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“IGOR SIKORSKY KYIV POLYTECHNICAL INSTITUTE”

Institute of Energy Saving and Energy Management

Power Supply Department

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“Accepted to the defence”
Head of the Department
__________ Vladimir POPOV
“___” _____________ 2020

Master’s thesis

under the speciality: 141 Electrical Energetics, Electrical Engineering and Electromechanics
Educational and Professional Program: Energy Management and Energy Efficient Technologies

on the topic: “Short-term electricity price forecasting of day-ahead market”

Completed by: Master student (2d year), group OH-91мп

Kateryna Batiuta ____________________________________ __________
(Full name) (Signature)

Research Advisor Candidate of Physical and Mathematical Sciences, Associate Professor at the Department of Power Supply Halyna Strelkova __________
(Scientific degree, academic title, full name) (Signature)

Reviewer _______Professor Konrad Świrski___________________ __________
(Scientific degree, academic title, full name) (Signature)

I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.
Student _____________
(Signature)

Kyiv, 2020

National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute"

Institute of Energy Saving and Energy Management

Power Supply Department

Level of higher education: second (Master's), educational and professional program

Speciality: 141 Electrical Energetics, Electrical Engineering and Electromechanics
Name of the program: Energy management and energy efficient technologies

"APPROVED"
Head of the Department
__________ Vladimir POPOV
"___" _____________ 2020

TASK
on the Master's thesis research to student
Kateryna Batiuta

1. Topic of the Master's thesis: Short-term electricity price forecasting of day-ahead market
research advisor: Candidate of Physical and Mathematical Sciences, Associate Professor at the Department of Power Supply Halyna Strelkova
approved by the university order dated on «03» November 2020 № 3199-c

2. Deadline for the Master's thesis submission by student: 14.12.2020

3. Object of research: short-term forecasting of electricity prices

4. Input data: methodologies and methods of forecast models of wholesale electricity price formation.

5. List of the tasks that have to be performed:

- study of the regulatory framework of Ukraine on the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM;
- research of the existing methodology and methods of forecast models of formation of the wholesale price of the electric power on DAM;

– identification of open sources and formation of a database of wholesale price statistics in the DAM electricity market segment;
– study of the European experience concerning innovative approaches on overcoming obstacles of functioning of DAM in the conditions of liberalization.

6. List of the graphical (illustrative) material:

- Classification of electricity price model;
- Factors affecting Electricity Price;
- Daily dynamics of electricity prices in the UES zone from January 1, 2020 to September 30, 2020;
- Timely dynamics of electricity prices as of September 1, 2020;
- price dynamics as of September 1 (Tuesday) 2020;
- Timely price dynamics as of September 5 (Saturday) 2020;
- Timely dynamics of electricity prices on weekends and working days as of November 2020;
- Forecast for the period from September 16, 2020 to September 30, 2020;
- Forecast of electricity prices in the period from September 25, 2020 to November 26, 2020;
- Forecasting of electricity prices by the ARIMA model for the IPS of Ukraine in the period from 25.09.2020 to 15.11.2020;
- Forecasting of electricity prices by the ANN model for the IPS of Ukraine in the period from 25.09.2020 to 15.11.2020;
- Electricity price forecasting model ANN for BEI of Ukraine in the period from 25.09. 2020 to 15.11. 2020;
- Actual hourly dynamics of electricity prices as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the IPS zone;
- Actual hourly dynamics of electricity prices as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the BEI zone.

7. Indicative list of publications:

- Forms of organization of competitive trade in the wholesale market of electric energy for the day ahead / G.G. Strelkova, M.T. Strelkov, K.V. Batiuta // Energy. Ecology. Man: collection of scientific works of the XII scientific and technical conference of the Institute of Energy Conservation and Energy Management, May 7-8, 2020, Kyiv. - Kyiv: KPI named after Igor Sikorsky, 2020. - P. 81-86. [Electronic resource]. - Access mode: URL: https://ela.kpi.ua/handle/123456789/36865
- Batiuta K.V. Classification and comparative analysis of models for forecasting electricity prices / Batyuta KV // Energy. Ecology. Man: III scientific and technical conference of IEE undergraduates, November 26-27, 2020, Kyiv. - Kyiv: Igor Sikorksy Kyiv Politechnic Institute, 2020. - P. 7-13.

[Electronic resource]. - Access mode: URL: https://iee.kpi.ua/iii-науково-технічній-конференції-ма/

8. Consultants for different chapters of the Master's thesis:

Regulatory control as. Iryna Prokopenko

9. Date, when the task was issued: 01.09.2020

Calendar plan

№ з/п	Name of the stage of the Master's thesis implementation	Terms of implementation	Notes
1.	Identification the purpose of research, object and subject of research	20.04.2020-01.06.2020	
2.	Identification the preliminary structure of the Master's thesis	01.06.2020-01.08.2020	
3.	Literature review and work on the first chapter of the Master's thesis	01.09.2020-01.10.2020	
4.	Define methodology and methods of research (the second chapter)	01.10.2020-04.11.2020	
5.	Literature review and work on the third chapter of the Master's thesis	04.11.2020-20.11.2020	
6.	Literature review and work on the fourth chapter of the Master's thesis	20.11.2020-01.12.2020	
7.	Formatting the text of the Master's thesis	01.12.2020-10.12.2020	
8.	Preparing the Abstract and PowerPoint Presentation of the Master's thesis; receiving an official protocol of plagiarism detection results and peer review	30.10.20-10.12.20	
9.	Preliminary Master's thesis defense	10.12.20-14.12.20	
10.	Master's thesis defense	17.12.20-22.12.20	

Student __________ Kateryna Batiuta

Research Advisor __________ Halyna Strelkova

ABSTRACT

Structure and scope of work. The Master's dissertation on "Short-term forecasting of electricity prices in the market" for the day ahead "" consists of a list of symbols, introduction, four sections, conclusions and a list of sources used. The total volume of the work is 112 pages, including 8 tables, 16 figures, 86 bibliographic references.

Relevance of research. After the reforms in the domestic economy in the energy sector, new conditions were created for the functioning of the electricity market and the participation of industrial enterprises in it, which are characterized by a high degree of uncertainty and growth of various types of risks, including market risks. An example of such risks is the lack of profit; change in the cost of capital; the emergence of the impact of large transactions on market parameters; changes in market conditions; changes in fuel prices; financial and economic losses; bankruptcy; emergence of new economic agents; growth of defaults of consumers and contractors, etc. The processes of liberalization of the electricity market taking place in Ukraine have led to the following specific risks: the risk of differences between actual and contract prices when concluding long-term contracts; spot price risks; the risk of forecasting the amount of electricity consumed and electricity prices; the risk of accurate profit forecasting for large market players who are joint stock companies; risks of forecasting the load of both individual customers and customer groups. If such risks are ignored or insufficiently taken into account, the lost consequence may be a lost consequence; reduction of the size of profit in comparison with expected; reduction of investment efficiency, etc.

In order to minimize the risks that may arise during the purchase and sale of electricity and improve forecasts at the system level, it is necessary to research and develop tools for short-term forecasting of the wholesale electricity price in the market "day ahead" (DAM).

In addition, price forecasting is a very important component for the development of the future development strategy of the entire electricity sector and is the basis for balanced growth of various sectors of the economy in the future.

Relationship of work with scientific programs, plans, themes. The study was performed within the framework of the tasks provided by the Law of Ukraine "On the Electricity Market", as well as within the implementation of the "Energy Strategy of Ukraine until 2035" "Security, energy efficiency, competitiveness"".

Purpose and tasks of the research is to conduct a criterion analysis of forecast models of wholesale electricity prices in the market "day ahead" to reduce the uncertainty of decision-making economic agents of the market and the implementation of short-term forecast of wholesale electricity prices.

To achieve this goal, the following tasks were set:

- study of the regulatory framework of Ukraine on the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM;
- research of the existing methodology and methods of forecast models of formation of the wholesale price of the electric power on DAM;
- identification of open sources and formation of a database of wholesale price statistics in the DAM electricity market segment;
- study of the European experience concerning innovative approaches on overcoming obstacles of functioning of DAM in the conditions of liberalization.

