, their output is completely determined by the values of input vectors and values of weight coefficients. Such networks are also referred to as NNs without feedback.

NNs that have bundles from the original layers to the inputs are termed networks with reversed bonds. In some NN with backlinks, the value of the output from the network is returned to the input layers, that is, the output will be the input. Therefore, NN with reverse bonds has the property, similar to short-term human memory.

The algorithm of back propagation of the signal in the NN consists of two directions of signal propagation:

1) the direct direction of propagation of the signal from the zero layer to the output layer;

2) the reverse direction of the propagation of the signal from the output layer to the input, passing the error value from the output layer to the input (first) layer, which determines the value of which it is necessary to adjust the weight factors in the learning process of the NN, which is used to ensure that the NN can perform the delivered before it the task of the data that it receives.

Reverse signal propagation mechanism:

1) in the direct propagation of the signal the hidden layer neuron sends signals to each neuron of the output layer;

2) in the reverse propagation of the signal of the hidden layer neurons, receive error signals from each neuron of the output layer.

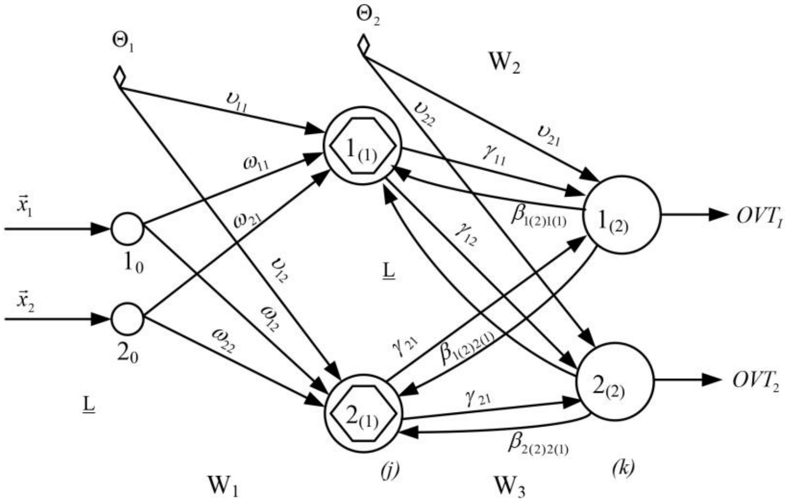


Figure 4.2 – Scheme of NM with feedback

Matrixes of weight coefficients: $W_1 = \begin{vmatrix} \omega_{11} & \omega_{12} \\ \omega_{21} & \omega_{22} \end{vmatrix}$, $W_2 = \begin{vmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{vmatrix}$, $W_3 = \begin{vmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{vmatrix}$, $W_{\Theta_1} = \begin{vmatrix} \vartheta_{11} \\ \vartheta_{12} \end{vmatrix}$, $W_{\Theta 2} = \begin{vmatrix} \vartheta_{21} \\ \vartheta_{22} \end{vmatrix}$, $\beta_{1(2)1(1)}$, $\beta_{1(2)2(1)}$, $\beta_{2(1)1(1)}$, $\beta_{2(2)2(1)}$ - are weight coefficients of feedback between k-m and j-th layer.

When learning NN, every input sample of input signals has its own target output y_k, which corresponds to this input signal x_i, and the actual output from NN is denoted by $\hat{y}_k$, then the error value:

$$\delta_k = y_\text{k} - \hat{y}_k. \tag{4.24}$$

Therefore, the algorithm for the propagation of the NM error signal δ_j is based on the generalization of the delta rule.

The error δ_j corresponds to the error of the neuron of the output layer, but the error of the hidden layer neurons does not directly correlate with the target output values, so the weighted values of the hidden layer neurons need to be corrected in proportion to their effect on the magnitude of the error of the next layer (the output layer for the NN with one hidden layer). That is, the output neuron with greater error more influences the error of the hidden layer neuron, which is associated with this output neuron greater than the weight. Then for a hidden neuron the error can be calculated by the formula:

$$\delta_{\mathrm{j}} = F'(NET_j) \cdot \sum_k \delta_k \beta_{kj}, \qquad (4.25)$$

where k - the index of the layer that sends the error in the opposite direction, β_{kj} is the weighting factor of the feedback.

If the NN has one hidden layer, then the index β corresponds to the original layer. If the NN uses the logistic function of activating the species

$$F(NET) = \left[1 + \exp(-NET_j)\right]^{-1}, \qquad (4.26)$$

Then its derivative has the following entry:

$$F(NET_j) = \exp(-NET_j)\left[1 + \exp(-NET_j)\right]^{-2}. \qquad (4.27)$$

Converting this expression, we obtain:

$$F'(NET_j) = \exp(-NET_j)(1 + \exp(-NET_j)^{-1}(1 + \exp(-NET_j)^{-1} =$$

$$= \frac{\exp(-NET_j)}{1 + \exp(-NET_j)} F(NET_j) = \frac{(\exp(-NET_j) + 1) - 1}{1 + \exp(-NET_j)} F(NET_j) = \left(1 - \frac{1}{1 + \exp(-NET_j)}\right) F(NET_j) =$$

$$= F(NET_j)\left[1 - \left[1 + \exp(-NET_j)\right]^{-1}\right] = F(NET_j)\left[1 - F(NET_j)\right].$$

Then the error of the hidden j neuron can be calculated by the expression:

$$\delta_j = F(NET_j)\left[1 - F(NET_j)\right]\sum_k \delta_k \beta_{kj}, \qquad (4.28)$$

where k - the index of the layer that sends the error δ_k in the opposite direction, β_{kj} is the weight ratio of the feedback between the neuron of the k-th layer and the j-neuron of the hidden layer, j is the index of the neuron in the hidden layer, $F(NET_j)$ - the logistic function of activating the exit from the j neuron of the hidden layer.

ANN can learn how to solve their tasks. F. Rosenblatt proposed a method of teaching perceptron and proved the statement: "the perceptron can be trained for everything that it can practically realize." Learning perceptron can be done both as a teacher and without him. Teaching with a teacher implies the presence of influence from the outside, with the purpose of assessing the behavior of the NN and managing it with the aim of making the necessary modifications. Construction of a matrix of weight coefficients that would gradually reduce the error in the output of the neural network. Teaching without a teacher is carried out through the self-organization of the NN, in order to carry out the necessary changes in weight coefficients, to change the vector of weight coefficients in the field of small errors, is proportional to the error of the output and is equal to zero, if the error is zero. The vector of weight coefficients is modified by the formula:

$$W(t+\Delta T) = W(t) + \eta x^{\alpha} (\delta^{\alpha})^{T}, \qquad (4.29)$$

Where $W(t)$, if $t=0$ - the initial state of the weight coefficients of all neurons (correction), x^{α} - input image, $\alpha = 1, p$, $\delta^{\alpha} = y^{\alpha} - \hat{y}^{\alpha}$ - error vector at the output of the NN, η- subjects of training, $0<\eta<1$, $W(t+\Delta T)$ - (state) of the weight coefficients of all neurons at the moment $(t+\Delta T)$, ΔT - increase of time (after correction).

A set of pairs of vectors of the species (x^{α}, y^{α}), where $\alpha = 1, p$, which is called a tutorial sample. The NN becomes trained on some training sample (TS), if at the input to the inputs of the NN of each vector x^{α} on the output each time we get the corresponding vector y^{α}.

The algorithm for training the neuron has 5 steps (0,1,2,3,4,5), developed by F. Rosenblatt:

Step 0 - the random values of the weight coefficients of all the neurons that form the matrix $W(t_0)$ are given;

1st step - an input sample x^{α} is submitted to the NN, which will cause formation at the output $\hat{y}^{\alpha} \neq y^{\alpha}$ of the NN.

The second step is to calculate the error vector $\delta^{\alpha} = y^{\alpha} - \hat{y}^{\alpha}$ at the output of the NN, which determines the nature of the change in the vector of weight coefficients in the field of small errors.

3rd step – modification of the vector of weight coefficients by the formula.

Step 4 – Steps 1,2,3 are repeated for all tutorial vectors. One cycle of sequential input to the NN of the entire sample is called an epoch. The training ends in a few epochs:

1) if the vector of weight coefficients does not change;

2) if the absolute error, which is elucidated in all vectors, will be less than a certain small predetermined value.

That is, the HN is trained to get the desired set of outputs for a certain set of inputs to the 0-th layer.