Object of research is short-term forecasting of electricity prices.

Subject of research — methodologies and methods of forecast models of wholesale electricity price formation.

Practical value of the results. The mathematical model of the wholesale price of electricity based on the Random Forest method allows to obtain information about the short-term forecast of the future price of electricity in the market "for the day ahead". The obtained results make it possible to minimize the risks when buying and selling electricity, show a more accurate and easier way to make pricing decisions in a competitive electricity market, analyzing all the factors for the formation of the pricing process. The proposed product incremental innovation in forecasting services allows end consumers to build more accurate short-term forecasts of price changes in the market "day ahead".

Scientific novelty of the obtained results. Based on the study, it was determined that in the context of reforming the energy sector of Ukraine and the introduction of a competitive electricity market, the following proposals for innovative developments can be provided. A promising innovation direction is the introduction of incremental (improving) product innovations in the field of digital technologies and application software. For electricity market participants, the most attractive are innovative solutions for the provision of services using software for forecasting the wholesale price of electricity at DAM.

Approbation of the Master's thesis and publications. Materials of the master's dissertation were published:

- XII International Scientific and Technical Conference "ENERGY. ECOLOGY. HUMAN" from 07.05.2020, Institute of Energy Conservation and Energy Management, National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky".

- III Scientific and Technical Conference of IEE undergraduates from 26.11.2020, Institute of Energy Conservation and Energy Management, National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky".

Publications. Materials of the master's dissertation are published:

– Forms of organization of competitive trade in the wholesale market of electric energy for the day ahead / G.G. Strelkova, M.T. Strelkov, K.V. Batiuta // Energy. Ecology. Man: collection of scientific works of the XII scientific and technical conference of the Institute of Energy Conservation and Energy Management, May 7-8, 2020, Kyiv. - Kyiv: KPI named after Igor Sikorsky, 2020.

- P. 81-86. [Electronic resource]. - Access mode: URL: https://ela.kpi.ua/handle/123456789/36865

- Batiuta K.V. Classification and comparative analysis of models for forecasting electricity prices / Batyuta KV // Energy. Ecology. Man: III scientific and technical conference of IEE undergraduates, November 26-27, 2020, Kyiv. - Kyiv: Igor Sikorksy Kyiv Politechnic Institute, 2020. - P. 7-13. [Electronic resource]. - Access mode:
URL: https://iee.kpi.ua/iii-науково-технічній-конференції-ма/

Keywords*:* ELECTRICITY, INNOVATIVE SOLUTIONS, FORECASTING MODELS, WHOLESALE PRICE, MARKET "DAY AHEAD", PRICE FORMATION, TIME SEG.

РЕФЕРАТ

Структура та обсяг роботи. Магістерська дисертація за темою «Короткострокове прогнозування ціни електричної енергії на ринку «на добу наперед»» містить перелік умовних позначень, вступ, чотири розділи, висновки та перелік використаних джерел. Загальний об'єм роботи складає 112 сторінок, в тому числі 8 таблиць, 16 рисунків 86 бібліографічних посилань.

Актуальність теми. Після проведення реформ у вітчизняній економіці в енергетичному секторі було створено нові умови функціонування ринку електричної енергії та участі в ньому промислових підприємств, які характеризуються великим ступенем невизначеності і зростанням різноманітних видів ризиків, і зокрема – ринкових. Прикладом таких ризиків є недоотримання прибутку; зміну вартості капіталу; появу впливу великих транзакцій на параметри ринку; зміни кон'юнктури ринку; зміни цін на паливо; фінансово-економічні втрати; банкрутство; появу нових економічних агентів; зростання неплатежів споживачів і контрагентів тощо. Процеси лібералізації ринку електричної енергії, що відбуваються в Україні, призвели до появи наступних специфічних ризиків: ризик відмінності фактичних та контрактних цін при укладанні довгострокових договорів; ризики спотових цін; ризик прогнозування обсягу електроенергії, що споживається і цін на електричну енергію; ризик точного прогнозування прибутку для великих гравців ринку, які є акціонерними товариствами; ризики прогнозування навантаження як окремих клієнтів так і груп клієнтів. У випадку ігнорування або недостатнього врахування таких ризиків можливим наслідком може стати втрачена вигода; зменшення розмірів прибутку в порівнянні з очікуваним; зниження ефективності інвестицій тощо.

Для мінімізації ризиків, що можуть виникати під час купівлі-продажу електричної енергії та покращення прогнозів на рівні системи, слід досліджувати та розвивати інструменти короткострокового прогнозування оптової ціни електроенергії на ринку «на добу наперед» (РДН).

До того ж прогнозування цін є дуже важливим компонентом для розробки майбутньої стратегії розвитку всієї галузі електроенергетики та є основою збалансованого зростання різних секторів економіки у майбутньому.

Зв’язок з науковими програмами. Дослідження виконано в рамках впровадження завдань, передбачених Законом України «Про ринок електричної енергії», а також в межах імплементації «Енергетичної стратегії України на період до 2035 року “Безпека, енергоефективність, конкурентоспроможність” ».

Метою магістерської дисертації є проведення критеріального аналізу прогнозних моделей оптової ціни електроенергії на ринку «доба наперед» для зменшення невизначеності прийняття рішень економічних агентів ринку та здійснення короткострокового прогнозу оптової ціни на електричну енергію.

Для досягнення цієї мети були поставлені наступні завдання:

- вивчення нормативно-правової бази України щодо порядку визначення ціни на електричну енергію та обсягів купівлі - продажу електричної енергії на РДН;
- дослідження існуючої методології та методів прогнозних моделей формування оптової ціни електроенергії на РДН;
- визначення відкритих джерел та формування бази статистичних даних з оптової ціни на сегменті ринку електричної енергії РДН;
- вивчення європейського досвіду відносно інноваційних підходів з подолання перешкод функціонування РДН в умовах лібералізації.

Об’єктом дослідження є короткострокове прогнозування ціни на електричну енергію.

Предметом дослідження є методології та методи прогнозних моделей формування оптової ціни електроенергії.

Практичне значення роботи. Математична модель оптової ціни на електричну енергію на основі методу Random Forest дозволяє отримати інформацію про короткостроковий прогноз майбутньої ціни на електричну енергію на ринку «на добу наперед». Отримані результати дають можливість мінімізувати ризики під час купівлі-продажу електричної енергії, показують більш точний та легший шлях для прийняття цінових рішень на конкурентному ринку електричної енергії, аналізуючи усі фактори для формування процесу ціноутворення. Запропонована продуктова поліпшуюча інновація з посуги прогнозування дозволяє кінцевим споживачам будувати більш точні короткострокові прогнози щодо зміни ціни на ринку «на добу напред».

Наукова новизна отриманих результатів. На підставі проведеного дослідження було визначено, що в умовах реформування енергетичного сектору України та впровадження конкурентного ринку електричної енергії можна надати наступні пропозиції щодо інноваційних розробок. Перспективним інноваційним напрямком є впровадження приростових (поліпшуючих) продуктових інновацій зі сфери цифрових технологій та прикладного програмного забезпечення. Для учасників ринку електричної енергії найбільш привабливими є інноваційні рішення зі надання сервісних послуг із застосуванням програмного забезпечення з прогнозування оптової ціни електричної енергії на РДН.

Апробація результатів. Матеріали магістерської дисертації були опубліковані:

– XII Міжнародна науково-технічна конференція "ЕНЕРГЕТИКА. ЕКОЛОГІЯ. ЛЮДИНА" від 07.05.2020 р., Інститут енергозбереження та енергоменеджменту, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського".

– III Науково-технічна конференція магістрантів ІЕЕ від 26.11.2020р., Інститут енергозбереження та енергоменеджменту, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського".