$\{(0;1),(1;1),(1;0),(0;0)\}$ $T_1=T_2=0{,}5$; $\Theta_{1(1)}=1{,}4$, $\Theta_{2(1)}=0{,}6$, $\Theta_{1(2)}=-0{,}3$.

$$W_1=\begin{vmatrix}0{,}3 & -0{,}4\\ -0{,}6 & 0{,}2\end{vmatrix},\quad W_2=\begin{vmatrix}0{,}9\\ -0{,}2\end{vmatrix}.$$

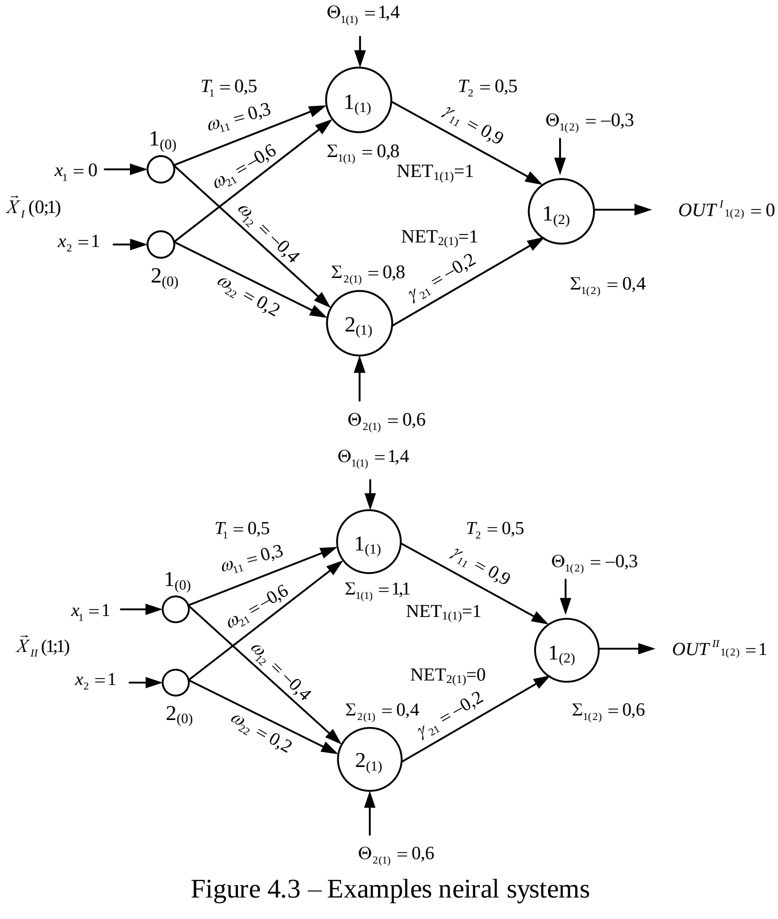


Figure 4.3 – Examples neiral systems

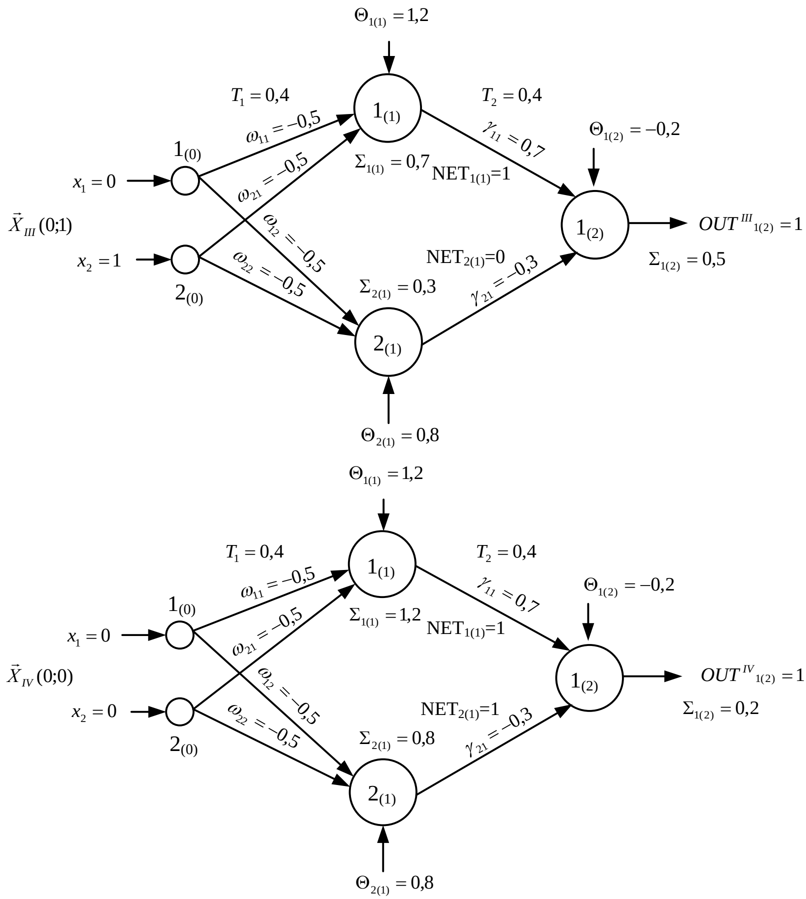


Figure 4.4 – Out of print of neiral systems

The algorithm of training perceptron is fashionable to use for multilayered perceptrons, taking into account the following basic properties of the perceptron:

1) any perceptron may have one or two layers if two layers and weighing characteristics of the first layer are not taught;

2) weighing coefficients of any perceptron can be replaced by integers;

3) during training, after the number of iterations, the following options are possible:

a) perceptron has finished training

b) stagnates.

The algorithm for training perceptron gives answers as to how many steps it requires for its training and its possible advantages over other methods of learning perceptron.

The multilayer structure of NN is one of the most common, in which each neuron of any layer is bound to the neurons of the previous layer, and the first layer of the neurons is bound to the neurons of the zero layer (input layer) of the NN, and therefore they are called completely connected Nm In multi-layer neural networks, the initial values of the neurons of all layers, except for the latter, are unknown, and therefore the perceptron of two and more layers can not be trained only by the magnitude of the error (δ_k) at the input of the NN, and therefore the most suitable variant of training NN is the algorithm of the propagation of the signal from the original layer to previous layers

In the NN reverse propagation (NNRP), the main element of the network is a neuron that has a matching block (MB) and an activation block (AB) with an activation function F that has a certain T threshold and outputs a resulting output signal OUT. For the logistic (sigmoidal) activation function $OUT = 1 + \exp(-NET)^{-1}$, for which the first derivative takes place by N = T:

$$\frac{\partial OUT}{\partial NET} = OUT(1 - OUT = OUT - (OUT)^2 \cdot \qquad (4.30)$$

OUT values are in the range (0; 1) for the logistic function, and therefore it provides the necessary non-linearity, which automatically controls the gain of the signal:

1) for weak signals ($NET \to 0$) the input-output graphic has a strong angle of inclination, which provides a high value of signal amplification;

2) for strong input signals amplification of input signals is reduced.

NN with the propagation of neuro-pulses from the 0-th (input) layer through several hidden layers to the source layer of the neurons is called a "generalized multilayered perceptron", that is, an NN that consists of several consecutively connected layers of the neurons:

1) input layer (0th layer). And distribution of NN input elements;

2) hidden layers - in which each neuron has several inputs connected to the outputs of the neurons of the previous layer and have only one output;

3) outputs of the neurons of the output layer give the result of the work of the NN - OUT.

The purpose of NN training is to provide the necessary set of output signals from the output layer for a given set of inputs by selecting weight coefficients. That is, for each input vector in the NN there is a corresponding target vector y at the output of the NN, which is called the learning pair (LP) of the vectors $[x, y]$, a certain set of which ensures the learning process of the NN. And a certain set of LP form a teaching set

$$Y = \{(x_1; y_1), (x_2; y_2), (x_3; y_3)...(x_n; y_n)\}. \qquad (4.31)$$

A set of random values of weight coefficients provides a normal course of LP training. The training algorithm for NNRP involves the following sequence of operations:

1) from the teaching set "U", a vector $\vec{x}$ is applied successively to the input of the NN;

2) the resulting output and NN are compared with the required value by determining the difference δ_k between the target vector of the LP and the real output from the NN;

3) the weighting correction is carried out in order to achieve the minimum value δ_k;

4) the repetition of the points of the algorithm 1,2,3 for each vector of the teaching set until δ_k reaches the desired result, given that the calculations are performed in a layered manner. That is, firstly, the outputs of the previous layers are calculated, and then the results obtained are used as inputs to the next layer, and also calculate the output from the source layer neurons (OUT) that form the source vector of the NN.

From the outgoing NN signals (OUT) subtract the corresponding components of the target vector, find the numerical value of the error (δ_k), which affects the level of correction of the weight factors of the NN.

If, after a sufficient repetition, p. 1,2,3 assumes a value from the permissible interval, then it is assumed that the NN has successfully passed training and the NN is modest to use for recognition, with constant values of weight coefficients.

The propagation of the signal from the input to the input layer is called the forward signal passing (FSP), and from the output layer to the input - the reverse passage of the signal (RPS) in the NN.

Then "forward signal passing" (FSP) can be symbolically written as follows:

$$X \xrightarrow[i\,F(NET)]{\Sigma\omega x_i} Y \xrightarrow[j\,F(NET)]{\Sigma\omega x_i} \{OUT_k\} = Y_k . \qquad (4.32)$$

That is, for an arbitrary layer of NN, the output vector NET can be presented as a product of vectors $\vec{X}$ and $\vec{W}$, where $\vec{X}$ - the vector of input signals to the zero layer of NN, $\vec{W}$ - the matrix of weight coefficients between the neurons of the previous and subsequent layers. Applying the activation function F to each vector component of the NET receives the source vector $\vec{Y} = F(\hat{\vec{X}}\vec{W})$.

That is, the calculation of the results of the output layer (k) forgets the application of the equation $Y = F(\hat{\vec{X}}\vec{W})$ to each layer from the input layer (zero) to the output layer (k).