Публікації. Матеріали магістерської дисертації опубліковані:

– Форми організації конкурентної торгівлі на оптовому ринку електричної енергії на добу наперед / Г. Г. Стрелкова, М. Т. Стрелков, К. В. Батюта // Енергетика. Екологія. Людина : збірник наукових праць XII науково-технічної конференції Інституту енергозбереження та енергоменеджменту, 7-8 травня 2020 р., м. Київ. – Київ : КПІ ім. Ігоря Сікорського, 2020. – С. 81-86. [Електронний ресурс]. – Режим доступу : URL : https://ela.kpi.ua/handle/123456789/36865

– Батюта К.В. Класифікація та порівняльний аналіз моделей прогнозування цін на електричну енергію/ Батюта К.В.// Енергетика. Екологія. Людина : III науково-технічна конференція магістрантів IEE, 26-27 листопада 2020р., м. Київ. – Київ : КПІ ім. Ігоря Сікорського, 2020. – С. 7-13. [Електронний ресурс]. – Режим доступу :
URL : https://iee.kpi.ua/iii-науково-технічній-конференції-ма/

Ключові слова: ЕЛЕКТРИЧНА ЕНЕРГІЯ, ІННОВАЦІЙНІ РІШЕННЯ, МОДЕЛІ ПРОГНОЗУВАННЯ, ОПТОВА ЦІНА, РИНОК «ДОБА НАПЕРЕД», ФОРМУВАННЯ ЦІНИ, ЧАСОВИЙ СЕГМЕНТ.

CONTENT

LIST OF SYMBOLS AND ABBREVIATIONS

AS– Ancillary services

BAM– Bilateral agreements market

BEI – Burshtyn energy island

BM– Balancing market

DAM– Day-ahead market

DSO – Distribution system operators

GB – State Company “Guaranteed Buyer”

IDM – Intraday market

IPS – Integrated power system

OECD – Organisation for Economic Co-operation and Development

MO –The State Company "Market operator"

TSO – Transmission system operator

SC –The State Company

USP – universal service providers

V_{Szip} – the volume of electricity sales at the DAM determined by the DAM/IDM participant in the trading zone and the settlement period, MWh;

P_{Szip} – the price of purchase and sale of electricity at DAM in the trading zone and the settlement period determined at the auction at DAM, UAH / MWh;

z – index of the trading zone;

i – number of the settlement period;

p – participant of DAM/IDM.

D_{dzip} – the cost of purchased electricity at the DAM by the DAM / IDM participant in the trading zone (z) and the settlement period (i), UAH;

V_{dzip} – the volume of electricity purchase at the DAM determined by the DAM / IDM participant in the trading zone and the settlement period determined at the auction at the DAM, MWh.

INTRODUCTION

Structure and scope of work. The Master's dissertation on "Short-term forecasting of electricity prices in the market" for the day ahead "" consists of a list of symbols, introduction, four sections, conclusions and a list of sources used. The total volume of the work is 112 pages, including 8 tables, 16 figures, 86 bibliographic references.

Relevance of research. After the reforms in the domestic economy in the energy sector, new conditions were created for the functioning of the electricity market and the participation of industrial enterprises in it, which are characterized by a high degree of uncertainty and growth of various types of risks, including market risks. An example of such risks is the lack of profit; change in the cost of capital; the emergence of the impact of large transactions on market parameters; changes in market conditions; changes in fuel prices; financial and economic losses; bankruptcy; emergence of new economic agents; growth of defaults of consumers and contractors, etc. The processes of liberalization of the electricity market taking place in Ukraine have led to the following specific risks: the risk of differences between actual and contract prices when concluding long-term contracts; spot price risks; the risk of forecasting the amount of electricity consumed and electricity prices; the risk of accurate profit forecasting for large market players who are joint stock companies; risks of forecasting the load of both individual customers and customer groups. If such risks are ignored or insufficiently taken into account, the lost consequence may be a lost consequence; reduction of the size of profit in comparison with expected; reduction of investment efficiency, etc.

In order to minimize the risks that may arise during the purchase and sale of electricity and improve forecasts at the system level, it is necessary to research and develop tools for short-term forecasting of the wholesale electricity price in the market "day ahead" (DAM).

In addition, price forecasting is a very important component for the development of the future development strategy of the entire electricity sector and is the basis for balanced growth of various sectors of the economy in the future.

Relationship of work with scientific programs, plans, themes. The study was performed within the framework of the tasks provided by the Law of Ukraine "On the Electricity Market", as well as within the implementation of the "Energy Strategy of Ukraine until 2035" "Security, energy efficiency, competitiveness"".

Purpose and tasks of the research is to conduct a criterion analysis of forecast models of wholesale electricity prices in the market "day ahead" to reduce the uncertainty of decision-making economic agents of the market and the implementation of short-term forecast of wholesale electricity prices.

To achieve this goal, the following tasks were set:

- study of the regulatory framework of Ukraine on the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM;
- research of the existing methodology and methods of forecast models of formation of the wholesale price of the electric power on DAM;
- identification of open sources and formation of a database of wholesale price statistics in the DAmM electricity market segment;
- study of the European experience concerning innovative approaches on overcoming obstacles of functioning of DAM in the conditions of liberalization.

Object of research is short-term forecasting of electricity prices.

Subject of research — methodologies and methods of forecast models of wholesale electricity price formation.

Practical value of the results. The mathematical model of the wholesale price of electricity based on the Random Forest method allows to obtain information about the short-term forecast of the future price of electricity in the market "for the day ahead". The obtained results make it possible to minimize the risks when buying and selling electricity, show a more accurate and easier way to make pricing decisions in a competitive electricity market, analyzing all the factors for the formation of the pricing process. The proposed product incremental innovation in forecasting services allows end consumers to build more accurate short-term forecasts of price changes in the market "day ahead".

Scientific novelty of the obtained results. Based on the study, it was determined that in the context of reforming the energy sector of Ukraine and the introduction of a competitive electricity market, the following proposals for innovative developments can be provided. A promising innovation direction is the introduction of incremental (improving) product innovations in the field of digital technologies and application software. For electricity market participants, the most attractive are innovative solutions for the provision of services using software for forecasting the wholesale price of electricity at DAM.

Approbation of the Master's thesis and publications. Materials of the master's dissertation were published:

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- III Scientific and Technical Conference of IEE undergraduates from 26.11.2020, Institute of Energy Conservation and Energy Management, National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky".

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– Batiuta K.V. Classification and comparative analysis of models for forecasting electricity prices / Batyuta KV // Energy. Ecology. Man: III scientific and technical conference of IEE undergraduates, November 26-27, 2020, Kyiv. - Kyiv: Igor Sikorksy Kyiv Politechnic Institute, 2020. - P. 7-13. [Electronic resource]. - Access mode:
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1 REGULATORY AND LEGAL BASIS OF UKRAINE ON THE PROCEDURE FOR DETERMINING THE PRICE OF ELECTRICITY AND THE VOLUMES OF PURCHASE AND SALE OF ELECTRICITY "ON THE MARKET «DAY-AHEAD»

1.1 Organization of purchase and sale of electricity on the market "day ahead" by the state enterprise "Market Operator"

The State Company (SC) was established on June 18, 2019 in accordance with the Law of Ukraine "On the Electricity Market". SC MO does not receive support from the state budget. Purchase and sale of electricity at DAM and IDM is carried out at organized electronic auctions conducted with the help of MO software. Financing of PR activities is carried out at the expense of DAM and IDM participants according to the tariff for purchase and sale operations on DAM and IDM and a fixed payment for DAM and IDM participation (target payment for the right to use software), agreed by the regulator (NKREKP). In order to trade on the DAM market, each participant must apply for MO participation. The form and procedure of these applications are approved by the National Commission for Regulation of Economic Competition. The subject of bidding is the amount of electricity declared by market participants for sale or purchase for each operating period in a certain amount. Only those participants who have passed the financial operator's financial capacity test are allowed to trade on the OP platform.