The reverse signal propagation (RSP) in the NN involves determining the difference between the target value y_k and the output actual (actual y_k) value of the signal and the neuron of the output layer (k) $\delta^{\alpha}_{q_k} = y_{q_k} - \hat{y}_{q_k}$, given that the inner (hidden) layers do not have target values for their output signals, where $\delta^{\alpha}_{q_k}$ - the error (difference) of the output signal from q of the neuron of the output layer (k), $\alpha = \overline{1, p}$.

Then the error $\delta_{q_k} = F`(NET_{p_j})\delta^{\alpha} = F(NET_{p_j})(1 - F(NET_{p_j})\delta_{q_k}{}^{\alpha}$

The magnitude of the change in the weight ratio between the neuron p_j and q_k is calculated by the formula:

$$\Delta\omega_{p_j q_k} = \eta\delta_{q_k} OUT_{p_j} = \eta F(NET_{p_j})(1 - F(NET_{p_j})\delta_{q_k}{}^{\alpha} OUT_{p_j} , \qquad (4.33)$$

where OUT_{p_j} – the signal from the neuron p_j, η - the rate of learning.

Then the value of the weight coefficient from the neuron p in the hidden layer "j" to the neuron q in the output layer "k" in the (n + 1) -th step (after correction) is calculated by the formula:

$$\omega_{p_j q_k}(n+1) = \omega_{p_j q_k}(n) + \Delta\omega_{p_j q_k} \qquad (4.34)$$

where $\omega_{p_j q_k}(n)$ – the magnitude of the weight coefficient from the p neuron in the hidden layer "j" to the neuron q in the output layer "k" (to the correction) of the weight coefficients (in step n), $\omega_{\mathrm{p_j q_k}}(n+1)$ is the magnitude of the weight coefficient in the step (n + 1) from the p_j neuron to q_k after correction), $\Delta\omega_{\mathrm{p_j q_k}}$ – the value for which it is necessary to change (correct) the weight coefficient, which comes from the neuron p_j and enters the neuron q_k.

Each neuron of the latent layer "j" transmits its $\mathrm{OUT_{ij}}$ signal to the neurons in the output layer "k" by connecting their weight bonds, and during the training, the weight bundles are directed in the opposite direction, directing the value $\delta_{\mathrm{q_k}}$ from the output layer "ξ" to the hidden layer "j", each weight coefficient is multiplied by the magnitude of the error of the neuron of the output layer "k", from which the weighting factor is obtained. Weights that connect the output layer (k) and the preceding layer (j) are multiplied by the magnitude of the error, between the target and actual values of the output signal from the given neuron of the output layer.

In the hidden layer (j), the product weight coefficients on the error of the output layer, in the block MB find the sum $\sum_q \gamma_{p_{qk}} \delta^{\alpha}_{\mathrm{q_k}}$ of these products and multiply the derivative of the logistic function $F(NET_{p_j})\lfloor 1 - F(NET_{p_j})\rfloor$. Then the magnitude of the error for the neuron p of the hidden layer is calculated by the expression:

$$\delta_{p_j q_k} = F(NET_{p_j})(1 - F(NET_{p_j})\sum \delta_{q_k} \lambda_{p_j q_k} \qquad (4.35)$$

After calculation δ_{pq_k}, the weighting factors correlating the output layers (k-th) and the preceding (j-th) layer are corrected. That is, for each neuron of the jth hidden layer, the error δ_{pq_k} and the value of the corrected weight coefficients are calculated, .until all weighting factors are corrected.

Enter the designation:

1) $C_i(\delta^k{}_q)$ - the set of errors $\delta^k{}_q$ from the q-neurons of the output layer (k-th), where $q = \overline{1, s}$;

2) $C_j(\delta^j{}_p)$ is the set of errors from p-th neurons of the j-th layer, where $p = \overline{1, k}$;

3) $W^j{}_k(\gamma^{q_k}{}_{p_j})$ is a matrix of weight coefficients of q-th neurons of the kth layer of the th-th neurons of the j-th layer.

Then, in the vector form, the operation of the reciprocal distribution of the error from the q-neurons of the output layer (k-th) to the p-th neurons of the j-th layer can be written as follows:

$$C_j(\delta_p^j) = \left\lfloor C_k(\delta_p^k)\hat{)} W_k^T(\gamma_{p_j}^{q_k}) \right\rfloor F`(NET_{p_j}), \qquad (4.36)$$

where $F`(NET_{p_j})$ is the derivative of the activation function of the p-th neuron in the j-th (hidden) layer; $\gamma_{p_j}^{q_k}$ – weight factors that come out of q-th neurons of the k-th layer and are included in the p-th neurons of the j-th layer; $W_k^T(\gamma_{p_j}^{q_k})$ – transposed matrix of weight coefficients, which connects the hidden layer neurons (j-th) with the neurons of the output layer (k-th).

If the activation function is a logistic function $F(NET) = \frac{1}{1+e^{-NET1}}$,

then $F`(NET_{p_j}) = F(NET_{p_j})(1 - F(NET_{p_j})$. Then $C_j(\delta_p^j)$ we write in the form:

$$C_j(\delta_{p_j}) = \left\lfloor C_k(\delta_{q_k}\hat{)} W_k^T(\gamma_{p_j}^{q_k}) \right\rfloor F(NET_{p_j}) \cdot \left\lfloor 1 - F(NET_{p_j}) \right\rfloor. \quad (4.37)$$

That is $C_j(\delta_{p_j})$, the result of the product of the vector of the initial layer (k-th) $C_k(\delta_{q_k})$ on the transpose matrix of weight coefficients $W_k^T(\gamma_{p_j}^{q_k})$, which connects the hidden layer neurons (j-th) with the neurons of the output layer (k-th), and the result of the component multiplied by the derivative of the logistic function of the corresponding (p_j) j-th layer neuron.

In order to accelerate the learning process, it is enough for each neuron to determine the training bias θ, which provides a change in the position of the initial reference of the logistic function, by providing in the training algorithm an increase in the numerical value of the weight coefficients ($\Delta\omega_i$) to each neuron. Moreover, the additional weighting factors take part in the process of learning NN. There are other methods for accelerating NN training for the algorithm of back propagation of the signal. Methods that accelerate the learning process and ensure its stable stability include the method of momentum and the method of exponential smoothing, each of which has both positive and negative manifestations, depending on what tasks they are offered to solve.

Thus, the "pulse" method involves an increase in the correction of the weight coefficient by a value proportional to the value of the previous change in weight coefficients. That is, the magnitude of each correction of weight coefficients affects the nature of all subsequent corrections. Consider the correction equation at the stages "n" and "n + 1", which can be written symbolically in the following way:

$$\omega_{p_j q_k}(n+1) = \omega_{p_j q_k}(n) + \Delta\omega_{p_j q_k}(n+1), \qquad (4.38)$$

where $\omega_{p_j q_k}(n)$ is the value of the weight coefficients between p-th neurons of the j-th layer and q-neurons of the k-th layer at the stage n (before correction), $\omega_{p_j q_k}(n+1)$ - the importance of the weight coefficients between the neurons of the j-th layer and the q-mi neurons k-th layer at the stage (n + 1) (after correction) $\Delta\omega_{p_j q_k}(n+1)$ is the value for which the numerical value of the weight coefficients between the neurons of the j-th layer and the k-th layer at (n + 1) stage (after correction) has changed.

The magnitude of the change in weight coefficients $\Delta\omega_{p_j q_k}(n+1)$ at (n + 1) stage is calculated by the formula:

$$\Delta\omega_{p_j q_k}(n+1) = \eta\delta_{q_k} OUT_{p_j} + \alpha\Delta\omega_{p_j q_k}(n), \qquad (4.39)$$

Where $\Delta\omega_{p_j q_k}(n+1)$ - the value for which the numerical value of the weight coefficients between neurons p_j and neurons q_k changed at (n + 1) stage (after correction); η - coefficient of speed of training NM (0,01≤η≤0,1); δ_{q_k} - the magnitude of the error for the q-th neuron in the output layer k; OUT_{p_j} - the magnitude (output signal) of the p-th neuron in the hidden layer j; α - the pulse coefficient, the value of which is taken in the vicinity of the number 0.9 (approximately 0.9, $\Delta\omega_{p_j q_k}(n)$ - the magnitude of the change in the weight coefficients between the neurons "p" in the hidden layer "j" to the neurons q-them in the initial layer "k", at the stage " n "(before correction).

For the method of exponential smoothing, the equation of correction of weight coefficients at the stages "n" and "n + 1" can be written as follows:

$$\omega_{p_j q_k}(n+1) = \omega_{p_j q_k}(n) + \eta\Delta\omega_{p_j q_k}(n+1), \qquad (4.40)$$

where $\omega_{p_j q_k}(n+1)$ - the value of weight coefficients at the stage (n + 1) (after correction);

$\omega_{p_j q_k}(n)$ - the magnitude of the weight coefficients between p-neurons of the hidden layer j and q-neurons of the initial layer k in the p-stage (to the correction); η - coefficient of speed of training NM ($0{,}01 \le \eta \le 0{,}1$), affects the average value of change of weight coefficients; $\Delta\omega_{p_j q_k}(n+1)$ - the value to which the corrected numerical values of the weight coefficients between r-th neurons of the k-th layer at (n + 1) stage have changed.