In order to ensure liquidity, the regulator has the right to set:

– producers (except for micro-, mini-, small hydroelectric power plants and electric power plants that produce electricity from alternative energy sources) - the lower limit of the mandatory sale of electricity at DAM, but not more than 15 percent of their monthly electricity supply, respectively to market rules;

– TSO and DSO — the lower limit of the mandatory purchase of electricity at DAM in order to compensate for technological losses of electricity for its transmission and distribution by electricity, respectively;

– producers producing electricity at hydro-storage substations, - the lower limit of the mandatory purchase of electricity at the DAM to cover the technological needs of hydro-storage stations.

SC MO is responsible for organizing the purchase and sale of electricity at DAM and IDM, helps to ensure a balance between supply and demand in the electricity market.

The difference between the organization of purchase and sale of electricity at DAM and IDM is as follows.

In the IDM, the purchase and sale of electricity is carried out continuously after the completion of bidding on the DAM and during the day of physical supply of electricity. This market segment allows market participants to adjust and change their trading positions and works on the principle of "each product has its own buyer." That is, sellers and buyers declare the volumes and prices at which they are ready to sell / buy electricity, sign a contract on the volume and price and wait for their counterparty. In IDM, the purchase and sale price of electricity is determined on the principle of pricing "at the stated (proposed) price" in accordance with the Rules of DAM and IDM.

At DAM, the purchase and sale of electricity is carried out on the next day after the day of the auction. The price in this market segment is determined by the principle of marginal pricing with minimization of price and maximization of trade. No participant sees the stated prices and volumes of purchase / sale of electricity by other participants. At DAM, the purchase and sale price of electricity is determined separately for each billing period (hour) by the market operator on the principle of marginal pricing based on the balance of aggregate demand for electricity and its aggregate supply. This technology of trading on DAM promotes the development of competition in the market.

Since July 2019, SE "Market Operator" publishes daily data on the results of orgs on DAM and IDM, publishes information on operating activities, financial indicators, and socially important events on the official website of the company www.oree.com.ua, Prozorro and other open platforms. In accordance with the

Rules of DAM and IDM, the price and volumes of purchase and sale of electricity for each billing period are published based on the results of the bidding. Daily, decadal and monthly in-depth analysis of DAM and IDM work is also published [5].

1.2 Rules for determining the cost of electricity sold at DAM by a participant of DAM/IDM

The sale of electricity at DAM by a participant of DAM / IDM is determined in accordance with the Resolution of the National Commission for State Regulation of Energy and Utilities of March 14, 2018 N 308 "On approval of the Rules of the market" day ahead "and intraday market" [7] .

1.2.1 Cost of electricity sold and purchased at DAM by DAM/IDM participant in trade zone (z) and settlement period (i)

The cost of electricity sold at the DAM by the DAM/IDM participant in the trading zone (z) and the settlement period (i) is determined by the formula:

$$D_{Szip} = V_{Szip} \times P_{Szip} \text{ (UAH)}$$

where V_{Szip} – the volume of electricity sales at the DAM determined by the DAM/IDM participant in the trading zone and the settlement period, MWh;

P_{Szip} – the price of purchase and sale of electricity at DAM in the trading zone and the settlement period determined at the auction at DAM, UAH / MWh;

z – index of the trading zone;

i – number of the settlement period;

p – participant of DAM/IDM.

The cost of purchased electricity at the DAM by the DAM/IDM participant in the trading zone (z) and the settlement period (i) is determined by the formula:

$$D_{dzip} = V_{dzip} \times P_{dzip} \text{ (UAH)}$$

where V_{dzip} – the volume of electricity purchase at the DAM determined by the DAM/IDM participant in the trading zone and the settlement period, MWh, determined at the auction at DAM.

1.2.2. The cost of electricity sold at the DAM by the DAM/IDM participant in the trading area on the day of delivery is determined

In the trading area on the day of delivery, ***the cost of electricity sold at the DAM*** by the DAM/IDM participant is determined by the formula:

$$D_{Szp} = \sum_{i=1}^{t} D_{Szip} \text{ (грн)},$$

where t – is the number of hours in the day of delivery.

The cost of purchased electricity at DAM by a participant of DAM/IDM in the trading area on the day of delivery is determined by the formula:

$$D_{dzp} = \sum_{i=1}^{t} D_{dzip} \text{ (UAH)}.$$

1.3 Price restrictions on DAM and VDR for bids of DAM/IDM bidders starting from the day of delivery on August 8, 2020

Resolution of the NKREKP of August 6, 2020 №1526 amended the resolution of the NKREKP of 08.04.2020 №766 "On the actions of electricity market participants during quarantine and restrictive measures related to the spread of coronavirus disease (COVID-19)" [8 -9].

In particular, it was determined that the participants of DAM and IDM in their bids in the trade zone "IPS of Ukraine" indicate the prices for electricity during minimum load hours (from 00:00 to 07:00 and from 23:00 to 24:00) not higher 60% of the price during maximum load hours determined by the market operator in accordance with the third paragraph of Chapter 5.1 of Section V of the Market Rules "day ahead" and intraday market, approved by the resolution of the NKREKP of March 14, 2018 № 308 [7].

Therefore, for the bids of DAM/IDM participants for bidding starting from the date of delivery on August 8, 2020, the following maximum levels of marginal prices for both trade zones have been determined (Table 1) [10]:

Table 1.1 — Maximum levels of marginal prices in both trade zones for applications of participants DAM/DAM

	"IPS of Ukraine"	"Burshtyn TPP Island"
for minimum load hours (period from 00:00 to 07:00 and from 23:00 to 24:00):	UAH 1228.94 / MWh (excluding VAT)	UAH 959.12 / MWh (excluding VAT)
for minimum load hours (period from 07:00 to 23:00):	2048.23 UAH / MWh (excluding VAT)	2048.23 UAH / MWh (excluding VAT)

If the bidder DAM/IDM specifies in the bid a price that exceeds the maximum price for the relevant period of the day, such bid shall be rejected.

1.4 Special responsibilities of electricity market participants to ensure the general public interest

The Resolution on "Regulations on the imposition of special responsibilities on participants in the electricity market to ensure the public interest in the functioning of the electricity market" (hereinafter - the Regulations) was adopted by the Cabinet of Ministers of Ukraine on June 5, 2019 [11]. This Regulation defines the scope and conditions of performance of special obligations by participants in the electricity market to ensure the general public interest in the functioning of the electricity market. The performance of special duties by electricity market participants concerns the provision of services to household consumers. In particular, special responsibilities include the provision of services to ensure the availability of electricity to household consumers in order to ensure stability, proper quality and availability of electricity, maintaining an adequate level of security of supply without compromising the primary goal of creating a full-fledged electricity market based on free competition in compliance with the principles of transparency and non-discrimination.

Special responsibilities are assigned to the following electricity market participants:

– guaranteed buyer of electricity (GB);
– producers of electricity;
– universal service providers (USP).

According to the Regulations, the special responsibilities of GP, electricity producers and USP include:

– sale of electricity by electricity producers – State Company " National Nuclear Energy-generating Company " Energoatom (SC "NAEC" Energoatom " "), producer of electricity at nuclear power plants and PJSC" Ukrhydroenergo ", producer of electricity at hydroelectric power plants, for contracts electronic auctions of GBs at the price of UAH 10 per 1 MWh (for details, see below);

– sale of GP of electric energy of USP under bilateral contracts of purchase and sale of electric energy in the hourly volumes necessary for satisfaction of needs of household consumers, at the price established by this Provision (in more detail see further);

– purchase and / or sale in the trade zone "Integrated power system of Ukraine" by GB in organized segments of the electricity market and / or under bilateral agreements of purchase and sale of electricity concluded as a result of electronic auctions;

- purchase by GB of electricity under bilateral agreements and / or on organized segments of the electricity market in the trade zone "Burshtyn TPP Island" in order to provide the necessary hourly volumes of electricity to ensure public interests in the functioning of the electricity market;
- provision of USP services to ensure the availability of electricity for household consumers under the relevant agreements of the GB;
- directing the difference between revenues and expenses incurred by the GB during the performance of special obligations specified in this Regulation to cover its own economically justified costs for the performance of special obligations for the purchase of electricity at the "green" tariff and at the auction price .