The magnitude on which the weight coefficients $\Delta\omega_{p_j q_k}(n+1)$ are corrected for the (n + 1) stage are calculated by the formula:

$$\Delta\omega_{p_j q_k}(n+1) = \alpha\delta_{q_k} OUT_{p_j} + \alpha\Delta\omega_{p_j q_k}(n), \tag{4.41}$$

where $\Delta\omega_{p_j q_k}(n+1)$ – the value for which the weight coefficients were corrected on the (n + 1) stage between the neurons j and the neurons of the k-th layer, α – the smoothing factor ($0{,}01 \le \alpha \le 1{,}0$); δ_{q_k} – the magnitude of the error for the q-th neuron in the output layer k; OUT_{p_j} – the magnitude of the output signal from the p-th neuron in the hidden layer j; $\Delta\omega_{p_j q_k}(n)$ – the value from which corrected weight factors at the "n" stage between neurons j-th and neurons k-th layer. If $\alpha = 1{,}0$, then the new correction is not carried out, but the previous one is repeated, and if $0 \le \alpha \le 1$, the correction of the weight coefficients is smoothed in proportion to the value α .

Theoretically it is found, according to Kolmogorov's theory, that for simulation of any task a sufficiently multilayer perceptron with 2 intermediate layers is possible, but it is possible that for solution of some problem the simpler and more convenient NN will be with more layers, and for the vast majority of tasks are only one intermediate (hidden) layer, and the two layers are used as a reserve in individual cases. NN with 3 balls apply very little (infrequently).

In the application of NN with the back propagation of the signal, the negative moment is the indefinite long learning process of the network, which is the result of a non-optimal choice of the length of step η, which can cause paralysis of the network or entry into the local minimum. If the size of step Z is very small, then the convergence is rather slow, and if η is very large, then there may be paralysis or constant instability of the neural network. The learning process of the NN must take place on all elements of the training set without passing through the previously studied one. The correction of weighting factors should be calculated on the whole training set and only after a certain number of training cycles, the weighting factors of the equipment have a minimum error on the output of the NN.

To improve and generalize the main algorithm for back propagation of the signal, a large number of methods have been developed in different countries for solving various applications, for example:

1) In Japan, the NEC company applied a reverse signal propagation for visual recognition of letters;
2) conversion of printed English text into high-quality language;
3) machine recognition of handwritten English words;
4) to convert images that are eight times better than the input data.
5) Conclusion

When applying the reciprocal distribution algorithm in the learning process, the NN minimizes the error in the training set, and not the error that was obtained from the NN in the processing of completely new observations. NN with a large number of weight factors can solve more complex tasks, at the same time they are more prone to retraining, and with such a number of weight coefficients NN is not flexible enough to solve certain types of tasks. NNs without intermediate (hidden) layers can solve (simulate) only tasks with ordinary linear dependence. At the same time, the NN with a more complex structure gives an output error, but it can be an overload of the network, which can be prevented by using the check-up mechanism (cross-check) to reserve part of the training observations in order not to use them in the learning process. An important indicator of the quality of NN work is the control error. For almost identical values of control errors, it is necessary to choose NN with a simpler model. With multiple experiments over NN, a control error is decisive when choosing a model for a future NN. In order to confirm the correct choice of model, it is tested on a test set of observations, which is used only once. That is, all classes of training on the algorithm of reciprocal propagation foresee the use of the following sets: 1) educational; 2) control; 3) tests that should be representative from the point of view of the content of the task, as well as individually taken, these sets should be representative. If the training set is not representative, then the NN model will not be qualitative, or completely (unnecessary) not suitable for solving tasks.

The main reasons that worsen the quality of the training set: 1) the choice of historical data law, in which there is no place in the future development of the process, that is, the future does not always resemble the past; 2) insufficient level of taking into account the properties of NN data (did not take into account all possibilities of the neural network); 3) insufficiently deeply analyzed the selected all possible properties of the object of the analysis of NN (neural network is learning all that is easier and faster to learn); 4) imbalance of the set of data of the training set, that is, the unevenness of the selection of data of observations of different types.

CHAPTER 5
INTELLIGENT CONTROL SYSTEMS IN TRANSPORT

5.1 General provisions on the implementation of intelligent control systems in transport

Among the scientific works in which the theoretical foundations of intellectual management are studied, it is worth noting scientists such as V. Andrianov [2], A. Beider [3], T. Gavrilyuk, V. Khoroshevsky [4], A. Yeremin [5], P. Kuzhelev [6], V. Markelov, I. Solovyov, V. Tsvetkov [7], V. Pavlov, S. Pavlova [8], A. Semenov, N. Solovyov, E. Chernoprudova, A. Tsygankov, A. Semenov [9], V. Tsvetkov [10, 11, 12, 13], I. Shcherbatov [14], I. Rosenberg [15], Panos J. Antsaklis [17], Alyus J.S . (J.S. Albus) [19], Ponce-Cruz Pedro, Ramírez-Figueroa, Fernando D. (Ponce-Cruz, Pedro, Ramírez-Figueroa, Fernando D.) [21], Cai Zixing (Cai Zixing) [18], Nazmul H Siddique (Nazmul H Siddique) [20] and others.

The policy of scientific research and innovation in transport should increasingly contribute, in a correspondingly coordinated manner, to the development and application of leading technologies necessary for the development of the EU transport system to the state of a modern, efficient and user-oriented system. To ensure higher efficiency, technology research needs to be complemented by a systemic approach, taking into account infrastructure and regulatory requirements, coordination of multiple actors and large-scale demonstration projects to encourage market penetration. The commission will develop an innovation and implementation strategy for the transport sector, in close cooperation with the strategic plan for energy technologies (SET-plan), identifying the optimal management and funding tools to ensure the rapid implementation of scientific research results.

This will also apply to the implementation of intelligent mobility systems developed by EU-funded research, including the future Air Traffic Management System (SESAR), the European Rail Transport Management System (ERTMS) and the Railway Information System, the Maritime Surveillance System (SafeSeaNet), the Services information on rivers (RIS), intelligent transport systems (ITS) and interoperable interconnected solutions for the next generation of management systems and information systems of multimodal transport (in particular for receiving payments). There is also a need for an investment plan for new navigation, traffic monitoring and information dissemination services. Equally important are scientific research and innovations in the field of vehicle traction system technologies and alternative fuels (green car initiative, clean sky).

In terms of the sector, a range of technologies are being used to improve the efficiency of vehicle movement and related commercial operations as a link in the supply chain. These different technologies are now collectively known as Intelligent Transportation Systems (ITS). Intelligent transport system (ITS, Intelligent transport management) is a system that combines computer, information and communication technologies to manage the movement of transport and goods in real time, and allows to improve road safety and the quality of transport services. Intelligent ITS is currently the largest and most diverse group. It covers a wide range of information, road, navigation, automotive, insurance and vehicle/driver control systems and thousands of other systems that use data to create "intelligent" solutions in the field of transport. Most of the transport "apps" available on modern smartphones belong to this category. ITS guarantees huge economic benefits as carriers and transport users can make more informed decisions to reduce passenger and freight transport times, transport costs and delays [1].

The use of ITS contributes to the construction of a more reliable, safer and more efficient transport system, as well as to reduce its impact on the environment. Future development should be based on a number of the following directions:

1. Improvement of energy efficiency indicators of vehicles of all types of transport; development and application of ecological types of fuel and power plants.

2. Optimizing the operation of multimodal logistics schemes, in particular due to the wider use of modes of transport that are more resource-efficient in nature, where other technological innovations may be insufficient (for transporting goods over long distances).

3. More efficient use of transport and infrastructure due to improved transport management and information systems (ITS, SESAR, ERTMS, SafeSeaNet, RIS7), advanced logistics and market measures, in particular the full development of the integrated European railway market, removal of restrictions on internal transport, elimination of obstacles for cabotage, balanced pricing, etc.

Addressing the above issues will mean achieving very difficult tasks by 2050 – and incredibly difficult ones by 2020-2030 to ensure we are moving in the right direction. The scale of changes in the transport functioning system is different depending on the transport segment, as the technological options for each segment differ. Therefore, the Commission focuses its attention on three main transport segments: medium-distance transport, long-distance transport and urban transport. The implementation of this work will depend on many actors - the EU, member states, regions, cities, but also the industry, social partners and citizens will have to play their role [50-60].

The implementation of ITS on a global scale became possible only in the conditions of a saturated communication space, when there are no problems with the cheap transfer of significant volumes of digital information in real time at any point of the transport network. Basic technologies for transport infrastructure and vehicles are developing most actively today:

1. Intelligent systems for infrastructure: – traffic management on highways;

– commercial road transport;

– prevention of vehicle collisions and safety of their movement;

– electronic payment systems for transport services;

– emergency management;

– traffic management on the main street network and elimination of the consequences of road accidents;

– intermodal cargo transportation;

– highway operation;

– management of public transport;

– information for movement participants;

2. Intelligent systems for vehicles:

– collision prevention systems;

– collision notification systems;

– driver assistance systems [60-70].

Given that our country lags far behind in the field of intellectualization of the transport process, the development of proposals for the development of ITS in Ukraine primarily involves the analysis of world experience, the use of foreign analogues in the development and implementation of ITS, taking into account the Ukrainian reality. Therefore, it is necessary to use the leading world experience, the most modern technical and technological developments, to stimulate new domestic research. The problem of the implementation of ITS is of a strategic nature, its solution generally determines the competitiveness of each country on the world market and, due to the significant capital intensity, cannot be implemented without direct state participation. Development of a national transport strategy for ITS at the state level, regional and local governments should take the initiative in: developing standards and protocols taking into account the applicable jurisdiction.