The price of electricity at which the GB sells electricity to the USP. This price for electricity is calculated as the difference between the weighted average fixed price for electricity for household consumers and tariffs for electricity transmission services, electricity distribution services and USP services, but not less than 10 hryvnias per 1 MWh. The fixed price of electricity for household consumers is set by the Cabinet of Ministers of Ukraine.

Until a decision is made to set a fixed price, such a price is applied at the level of electricity tariffs for household consumers (taking into account tariffs differentiated by time periods), which were in force as of June 30, 2019. The weighted average fixed price is determined taking into account the actual volumes of electricity consumption by household consumers in the month preceding the previous billing month.

If the estimated value of the price of electricity is less than 10 hryvnias per 1 MWh, the GB pays the USP under the contract for the provision of services to ensure the availability of electricity for household consumers. The cost of services to ensure the availability of electricity for household consumers is defined as the product of the volume of electricity consumption by household consumers and the difference between the price of electricity, which is 10 hryvnias per 1 MWh, and the estimated price of electricity.

On obligations of electricity producers SC “NAEC “Energoatom”” and PJSC “Ukrhydroenergo”. Electricity producer SC “NAEC “Energoatom”” is obliged to sell by GB at electronic auctions in each settlement month in the manner prescribed by law in the hourly volumes necessary to meet the needs of household consumers in the trade zone "Intagrated power system of Ukraine". Hourly volumes required to meet the needs of household consumers are calculated by the GB and provided by NAEC “Energoatom” by the 20th day of each month preceding the settlement month. The volume for each settlement hour is determined by the GP as a total within the relevant hour for all USP and is calculated on the basis of the information received in accordance with this Regulation.

The electricity producer PJSC “Ukrhydroenergo” is obliged to sell SOEs at electronic auctions in each settlement period in the manner prescribed by law, 30 percent of the forecast volume of electricity supply at hydroelectric power plants, approved in the forecast balance of the integrated energy system of Ukraine for the month.

According to the Resolution of the Cabinet of Ministers of Ukraine of August 19, 2020 [12], the Regulations were amended to ensure the performance of special duties. According to the changes, NAEC Energoatom and PJSC Ukrhydroenergo (separately for each producer) must provide in each settlement month the weighted average price of electricity sales in all commercial market segments (DAM, IDM, BM, BAM and RDP) at the level of not lower than the price of cost recovery, namely:

$$P_{cost\ coverage} = \frac{C_{cost} \times V_{actual} - P_{SSR} \times V_{SSR}}{V_{actual} - V_{SSR}}$$

where C_{cost} - production cost of electricity production of NAEC Energoatom or PJSC Ukrhydroenergo (separately for each producer) in accordance with the financial plan for the respective year, UAH / MWh;

V_{actual} - the actual supply of electricity by the state enterprise NAEC Energoatom or PJSC Ukrhydroenergo (separately for each producer) in each billing month, MWh;

P_{SSR} - the sale price of electricity of NAEC Energoatom or PJSC Ukrhydroenergo (separately for each producer) within the framework of special obligations of SE, UAH / MWh;

V_{SSR} - the volume of electricity sold by NAEC Energoatom or PJSC Ukrhydroenergo (separately for each producer) within the framework of performing special duties in the respective settlement month of SE, MWh.

Conclusions on the first section

Starting from 2019, the electricity market was introduced according to the new model. To ensure the functioning of a competitive wholesale electricity market, a regulatory framework has been developed since the introduction of the new electricity market model.

The purpose of the regulatory changes was to create a competitive environment for all market players.

Regarding DAM, during this time the principles of organization of purchase and sale of electricity at DAM by the state enterprise "Market Operator" have been determined.

There is a significant improvement in data disclosure compared to previous market models. DAM is the most transparent segment of the electricity market in Ukraine: data are published regularly and there is regular reporting.

There have also been changes in the regulatory framework regarding the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM.

In particular, normative and legal documents concerning the rule of determining the cost of electricity sold at DAM by a participant of DAM/IDM came into force.

Taking into account the current state of the economy and society due to the introduction of quarantine and restrictive measures related to the spread of coronavirus (COVID-19), the actions of electricity market participants were identified and price restrictions on DAM and IDM were adopted for DAM/IDM participants.

A number of legal documents have been adopted regarding the special responsibilities of electricity market participants to ensure the public interest.

However, despite regulatory changes, the existing mechanism of special obligations restricts competition, imposes restrictions on state-owned producers and allows private companies to take advantage of imperfections in the DAM and IDM Rules.

Household consumers, regardless of their income, do not pay the full cost of electricity. The difference between the market price and the price for household consumers makes it possible to obtain volumes of electricity declared for the population at a price below the market price.

2 METHODOLOGY AND METHODS OF FORECASTING MODELS OF FORMATION OF THE WHOLESALE PRICE OF ELECTRICITY ON DAM

2.1 Short-term forecasting as a tool to reduce the risks of participants in the competitive electricity market

As a result of market reforms in the domestic economy in the energy sector, new conditions for the functioning of industrial enterprises have been formed, which are characterized by a high level of uncertainty and an increase in the types of risks.

To ensure sustainable development and fulfillment of strategic goals of the energy sector, it is necessary to be able to manage risks. However, in the domestic electricity industry it is not always possible to give an accurate quantitative assessment of risks in advance, and methods for determining the degree of risk are not yet sufficiently developed. In this regard, there are difficulties in minimizing risks and estimating the cost of managing them. Therefore, each company independently determines the level of acceptable risk, chooses tools and methods to avoid or reduce losses.

Market risks are external risks and include loss of profit; change in the cost of capital; the emergence of the impact of large transactions on market parameters; changes in market conditions; changes in fuel prices; financial and economic losses; bankruptcy; emergence of new economic agents; growth of non-payments of consumers and contractors; etc.

Risk management in generating companies requires a systematic approach that takes into account the specifics of the industry, using powerful tools of modern risk management, such as: operational hedging, limit policy, henging[1] using

[1] **Hedging** - the opening of transactions in one market to compensate for the impact of price risks on the opposite position in another market in equal parts. Hedging is realized to insure the risks of price changes through the conclusion of agreements within futures markets. Thus, due to hedging, a person is insured against the risks of market price fluctuations. However, there is a

derivatives [2] (derivative instruments), transfer of risks to third parties, optimization of commodity and cash flows, use of contracts with option characteristics and so on.

The consequences of ignoring or not taking into account the risks for businesses manifest themselves in the form of lost profits; reducing the amount of profit compared to expected; reducing the efficiency of investments; the emergence of unplanned costs of labor, material or financial resources; the emergence of excessive stocks of resources due to unsold products, etc.

Despite the potential danger of consequences and losses caused by the implementation of a particular type of risk, it is a catalyst for progress, a source of possible profit. Short-term load forecasting can reduce spot market risks an hour ahead by providing more accurate estimates of gradual load reduction from individual customers or customer groups [16-18].

The energy company must be able to establish the optimal ratio between the income from the sale of real assets and operations in derivatives markets, based on the first direction. In the long run, the management of the portfolio of generating capacities implies the commissioning or decommissioning of certain capacities, as well as their purchase or sale. In the medium term, working with the portfolio involves determining the period of time, the withdrawal of capacity for repair, reconstruction or technical re-equipment. In the short term, it is necessary to determine in which market sectors each unit of a power plant will operate.

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disadvantage of hedging, because when the risk increases for the buyer, the price of the contract always falls slightly. Hedging is primarily aimed at reducing losses, not increasing profits [13]. As for the electricity market, hedging is usually carried out by generating companies, network organizations, sellers and buyers of electricity. A distinctive feature of hedgers in the wholesale electricity market is the need to supply and receive electricity [14].