The introduction and spread of ITS today is an effective innovative business, capable of competing in national and international markets, and is also a stimulus for the development of a new sector of high-tech industry. The formation and implementation of ITS in Ukraine will increase the efficiency of transportation management, reduce the costs of transporting goods and passengers, contribute to reducing the level of congestion on streets and roads, ensure the improvement of road traffic safety, and contribute to informing road users about the current traffic situation and optimal traffic routes (for individual and public transport).

The following measures are envisaged in the field of transport and infrastructure:

– implementation of advanced AI technologies for the creation of autonomous vehicles, as well as fully automated infrastructure facilities;

– carrying out developments in the field of driving autonomous vehicles;

– intelligent traffic management;

– creation of an early warning system about the need for infrastructure replacement and repair;

– travel forecasting;

– optimization of transport routes.

Intelligent information systems are characterized by the following features:

– developed communication skills;

– the ability to solve complex poorly formalized problems;

– ability to self-study;

– adaptability.

Problems solved by humans and artificial intelligence:

– data interpretation (interpretation means the process of determining the content of data, the results must be agreed and correct);

– diagnostics (diagnostics means the process of comparing an object with some class of objects and detecting inaccuracies in some system);

– design (design consists in the preparation of specifications for the creation of "objects" with predetermined properties, the specification means the entire set of necessary documents - drawings, general plan, map);

– forecasting (forecasting allows you to predict the consequences of some events or phenomena based on the analysis of available data). Predictive systems logically derive probable consequences from given situations;

– planning (planning means finding action plans related to objects capable of performing some functions).

Models of the behavior of real objects are used to logically deduce the consequences of the planned activity.

5.2 Peculiarities of implementation of intelligent control systems in road transport

In the 1990 s in the USA, the main stages of solving the problems of the development and implementation of ITS were clearly formulated: mathematical modeling of the movement of cars and traffic flows (the so-called micro and macro modeling); unified information system; electronic route selection and indication system; driver assistance system.

Currently, the entire network of highways adjacent to major cities (Chicago, Detroit, Los Angeles, New York, etc.) is equipped with ITS.

In the USA and Canada, much attention is paid to the interconnections of the urban system with the system of roads and highways in suburban areas. A good example is the urban network in Montreal, where the urban traffic management system includes suburban highways, that is, up to approximately 70-100 km from the city.

In Japan, almost the entire road network, both in cities and on highways, is equipped with local ITS of varying degrees of complexity.

In modern practice, it is customary to attribute ITS to one of the four generations of the development of these systems:

Generation 1. The calculation of the control parameters and their entry into the ITS are performed manually.

Generation 2. The calculation of control parameters is automated. They are entered into the ACS manually.

Generation 3. The calculation of control parameters and their entry into the IT system are automated. Management (reaction to changes in traffic flow) is carried out taking into account the dynamics of traffic flows (TR-method) by changing pre-calculated temporary tables.

Generation 4. The calculation of control parameters and their entry into the IT system are automated. Management is carried out in real time (with short-term response delay or traffic flow forecasting), taking into account local changes in traffic flows.

Currently, ITS of the 3rd and 4th generations are installed in several dozen cities: in 53 cities of Great Britain, in Madrid, Hong Kong, Tokyo, Toronto, Bordeaux, Bahrain and a number of others. The most important component of ITS is the system of informing movement participants, which has become especially global with the development of Internet networks. Currently, a large part of the territory, for example, the USA or France, is covered by information systems that transmit quantitative data on traffic flows in real time.

In recent years, systems that predict the average speed and travel time on certain routes have become increasingly widespread. Such systems have a significant influence on the redistribution of traffic flows.

In the state of Texas, the Texas Department of Transportation has successfully implemented an ITS system based on a combination of central hourly and central adaptive control using a library of pre-calculated PCs.

Japan is an advanced country in the field of development and use of higher forms of automated traffic control systems (it has moved to the level of intelligent transport control systems). In addition to Japan and other countries of the Asia-Pacific region, they are purposefully investing in the development of management systems. In some Australian cities, the SCATS control system is used for zonal control of traffic controllers, often combined with other subsystems. A lot of attention is paid to these issues in South Korea. In China, there is a commission to manage the research development of intelligent transportation systems. A program has been developed, which includes a general strategy for the development of ITS and a list of pilot demonstration projects.

The assessment of the effect of creating a fully functional ITS includes the need to monitor performance indicators from the following components.

Social effect.

It consists in creating conditions for reducing the travel time of the population by all types of land transport at the expense of:

– increasing the carrying capacity of the city's roads due to the regulation of traffic flows (automatic control of the operation of traffic lights);

– obtaining the opportunity for the passenger to choose the optimal route of public transport from the starting point to the final point, taking into account the routes and schedules of all types of public transport, as well as the road situation and traffic flows;

– optimization of the vehicle traffic route taking into account the current state of traffic organization and the state of traffic flows.

An important component of the social effect is timely informing the population and road users about the organization of transport services, as well as about the current state and short-term forecast of the development of the transport situation both in specific areas and in the city as a whole.

Informing consists in bringing such information to the population and road users in a time regime close to the real one, using means of telecommunications:

– information about road sections with difficult traffic (traffic jams);

– changes in the organization of traffic (street closures, temporary signs, emergency areas, etc.);

– bypass schemes for problem areas;

– calculation of travel time from the starting point to the final point, taking into account the road situation;

– condition of the road surface (snow, rain, ice);

– recommended speed mode;

– laying the optimal traffic route taking into account the road situation;

– timetable of public transport;

– traffic patterns of public transport;

– cost of travel and baggage transportation;

– laying the optimal traffic route for passengers from the starting point to the final point by various modes of transport, taking into account the real road situation.

Improving the safety of transport and on transport.

Increasing the safety of transport and on transport due to the introduction of regional ITS will allow to increase the safety of road traffic, as well as the safety of all types of transportation.

Traffic safety is achieved through:

– prompt, complete and reliable provision of information to special services in the event of criminal or emergency situations in transport. In the event of such a situation, real-time information from special devices mounted on the vehicle is sent to the Unified Dispatch Center;

– ensuring unhindered movement of special transport to the scene of an accident or criminal situation. Due to the automated management of traffic light objects, the possibility of creating a "green" street for the passage of special vehicles is achieved;

– informing drivers about the current condition and short-term forecast of the condition of the road surface. In case of deterioration of the road situation (precipitation, formation of ice, etc.), drivers receive information about this in time and have the opportunity to prepare for such a situation;

– provision of automatic recording of facts of violation of traffic rules with identification and punishment of guilty persons. It is achieved by the implementation of appropriate automated systems;

– increasing the attention of drivers, due to the reduction of driver fatigue due to long traffic jams.

Safety during transportation by passenger transport is achieved by installing photo, video cameras, smoke and temperature sensors in passenger transport, capable of recording criminal (for example, acts of theft) or emergency situations (for example, facts of fire in the bus cabin). Information about such facts in real time is sent to dispatch centers, where measures to eliminate them are promptly implemented.

The safety of cargo transportation is achieved by installing special sensors in cars that monitor the condition of the cargo being transported. For example, temperature sensors are installed in refrigerating chambers in which food products (school breakfasts) are transported. In case of a malfunction of the refrigerating unit, information about this is sent to the control room, where appropriate measures are taken.

Economic efficiency.

It consists in creating conditions for ensuring the given mobility of citizens, timely and reliable control of the execution of municipal orders for the implementation of transport work by enterprises that carry out passenger transportation, street cleaning, removal of solid and liquid household waste.

The implementation of ITS in regional management bodies will improve the efficiency of state and municipal transport management due to customers and contractors receiving a complete, up-to-date picture of the planning and execution of transport work of enterprises.

Ecological effect.

An intelligent transport system using technologies for the redistribution of road congestion due to the effective operation of a number of subsystems (subsystems for controlling traffic light objects, subsystems for indirect control of traffic flows, subsystems for restricting access to certain sections of roads, subsystems for managing parking loads, other subsystems) allows to solve this the task of transferring or redistributing places of traffic concentration (traffic jams) to places where the ecological situation is not as serious as in residential areas or places of recreation of townspeople.

Intelligent control systems (ICS) are control systems (ICs) capable of "understanding" and learning about OK, disturbances, external environment and operating conditions. The main difference between intelligent systems is the presence of a system knowledge processing mechanism. The main architectural feature that distinguishes intelligent ICs from traditional ones is the mechanism for obtaining, storing and processing knowledge for the implementation of control functions.

The creation of intelligent ICs is based on two generalized principles: management based on the analysis of external data, situations and events (situational management); the use of modern information technologies for knowledge processing. There are several modern information technologies that allow creating intelligent IC: expert systems; artificial neural networks; fuzzy logic; evolutionary methods and genetic algorithms).

The concept of intelligence is based on: the ability to work with formalized human knowledge (expert systems, fuzzy logic); human learning and thinking methods (neural networks, genetic algorithms).

Structurally intelligent ICs contain additional blocks that perform systematic processing of knowledge based on these information technologies. Such blocks can be performed either as a superstructure over a regular regulator, adjusting its parameters properly, or directly included in the control loop [70-80].

The most significant reasons for the spread of intelligent ICs are as follows: special qualities of intelligent ICs, in particular low sensitivity to changes in IC parameters; the fact that the synthesis of an intelligent IC using modern means of hardware and software support is often simpler than traditional ones.

There are cases when the use of intelligent ICs is justified and gives a better result: regulation systems for which the OC model is defined only qualitatively or does not exist at all; as a superstructure over traditional systems to give them adaptive properties; reproduction of the actions of a human operator; systems of organizational management of upper (strategic and tactical) levels.

Autopilot is perhaps one of the main trends of recent years. Autopilot technology is practiced by many automakers, and some, like Tesla, are already using it in practice. The autopilot of the future will remember the owner's driving style [2].

Thus, intelligent transport systems control various aspects of traffic management in rail, road, air and water transport.

For example, traffic lights, arrows on railway tracks, air traffic control, as well as rules (including rules for financing the system: toll roads, fuel tax, etc.).

Management of the transport system is a set of measures aimed at the effective functioning of this system by means of coordination, organization, arrangement of the elements of this system, both among themselves and with the external environment.

Advantech offers its developments for the modernization of transport infrastructure: cost-effective platforms applicable for use on railways (at stations, in trains, track control), highways (tunnel control, information displays, entrance control, electronic payments), as well as on other types transport [6].

5.3 Peculiarities of implementation of intelligent control systems in railway transport

The choice of a strategy for the development of railway transport enterprises (RTE) is preceded by the determination of the type of basic and competitive strategy. We suggest choosing a basic development strategy based on the following elements it touches: market, product, production technology, the company's position within the industry. Such an element as "industry life cycle stage" will not be considered for the following reasons. There is no strategy that applies only to this element and does not have manifestations among others. That is, to change the stage of the life cycle, to give it a vector for renewal and growth (the transport industry can be characterized as mature) without changing either the product or the production technology (except for the transition to the stage of decline, which is unacceptable given its strategic importance) is not possible.

The use of the strategy of progressive vertical integration for the "market" element, i.e. the strengthening of the enterprise's influence on product sales channels and relations with consumers will provide an opportunity to strengthen consumer loyalty, create a favorable image, and increase the degree of loyalty to RTE activities.

Among the basic strategies related to the "product" element, i.e. cargo and passenger transportation services, we propose to include such a subtype of stability strategy as the product development strategy. The growing level of competition both from the enterprises of the motor vehicle industry (if we consider the domestic market) and from the railways of other countries (due to which Ukraine loses significant volumes of transit transportation), requires constant updating of products both from the standpoint of assortment and from the standpoint of its quality. analysis of growing consumer demand and finding ways to satisfy it.

For the "production technology" element, it is possible to use a strategy of centralized diversification, i.e. search for new opportunities for existing production, which would allow the enterprise to expand both the range of products and enter new market segments.

Considering the element "the position of the enterprise within the industry", it is advisable to use the strategy of strengthening and protecting the position in the market. In the crisis and post-crisis period, the volume of cargo transportation (main for generating profit) decreased significantly, a significant amount of clientele was lost due to the closure and reduction of production at other enterprises. That is, now it is extremely important to keep the remaining shippers and try to return the lost ones. Upon reaching the level of transportation volumes that were in the pre-crisis period, other strategies can be applied - for example, market development, the implementation of which, however, will be ineffective if it is applied immediately.

To implement the basic development strategies of RTE, it is necessary to define a competitive strategy, which includes cost leadership and differentiation strategies. The strategy of focusing (concentration on a segment) is inappropriate to apply in view of the strategic importance of the railway industry, the public and national importance of the enterprise, the volume of production and the size of the enterprise.

Each of the basic strategies corresponds to a certain competition strategy, which, in our opinion, is the most appropriate in the current conditions and selected strategic goals and guidelines. Depending on the types of basic and competitive strategies of RTE, we choose the strategy of managing intellectual capital (IC), which is the subject of intellectually-oriented management of RTE development. In work [9], 8 alternative strategies for managing the company's IR are highlighted: optimization of intellectual infrastructure, development of intellectual infrastructure, intellectual stimulation, intellectual development, development of relations with suppliers, creation of consumer loyalty, intellectual training, intellectual expansion. The relationship between the basic, competitive strategies, which were chosen as optimal for RTE in modern operating conditions, and IC management is shown in Table 5.1.

Table 5.1 – IC RTE management strategies in terms of basic and competitive strategies

The element to which the base strategy applies	Kind of basic RTE strategy	A type of RTE's competitive strategy	A type of RTE IR management strategy	IC component to which the strategy is directed
Market	Strategy of progressive vertical integration	Strategy of image and service differentiation	Strategy for creating consumer loyalty	Consumer capital
Product	Product development strategy	Product and image differentiation strategy	Strategy of intellectual development	Human capital
Production technology	A strategy of focused diversification	Cost leadership strategy	Intellectual learning strategy	Human capital

The position of the enterprise within the industry	A strategy for strengthening and protecting the market position	Cost leadership strategy	Strategy for optimization of intellectual infrastructure	Organizational capital

Let's outline the contours of selected IC management strategies.

The strategy of creating consumer loyalty involves creating and maintaining the loyalty of consumers of transport services. By consumer loyalty, we will understand the commitment of buyers to a specific enterprise, its products, which is motivated by a positive experience of interaction with it (purchase of goods, use of a service). Loyalty is manifested in the decision to regularly consume a particular brand (consciously or unconsciously), which is expressed through attention or behavior.

This strategy should be focused on creating partnership relations with consumers, which will allow to retain existing customers, return lost ones and win new ones. It should be understood that consumer loyalty should be based on the value characteristics of the product (service), which separate it from competitors. Loyalty can increase the value of a product (service), but it cannot create it.

The strategy of creating consumer loyalty as part of the RTE development management strategy based on the use of intellectual capital should be based on:

– highlighting and emphasizing the indisputable advantages of railway transport: a high degree of safety for passengers and cargo, environmental friendliness, developed infrastructure, etc. in order to create a positive image of the enterprise;

– creation of "intellectual-innovative" groups, which should monitor changes in the structure of public and client needs in terms of those that may be, but are not implemented at RTE;

– creation of additional services capable of increasing the degree of comfort of using railway transport services in terms of meeting physical and informational needs.

The strategy of intellectual development provides for the creation of an organizational culture aimed at activating the generation of innovative ideas and rationalizing proposals by the company's personnel, creating an innovative and active environment and supporting initiative, a creative approach to solving tasks.

This strategy involves, on the one hand, the creation and support of the staff's desire to formalize existing knowledge regarding the improvement of production, marketing, and information processes, establishing the process of knowledge exchange between the company's employees, and on the other hand: the ability of the company to perceive and adequately respond in time to proposals that put forward by employees (evaluation, final decision, encouragement), creation of an environment encouraging self-learning and continuous professional development, which should become an unwavering rule for every employee.

The strategy of intellectual training provides for the organization of a system of continuous improvement of the qualifications of the company's employees in order to create a basis for innovative and intellectual work, that is, to generate innovative ideas, increase the degree of intellectualization of work, use of the latest equipment, management systems, etc. It is worth noting that there is a close relationship between the strategy of intellectual learning and development: a low qualification level of personnel will not allow to create an "intellectual" organizational culture or, if it is created, will not bring high results, and in the absence of an atmosphere of intellectual development, exchange and generation of knowledge even the high professionalism of employees will not be fully utilized. In the situation of high professional level of employees and appropriate organizational culture, it is possible to achieve a strategic effect from the interaction of personnel and the enterprise, which can be expressed not only in the high quality of innovative ideas. The ideal is a situation in which employees begin to implement the principles of continuous learning and knowledge exchange without external encouragement, so to speak, inertially.

The strategy of optimizing the intellectual infrastructure provides for the construction of an organizational structure aimed at rational use and management of the enterprise's intellectual capital.

In the opinion of the author, the creation of departments for professional development of personnel and management of the knowledge base acquires the greatest importance in this context.

Among the main tasks of the department of professional development of personnel, we highlight:

– coordination of the process of professional and technical training, retraining and advanced training of employees, namely: organization of the process of training employees at targeted courses, seminars, schools of best practices using effective forms and methods of training, organization of appropriate living conditions, etc.; establishment of priority areas of study; selection and approval of study groups; definition and coordination of the teaching staff;

– the organization of scientific and research competitions of employee teams, with the definition of topics, terms, requirements, expert council, types of incentives for participants;

– creation of a motivational system that would contribute to increasing the degree of interest of employees in increasing their professional level, improving skills;

– promotion and encouragement of the process of self-learning, transfer of experience among the company's employees;

– approval of the annual employee training program;

– creation of a system of motivation and encouragement of employees-generators of innovative ideas, rational proposals, inventions;

– establishment of cooperation with other railways, enterprises of railway subordination and railways of other states for the purpose of cooperation in the field of improving the qualifications of employees;

– search for the possibility of attracting third-party investments for the implementation of employee training programs;

– organization of an environment of information openness in terms of the department's activities in order to establish feedback with employees.

The purpose of the knowledge base management department is to create, organize and maintain the RTE knowledge base, which is an information system, i.e. a system of collecting, storing, processing, transforming, transmitting, updating and issuing information using modern computer and other technology for use in management process, organization of self-learning processes, professional development, creation of a modern information space for use by RTE management and employees. The knowledge base of RTE will allow bringing the knowledge of employees and other interested parties into the system, making it available for use not only by the owner, but also by other persons, increasing the speed and quality of information transmission, which will allow to achieve a synergistic effect due to joint activities and expansion of RTE's information space.