[2] **Explanation of the concept of "derivative" in the context of the electricity market.** A derivative is a financial instrument whose price comes from the price of the underlying asset (securities, currency, commodities, etc.). It is essentially a contract that may involve an obligation to buy or sell something in the future for a certain amount (for example, a forward, a futures, a swap) or a right (an option). However, if the derivative provides for an obligation, payment is made only at the end of the contract. If it is an option, then you need to pay a "premium" for its conclusion, and at the end of the contract, if the right to buy or sell the underlying asset will be used [15].

Liberalization of the electricity market leads to the following risks: most consumers are forced to pay all deviations in price, which leads to an increased risk of default; when concluding long-term contracts, sales companies bear the risks of deviation of actual prices from contract prices; risk of forecasting the volume and prices of electricity; the risk of the accuracy of the profit level forecast for large participants who are joint stock companies. [19-20].

The development of tools for short-term forecasting of the wholesale price of electricity at DAM can minimize the risks of buying and selling electricity for the day ahead, providing better forecasts at the system level.

2.2 Components of time series: trend, seasonality, cyclicity and irregularity

The key properties of time series, or components of time series in energy statistics, are trend, seasonality, cyclicality, and irregularity. In this case, time series can contain one component (trend, seasonality, cyclicity or irregularity), and several such components simultaneously [21].

Each level of the time series is formed under the influence of a large number of factors that cause the regularity or randomness of its formation. Identification and analysis of time series components are necessary for the choice of forecasting method, so an important step in the analysis of the time series is its decomposition (or decomposition into components).

The task of decomposition of the time series is to analyze the factors influencing the value of its levels, to distinguish between the main and random, and then among the main - evolutionary and periodic (seasonal, cyclical). Evolutionary factors determine the general direction of development of an economic indicator, its leading trend. Seasonal and cyclic components determine the regular fluctuations of the series. Random factors are not subject to measurement and accompany any economic process and determine the stochastic nature of its elements.

Therefore, in the analysis of time series it is customary to represent the time series in the form of the sum of the systematic component and the random deviation from it:

$$y_t = f(t) + \varepsilon_t, \tag{2.1}$$

where $f(t)-$ is a non-random function of time (deterministic part, systematic component);

$\varepsilon_t -$ random, nondeterministic part.

The deterministic part in equation (2.1) may include a trend component, a seasonal component and a cyclic component.

A trend component is a long-term non-random component of a time series that represents an increase or decrease in a time series over a long period of time. When data increases or decreases over several time periods, there is a trend (or trend) in the time series. From the point of view of forecast modeling, the trend is the most important component of the time series. The main factors that influence and help explain the trend of the time series are changes in population, prices, consumer preferences, technology, productivity, inflation and more. The trend component is described by a function, which will be further denoted by the symbol .

Seasonal component . A large amount of economic data is affected by the time of year. Seasonal fluctuations are periodic for one year with a more or less stable structure that appears annually and repeats year after year. Seasonal patterns arise from the effects of the weather or from calendar-related events such as school holidays and public holidays. For example, the demand for fuel oil increases in winter and falls in the warmer months. Seasonal fluctuations are usually found in quarterly, monthly or weekly data. Thus, the seasonal component is measured quarterly, monthly or weekly. For the lunar series, the seasonal component measures the variability of the data every January, every February, etc. ; for a quarterly time series there are four seasonal elements - one for each quarter. Therefore, in a number of monthly data we should expect the presence of seasonal fluctuations with a period of 12, in quarterly series - with a period of 4. The seasonal component is denoted by the symbol .

The cyclic component (or conjunctural oscillations) are undulating oscillations that are similar to seasonal ones, but appear at longer time intervals. Usually, one cycle is completed within a few years. The time series with a cyclic component has a cyclic peak and decline. Cyclical fluctuations are explained by the action of long-term cycles of economic, demographic or climatic nature, however, as a rule, cyclical fluctuations lead to changes in economic conditions. On the other hand, demand for basic consumer goods is less dependent on changing economic conditions. The cyclic component is described by a function denoted by the symbol .

Irregular (or random) **component** . The irregular component consists of unpredictable or random oscillations. The impact of random events, which alone may not be particularly important, but the combined effect can be large, such as earthquakes or sudden changes in weather. By their nature, these consequences are completely unpredictable. An irregular component is denoted by the symbol.

2.3 Characteristics of time series of electricity prices in wholesale markets

The dynamics of demand for electricity is influenced by economic and economic activity, as well as weather conditions. These key factors explain the high frequency of declining electricity prices reported for all wholesale markets. There are daily, weekly and seasonal frequency. A number of works also noted the number of prices in daylight - calendar effects (wholesale markets of California (USA), PJM (USA) and Spain) [22,23].

Virtually all of the studied series of electricity prices (both time and average daily) were to be distributed, different from normal by the available letters and important tails.

Price series are characterized by positive express coefficients - from measured values (in the optical markets of MISO (USA), Great Britain) to high values (in the optical markets of California (USA), New England (USA), LPE / EEX (Germany / Europe), Australia) .

Electricity price distribution functions have an asymmetry to the right (positive asymmetry coefficient).

In the long run, electricity prices ensure that power returns to average. With increasing demand for electricity, road generating units are loaded, which leads to an increase in equilibrium prices for electricity. As the survey decreases, it is satisfied with cheaper generating units. This dynamic description is influenced by a modified condition, which is a cyclic process that returns to the mean.

2.4 Review of methodology and methods of forecast models of formation of the wholesale price of electricity at DAM

Since the early 1990s, the process of deregulation and the introduction of competitive electricity markets has changed the landscape of the traditionally monopolistic and government-controlled energy sector. Across Europe, North America and Australia, electricity is now sold under market rules using spot and derivative contracts. [24-25].

However, electricity is a very special commodity: it is not stored in large quantities in a cost-effective way, and the stability of the energy system requires a constant balance between production and consumption. At the same time, the demand for electricity depends on the weather (temperature, wind speed, precipitation, etc.) and the intensity of business and daily activities (during peak and off-peak hours, weekdays against weekends, holidays, etc.). These unique characteristics lead to price dynamics that are not observed in any other market, demonstrating daily, weekly and often annual seasonality and sharp, short-lived and usually unpredictable price jumps [26].

The choice of management decision in a competitive market is often associated with the analysis and evaluation of the behavior of different types of economic agents, the specifics of electricity as a commodity, the conditions of management decisions in managing supply and demand in the electricity market and more. Therefore, over the past 15 years, electricity price forecasts have become a major contribution to decision-making mechanisms by energy companies at the corporate level.

Electricity price forecasting focuses on forecasting spot and forward prices in the wholesale electricity market.

High price volatility, which can be two orders of magnitude higher than that of any other commodity or financial asset, has forced market participants to hedge not only volume but also price risk. Price forecasts from several hours to several months ahead have become particularly interesting for government portfolio managers. An electricity market participant that is able to predict volatile wholesale prices with a certain level of accuracy can adjust its trading strategy and its own production or consumption schedule to reduce risk or maximize day-ahead trading profits [26]. Due to a 1% reduction in the average absolute percentage error (MAPE) of short-term price forecasts, the estimated savings for utilities with a peak load of 1 GW are $ 300,000 per year [27].

According to [24] in the classification of approaches to modeling the forecast of electricity prices can be conditionally defined six classes: multiagent models, fundamental (structural) models, quantitative stochastic models, statistical models and methods (econometric models), models based on artificial intelligence, machine learning , (nonparametric, nonlinear statistical models) and hybrid models. Consider further briefly the content of the main classes.

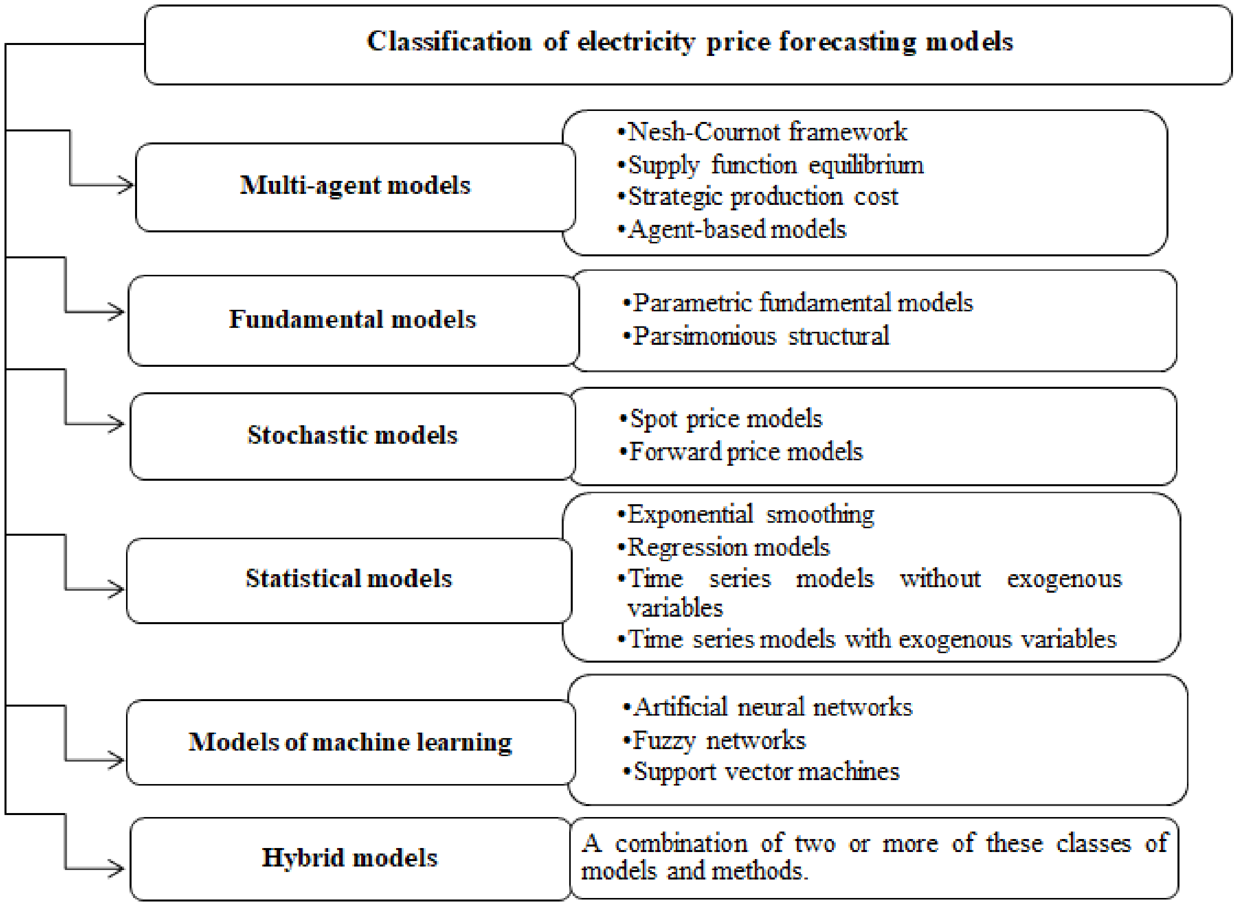


Figure 2.1. Classification of electricity price forecasting model

2.4.1 Class of multiagent models of electricity price forecast

Multiagent models (multiagent modeling, equilibrium, game theory) model the work of a system of disparate agents (generating units, companies), interacting with each other, and build a pricing process, matching supply and demand in the market [28].

Multi-agent models tend to focus on qualitative issues rather than quantitative outcomes. They can give an idea of whether prices will be above marginal costs and how this may affect player performance. However, they create problems if quantitative conclusions need to be drawn, especially if electricity prices are to be predicted with a high level of accuracy. This class of electricity price forecast modeling includes cost-based models (or production cost models, PCM) [29], equilibrium models or game theory (eg Nesha-Cournot, supply function equilibrium - SFE, strategic cost models - SPCM) [30-33], and agent-based models [33].

In models based on game theory, strategies for the behavior of participants in the wholesale electricity market are modeled. Using different models of achieving equilibrium, the influence of the behavior of individual producers on the equilibrium price is taken into account [35-37].

2.4.2 Class of fundamental (structural) models of electricity price forecast

Fundamental (structural) models try to cover the basic physical and economic relationships that exist in the production and trade of electricity [37]. In such models, functional relationships between the main drivers (load, weather conditions, system parameters, etc.) are postulated, and the main input data are modeled and predicted independently, often using statistical methods, artificial intelligence programming methods. In general, we can distinguish two subclasses of fundamental models: multiparameter models [38] and economic structural models of supply and demand [39].

The projected value of the price of electricity can be determined by the results of the auction. This pricing principle includes bids for the price of consumers (buyers) and producers (sellers) of electricity, as well as economic and technological limitations of the power system. That is why the forecast prices generated by such models are very sensitive to violations of these assumptions. Due to the fact that fundamental models require a large amount of source data, their use for short-term forecasting is limited.

In the practical implementation of fundamental models there are two main problems: the availability of data and the inclusion of stochastic oscillations of the main drivers. In setting the problem when creating a model, specific assumptions about the physical and economic relations in the market are introduced, and therefore the forecast prices generated by the models are very sensitive to violations of these assumptions.

2.4.3 Class of quantitative stochastic models of electricity price forecast

Quantitative stochastic models characterize the statistical properties of electricity prices over time, with the ultimate goal of estimating derivatives and risk management [24]. Their main intention is not to provide accurate hourly price forecasts, but rather to reproduce the main characteristics of daily electricity prices, such as marginal distributions at future time points, price dynamics and the correlation between commodity prices. If the chosen pricing process is not suitable for determining the main properties of electricity prices, the results of the model are likely to be unreliable. However, if the model is too complex, the computational load will prevent it from being used online in trading platforms.

Depending on the type of market under consideration, these models can also be further divided into two groups.

*The first group of quantitative stochastic models are spot price models.*These models provide a significant reflection of the dynamics of spot prices. Their main disadvantage is the problem of pricing for derivative financial instruments, ie the identification of spot and forward prices by risk premium [40]. Their two most popular subclasses include diffusion jump models and models with Markov switching modes.

The model of diffusion jumps can be considered as a one-factor medium-return model of jump diffusion, close to the classical exponential one used in the electricity markets. The model is easy to calibrate. Due to its simple and economical structure, the diffusion jump model is widely used among practitioners [41-42].

Markov chain model prediction models assume that the future state of a process depends only on its current state and does not depend on previous ones. In this regard, the processes modeled by Markov chains should refer to the processes with short memory. The structure of the Markov chain and the probabilities of state transition determine the relationship between the future value of the process and its current value [43].

The second group of quantitative stochastic models is forward price models. These models allow you to determine the prices of derivative financial instruments in a direct way, but only with those that are recorded on the forward price of electricity. However, they also have their limitations. The most important of them are the lack of data that can be used for calibration and the inability to obtain spot price properties based on the analysis of forward curves [38, 44].

2.4.4 Class of statistical models (econometric models) and methods of forecasting electricity prices

Statistical models (econometric models) and methods predict the current price using a mathematical combination of previous prices and / or previous or current values of exogenous factors, usually consumption and production indicators or weather variables [24].

Some statistical models are based on the analysis of time series. The two most important categories in the class of statistical models are additive and multiplicative models. They differ in whether the estimated price in the additive model is the sum of a number of components, and in the multiplicative model the estimated price is the product of a number of factors. Additive models are much more popular, but they are both closely related. The multiplicative price model can be converted into an additive model for a logarithmic price scale.

Statistical models are attractive in that a certain physical interpretation can be attached to their components, allowing engineers and system operators to understand their behavior. The statistical approach is the direct application of statistical methods of load forecasting, as well as the implementation of econometric models in energy markets. These models are often criticized for their limited ability to model (usually) nonlinear behavior of electricity prices and related fundamental variables. However, in practical application, their effectiveness is not worse than that of nonlinear methods of artificial intelligence.