It is proposed to be included in the RTE knowledge base: any data, information, information related to the improvement of production, service, information, etc. processes taking place at RTE, received from RTE employees, employees of scientific and research institutions, other state and non-state enterprises in the form of rationalizing proposals, inventive, creative, innovative ideas with the aim of expanding the information space of RTE. It is worth noting that not all proposed ideas and proposals can enter the knowledge base, that is, there must be an initial expert control. A group of experts can be formed by company employees: activists whose work will be rewarded with social recognition and moral encouragement. The knowledge base should be structured in detail for the purpose of attributing ideas to issues of work of a certain service or areas of activity.

The effect of the implementation of the proposed knowledge base will be determined by an increase in the number of implemented rationalization proposals, an increase in savings due to this implementation, an improvement in the moral and psychological climate in the team, and an increase in the professional and qualification level of employees. Indirect types of effect can be called an increase in the level of labor productivity, a decrease in operating costs, an increase in the volume of transportation due to the expansion of the circle of consumers, an improvement in the environmental situation, etc.

It should be noted that at the initial stage, the creation of the proposed departments will lead to an increase in the number of RTE employees, but later it is predicted to decrease due to both an increase in the qualification level of personnel, that is, an increase in their labor productivity, and the introduction of innovative ideas, rationalization proposals, increased automation and informatization of production and servicing processes.

In practice, to assess dynamic processes, which is the development of an enterprise, the so-called dynamic standard is used – "a set of indicators subject to growth rates in such a way that maintaining such an order for a long period of time ensures the best mode of functioning of the economic system" [80-90].

There are several models of dynamic regulations, in particular: the "golden rule of enterprise economics", the model of "economic growth" by M.S. Abayutina, the model developed by M.O. Kyzym, V.A. Zabrodskyi, V.A. Zinchenko, N.P. Lyubushyn, Motyshina M.S., Shinkarenko V.G. and others, which, however, do not take into account the peculiarities of the functioning and development of PZT. Based on the analysis of literary sources, we propose the following model for evaluating the intellectual development strategy of RTE (1):

$$T^{Pp} > T^{D} > T^{Qtp} > T^{Qpac} > T^{Фосн} > T^{IP} > T^{MB} > T^{B}, \qquad (5.1)$$

where T^{Pp}, T^{D}, $T^{Qгр}$, $T^{Qпас}$, $T^{Фосн}$, T^{IP}, T^{MB}, T^{B} – growth rates, respectively, of the company's profit, revenue from product sales, cargo transportation volumes, passenger transportation volumes, the cost of the company's main production assets, the indicator of "intellectual development", material costs, general costs for production and sales of products.

The indicator of "intellectual development" is determined by the formula (5.2):

$$ID = B_{LK} + Bок + AIA + Bск, \qquad (5.2)$$

where B_{LK} – expenses for training, retraining and professional training of personnel, increasing the innovative activity of personnel, revealing and applying creative abilities in the production process, for research; Вок – expenses for the development of organizational culture, creation, reorganization and relocation of the enterprise or its parts (optimization of the organizational structure); AIA – the amount of intangible assets of the company; Вск – expenses for the formation and improvement of the business reputation of the enterprise in the external environment.

The division of the indicator of the growth rate of the company's production volume into two indicators: the volume of cargo transportation and the volume of passenger transportation is due to the profitability of the first and the unprofitability of the second, as well as compensation of the unprofitability of passenger transportation at the expense of cargo. That is, in order to achieve the growth rate of total revenues from transportation, the volume of cargo transportation should be much larger than that of passenger transportation.

The allocation and introduction into the formula of the calculated indicator, conventionally called the indicator of "intellectual development", is due to the following. In the era of the development of a new type of economy - the post-industrial or knowledge economy - the IC possessed by the enterprise, as well as such a share of it as business reputation, which can significantly increase the profitability of the enterprise with their skillful use, is of great importance.

Part of the IC of the enterprise is reflected in the balance sheet in the form of intangible assets, the other part is not reflected (customer contracts, employment contracts), some are even difficult to account for (formalized knowledge of personnel that has not yet been reflected in the form of patents, licenses, developments, and informal knowledge - that is, those that theoretically exist, but do not yet have a material form and are inseparable from their owner).

The following costs are not recognized as tangible assets and are reflected in the company's balance sheet, which, in our opinion, have a significant impact (as well as AIA) on the degree of efficiency of RTE's activities: costs of training, retraining and professional training of personnel, research, increasing the innovative activity of personnel, disclosure and the application of creative abilities in the production process; expenses for the development of organizational culture, creation, reorganization and relocation of the enterprise or its parts (optimization of the organizational structure); expenses for the formation and improvement of the business reputation of the enterprise in the external environment. The first expense item is closely related to the concept of human capital, its increase and disclosure; skillful management of expenses for the development of an organizational culture based on innovative and creative work, improvement of business reputation leads to an increase in the number of consumers, growth of loyalty, creation of a positive image of the organization, etc. Reorganization (if necessary) is designed to optimize business processes occurring at the enterprise.

All this determines the need to include the proposed indicator in the formula.

It is advisable to apply the developed dynamic standard at the beginning of the implementation of the RTE development strategy on an intellectual basis (to build a basic ("initial") level of development), at the end of each of the stages of the strategy, during the implementation of the strategy (at any time interval) for the purpose of monitoring implementation and adjustment of developed development programs.

It is worth noting that the dynamic norm is an ideal model for the effective implementation of the RTE development strategy on an intellectual basis. It is practically possible to rearrange the indicators or change the sign in comparison with the proposed model.

5.4 Peculiarities of implementation of intelligent control systems in aviation transport

According to the Aviation Transport Strategy of Ukraine for the period until 2030, the importance of air transport in the world economy is constantly growing, which is facilitated by both technological development and the latest developments in the aviation industry, as well as globalization and ever closer business and cultural ties between different countries of the world.

Aviation transport has a positive effect on the development of tourism business and international trade. Today, more than 52% of international tourist trips are made by air. A developed aviation industry contributes to increasing the country's investment attractiveness and expanding opportunities for international companies to operate on its territory.

Air transport also provides extremely fast delivery of valuable and perishable goods to their destination, which is why it is widely used by large leading international logistics companies.

Today, aviation transport is characterized by the following world trends:

– high technological complexity of vehicles and ergonomics, development of intelligent transport systems, application of information and electronic technologies, satellite navigation tools;

– increasing the level of safety of air transport, strengthening measures to protect aviation from acts of illegal interference;

– development of multimodal transport technologies and infrastructure complexes for different types of transport, interoperability;

– globalization of transcontinental air transportation within the framework of powerful world alliances;

– growing role of cheap ("low-cost") air transportation for direct interregional connections;

– increasing the availability of air transportation for the population, development of international air tourism, migration of labor resources to more distant regions of the world.

Today, the aviation market of Ukraine is beginning its revival after a period of decline in activity over the past few years.

About three dozen domestic airlines operate on the passenger and cargo air transportation market of Ukraine, 19 of which carry out passenger transportation. 6 leading airlines, namely: "International Airlines of Ukraine", "Azur Air Ukraine", "Roza Vitriv", "YanAir", "Bravo" and "Atlasjet Ukraine" perform 95% of the total volume of passenger transportation.

Regular flights between Ukraine and the countries of the world are carried out by 10 domestic airlines to 42 countries of the world and 28 foreign airlines to 27 countries of the world. Regular domestic passenger transportation between 9 cities of Ukraine is performed by 5 domestic airlines.

Cargo and mail are transported by 18 domestic airlines, most of the transportation is carried out by charter flights in other countries within the framework of UN humanitarian and peacekeeping programs, as well as in accordance with contracts and agreements with other customers. At the same time, companies such as Antonov State Enterprise, Ukraine International Airlines, ZetAvia, Maximus Airlines, Urga and Europe Air perform more than 80% of the total volumes.

Currently, 19 airports and airfields operate and serve commercial flights of domestic and foreign airlines in Ukraine. Passenger flows through the airports of Ukraine amount to about 13 million people.

The number of departed and arrived aircraft exceeded 130,000 in 2016. Post-cargo flows – more than 40,000 tons.

7 leading airports – Boryspil, Kyiv (Zhulyani), Odesa, Lviv, Kharkiv, Dnipropetrovsk and Zaporizhzhia serve about 98% of total passenger traffic and mail-cargo traffic.

25 aviation enterprises carry out aviation works, processing about 0.5 million hectares of agricultural land.

State Enterprise of Air Traffic Services (hereinafter - Ukraeroruh) serves more than 200,000 flights. At the same time, the number of flights made by airplanes and helicopters of Ukrainian airlines is increasing, while the number of flights made by foreign airlines is decreasing.

The Aviation Transport Strategy of Ukraine (hereinafter referred to as the Aviation Strategy) defines the strategic directions for the development of the aviation industry for the period up to 2030 and the formation of an effective mechanism of public-private partnership in the field of managing air transport infrastructure facilities.

As part of the Aviation Strategy, tasks in the following areas should be solved:

1. Improvement of regulatory and state regulation in the field of air transport.
2. Increasing the level of safety of air transport.
3. Development of air transportation and increasing the level of their accessibility for the population.
4. Development and modernization of airports, liberalization of access to the aviation services market.
5. Development of multimodal transportation, provision of high-speed ground transportation between airports and settlements, creation of logistics centers and simplification of formalities.
6. Development of the air navigation system.
7. Development of general aviation and unmanned aerial systems.
8. Professional training of personnel, research work.

Pre-flight training plays a very important role in flying. Aircraft crews must be provided with a variety of information necessary to make the decision to take off and safely perform the flight. Responsibilities of providing pre-flight information and providing recommendations regarding the subsequent flight are assigned to flight controllers who provide flights in every modern airline. Very often, no less important information received by the flight controller is dynamic in nature, and the time for its perception and analysis becomes significantly shorter. Therefore, it is advisable to develop a decision support system for the flight controller during the preparation of pre-flight information [1].

Statistics show that almost 50% of aviation incidents were caused by violations of national aviation regulations, operational manuals, instructions and pre-flight training requirements. In some cases, temporary economic benefits take precedence and flight safety becomes at high risk. Sometimes, due to lack of time, the flight crew prepares for the flight during insufficient time, which leads to unknown situations and, worst of all, to aviation events. The nature, content, and complexity of information vary, so it is important to provide information in a way that pilots can easily understand [90-99].

There is an opportunity to increase the effectiveness of pre-flight information preparation by providing flight operations officer information during the provision of recommendations to flight crews regarding the possibility of helicopter departures. Such programs help create optimal operational flight plans with high accuracy in terms of wind, temperature, receive weather charts and reports, graphical representations of the route and flight profile, and other related information expected by the flight in question. Each helicopter operator chooses its own flight planning system that suits the objectives, strategy and requirements of flight operations.

During flight planning and preparation of pre-flight information, the aeronautical information specialist faces a number of difficulties, for example, the computer calculates only the shortest route, not taking into account the specifics of the operation of the given aircraft (restrictions related to the technical status) or the specifics of the zones. In addition, such systems do not allow partial information to be displayed when it is necessary to support the flight crew in the decision-making process [100-115].

Therefore, it is necessary to develop information support for making correct, safe decisions and that will provide, in such a dynamic environment, accurate, complete and biased information to assess all factors that may influence the decision to depart and the intention to continue a safe flight.

An aeronautical database is a collection of data that is generated in such a way that it can be easily stored and retrieved from the electronic memory of a system that supports the operation of airborne or ground aeronautical equipment. Such data can be transmitted to the user in the form of a database.

The task of the Aeronautical Information Service (AIS) is to ensure the flow of aeronautical data and aeronautical information necessary to ensure the safe, regular, cost-effective and efficient operation of the global air traffic management system on an environmentally sound basis. The role and importance of aeronautical data and aeronautical information have changed significantly due to the introduction of zonal navigation (RNAV), performance-based navigation (PBN), on-board automated navigation systems and data line systems.

The safe execution and successful completion of each flight is based on the proper pre-flight training of the crew operating the aircraft. Operators need detailed information and information on airspace and conditions of use, aerodromes, helicopters, navigational aids, meteorological services, communications services, air traffic services, procedures and related regulations in order to plan routes and submit scheduled flights.

Pre-flight information service is provided to all interested airspace users. The provision of pre-flight information services to airspace users, as well as the receipt and dissemination of notifications on air traffic services at Ukrainian airfields are carried out by pre-flight information services units (hereinafter - briefing offices). Appropriate software and means of communication are used.

The Pre-Flight Information Service (Briefing Office) is a body set up at an aerodrome to provide airspace users with the necessary aeronautical and meteorological information, as well as to receive and disseminate air traffic services and flight plans notifications before departure.

The main function of the briefing office is to provide a set of aeronautical and meteorological information necessary for the preparation and execution of the flight.

The briefing office consists of:

– Air Traffic Services Reporting Office (ARO);

– Aeronautical Information Services (AIS);

– Pre-Flight Meteorological Services (MET).

ARO directly provides:

– acceptance of flight plans and other notifications regarding aircraft traffic from aircraft crews and other airspace users;

– transmission of messages regarding the movement of the aircraft;

– transfer of information about planned departures to the airport services;

– receiving notifications on the organization of air traffic flows and their dissemination among air traffic services, airport services and airspace users;

– interaction with the Integrated Initial Processing System of Eurocontrol Flight Plans (IFPS) on aircraft traffic messaging;

– interaction with ARO of other airports;

– receiving and transmitting reports on air traffic incidents.

The ARO may be set up as a separate point or merged with an existing aerodrome dispatch service.

When combining at the ARO aerodrome with the aerodrome dispatch service body, it is necessary to determine:

– performance of ARO functions in the technology of aerodrome dispatching service;

– a room for self-training of crews for departure, which is equipped with equipment that provides airspace users with direct access to aeronautical and meteorological information.

– AIS directly provides:

– support of aeronautical information collections;

– receiving, processing, analyzing and systematizing HOTAM messages;

– preparation and provision of pre-flight information bulletins;

– conducting pre-flight consultations for airspace users;

– providing aeronautical information to aircraft crews and other airspace users;

– receiving post-flight information from aircraft crews on the condition and operation of air navigation facilities.

MET directly provides:

– obtaining and analyzing meteorological information;

– conducting meteorological consultation for aircraft crews and other airspace users;

– preparation and provision of flight meteorological documentation to aircraft crews and other airspace users.

Liaison between the MET and the AIS offices needs to be maintained on an ongoing basis. Air navigation users depend on the quality of certain aeronautical and meteorological information, as there is a high probability that the use of corrupted critical data may pose a serious risk of catastrophe. Thus, each state must constantly ensure that users (aviation industry, air traffic services, etc.) receive timely and high-quality aeronautical and meteorological information for the period of its intended use.

Aviation ergonomics, which is stimulated by the tasks of creating and effectively using aircraft, has gained the greatest popularity in many countries. Modern aviation, for which the speed, distance and height of flights are rapidly increasing, creates increased requirements for the flight structure and control systems of aviation equipment. Flight at an extremely low altitude above the ground, refueling in the air, the order of the aircraft in the absence of visibility and other navigational and special tasks require they have not only the flawless skill of the pilots, but also the perfect adaptive control system of aviation equipment [116].

Therefore, it is important that the control system of aviation equipment is maximally adapted to the real conditions of their operation. Meanwhile, the implementation of such a task is possible only with the use of modern software and hardware technologies. To date, the use of artificial neural network (NN) technology will allow aircraft control systems to fulfill their tasks, taking into account certain specifics of their application.

First of all, it has been theoretically clarified, according to Kolmogorov's theory, that a multilayer perceptron with 2 intermediate layers is sufficient for modeling any problem, but it is possible that a NN with a larger number of layers will be simpler and more convenient for solving some problem. and for the vast majority of problems, only one intermediate (hidden) layer is enough, and two layers are used as a reserve in some cases. NN with 3 layers is used quite little [2].

When applying NN with signal backpropagation, a negative moment is the indefinitely long process of learning the network, which is the result of a non-optimal choice of the step length η, which can cause paralysis of the network or hitting a local minimum. If the step size Z s very small, then the convergence is quite slow, and if η is very large, paralysis or permanent instability of the neural network may occur. The learning process of NN should take place on all elements of the training set, without skipping the previously learned. The correction of the weighting coefficients should be calculated on the entire training set and only after a certain number of training cycles the weighting coefficients should ensure the minimum error at the output of the NN.

At the same time, NNs with a more complex structure give an error at the output, but this can be an overload of the network, which can be prevented by applying a check (cross-check) mechanism of reserving part of the training observations in order not to use them in the training process. An important indicator of the quality of NN work is the control error. With almost the same values of control errors, it is necessary to choose a NN with a simpler model. With repeated experiments on the NN, the control error is decisive when choosing the model of the future NN.

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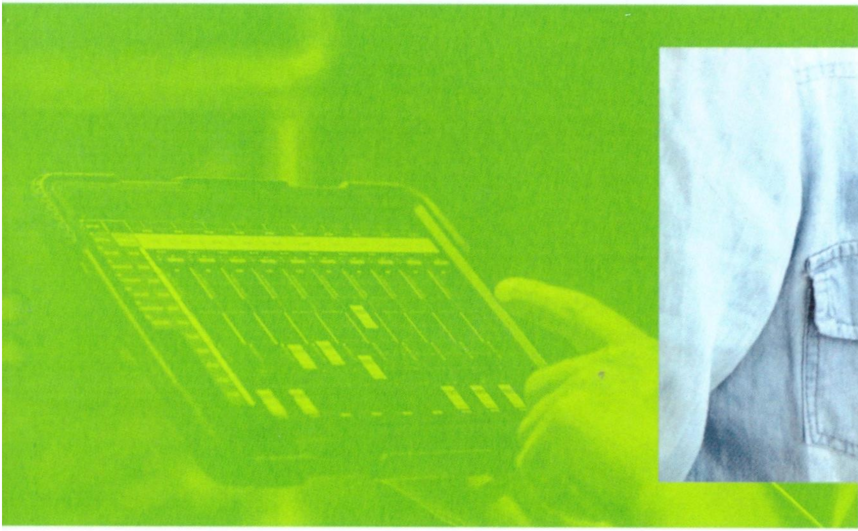

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