Statistical models are very diverse and include:

1. Models and methods of similar day and exponential smoothing [45].
2. Regression models [46].
3. Time series models [26, 45, 47-49]:
   - without exogenous variables (AR, ARMA, ARIMA, fractional ARIMA - FARIMA, seasonal ARIMA - SARIMA, threshold AR - TAR)
   - time series models with exogenous variables (ARX, ARMAX, ARIMAX, SARIMAX, TARX).
4. Models of heteroskedastic time series (GARCH, AR-GARCH) [26, 50].

Exponential smoothing is a very effective and reliable method of forecasting. The main advantages of the method include: the ability to account for the weights of the source information, the simplicity of computational operations, the flexibility of describing the various dynamics of processes. The method of exponential smoothing makes it possible to obtain an estimate of the trend parameters that characterize not the average level of the process, but the trend that has developed since the last observation. The method is most widely used to implement medium-term forecasts. For the method of exponential smoothing, the main and most difficult is the choice of the smoothing parameter α, the initial conditions and the degree of the prediction polynomial [51,52].

In exponential smoothing, as in the above models to obtain a forecast for a certain period of time, all past values of the time series are used. In these models, it is assumed that past values contain information about what will happen in the future. However, past values include both random fluctuations and information regarding the basic structure of the series. Therefore, it is assumed that due to exponential smoothing, extraordinary fluctuations that represent randomness in a number of historical observations will be eliminated, and non-random information of all observed values of the series will be preserved. The difference between the models of exponential smoothing is that the time series is smoothed using an exponentially weighted average, in which the weights are subject to the exponential law. Due to the change in the weight of the values over the time series, the initial and last values of the time series differ in their effect on the forecast. Forecasts for such models provide for regular recalculation at the end of the last period and the emergence of new data for the forecast. Many models of exponential smoothing have been developed, but in most practical cases the following three models are most often used to construct the forecast. The model of time series forecast by the method of simple exponential smoothing is used in cases when the time series does not contain a trend component and a seasonal component. According to this model, it is assumed that the time series of data has only a random component. The construction of the forecast according to this model is based on the simplest method of smoothing - the method of exponentially weighted average. The model of forecasting time series by the method of double exponential smoothing is used in cases where the time series in addition to the random component also contains a component of the trend, but no seasonal component. To build a forecast in this model uses the Holt method. The model of forecasting time series by the method of triple exponential smoothing is used when the series contains in addition to the random component and trend components, also the seasonal component. To build a forecast in this model uses the Winters method. This method is sometimes called the Holt-Winters method [21]. To build a forecast in this model uses the Holt method. The model of forecasting time series by the method of triple exponential smoothing is used when the series contains in addition to the random component and trend components, also the seasonal component. To build a forecast in this model uses the Winters method. This method is sometimes called the Holt-Winters method [21]. To build a forecast in this model uses the Holt method. The model of forecasting time series by the method of triple exponential smoothing is used when the series contains in addition to the random component and trend components, also the seasonal component. To build a forecast in this model uses the Winters method. This method is sometimes called the Holt-Winters method [21].

Regression analysis — a method of modeling the measured data and the study of their properties [53]. The data consist of pairs of values of the dependent variable and the independent variable. The regression model is a function of an independent variable and parameters with a random variable added. The model parameters are adjusted so that the model is closest to the input data. The criterion for the quality of the approximation (objective function) is usually the root mean square error: the sum of the squares of the difference between the values of the model and the dependent variable for all values of the independent variable as an argument. Regression analysis is used to predict, analyze time series, test hypotheses and identify hidden relationships in the data.

When creating a regression model, it should be borne in mind that the regression equation does not assess the impact of each factor on the studied indicator, such an assessment is possible only when all other factors are not related to the studied. If the studied factor is related to others that affect the indicator, then the assessment will be a mixed description of the influence of the factor. This characteristic contains the direct and indirect influence of the factor, which is made through the connection with other factors and their influence on the studied indicator. Therefore, the regression equation does not include factors that show a weak relationship with the studied indicator, but are closely related to other factors. Functionally related factors are also not included in the equation. To assess the quality of the calculated regression equation perform an assessment of the degree of similarity between the results of observations of the indicator and the calculated regression equation values at these points in the parameter space. The problem of regression analysis can be considered solved, and the model qualitative, if the results are close. Otherwise, the regression model is sent for revision, make changes to the regression equation and repeat the calculations to estimate the parameters. The problem of choosing independent influencing factors is quite difficult. All this leads to a rather complex implementation of multifactor regression forecasting models, provided that the specified accuracy of the forecast [51].

The price is modeled as a function of these variables:

$$y_t = \sum_{i=1}^{i=n} \alpha_i x_{it} + \varepsilon_t, \tag{2.2}$$

where α_i – the i-th regression coefficient,

x_i – regressors (independent variables),

ε_t – error.

Explanatory independent variables are established on the basis of correlation analysis of the relationships between them and the dependent change.

Arima models proposed by J. Box and G. Jenkins [55] cover a fairly wide range of time series, and small modifications of these models allow you to accurately describe the time series with seasonality, which include electricity consumption of industrial enterprises. The ARIMA models include, as individual cases, autoregression models of order p (AR (p) -model), models of variable mean order q (MA (q) -models) and ARIMA (p, q) -models, which are about connection of AR (p) -model and MA (q) -model.

The construction of ARIMA models is also an effective auxiliary tool for calculating the predicted values of individual factors that affect the variable of the dependent indicator during forecasting based on multifactor regression models, models of simulation equations, etc. In addition, in practice, you can build a variety of ARIMA models, in particular ARMAX models, which simultaneously with the lag variables of the studied indicator can take into account additional exogenous factors in various forms. Such peculiar "hybrids" of linear multifactor regression and ARIMA models with the correct specification are quite effective and can reduce the prediction error compared to classical multifactor regression models or even with pure ARIMA models [56].

Autoregression model AR (p) is a model of time series in which the values of the time series at a given time depend linearly on the previous values of this series (2.3):

$$y_t = c + \sum_{i=1}^{i=p} \alpha_i y_{i-1} + \varepsilon_t, \tag{2.3}$$

where $c -$ he constan,

$\alpha_i -$ the i-th regression coefficient,

$\varepsilon_t -$ error.

Autoregression model - variable mean ARMA (p, q) generalizes two simpler time series models - the autoregression model AR (p) and the model of the variable mean MA (q) (2.4):

$$y_t = c + \sum_{i=1}^{i=p} \alpha_i y_{t-1} + \sum_{i=1}^{i=q} \beta_i \varepsilon_{t-1} + \varepsilon_t. \tag{2.4}$$

The ARMA model can be interpreted as a linear model of multiple regression, in which the explanatory variables are the past values of the most dependent variable, and in the case of the regression residue - the moving averages of the elements of white noise. If the AR and ARMA models are correct, their random errors are white noise. These models are applied to stationary series.

In 1976, J. Boxing and J. Jenkins developed the ARIMA model. ARIMA models are applied to integrated or multistationary time series - non-stationary time series, the differences of some order from which are stationary time series. The ARIMA model (p, d, q) has the form:

$$\Delta^d y_t = c + \sum_{i=1}^{i=p} \alpha_i \Delta^d y_{t-1} + \sum_{i=1}^{i=q} \beta_i \varepsilon_{t-1} + \varepsilon_t, \tag{2.5}$$

where$\Delta^d -$ the d-order difference operator ($\Delta y_t = y_t - y_{t-1} -$ first-order difference)

In the study of series, it is advisable to assess the stationarity of the series, the presence of single roots, the order of integration of the time series. If the order of integration is greater than zero, the original series is converted by taking the difference of the corresponding order (in practice, the first or second order is usually used). The ARMA model is built for the obtained stationary series. In essence, the ARIMA model considers the evolution of the increase in electricity prices instead of the price value. If the model is chosen correctly, its random errors should behave like white noise. This model can also be used on time series, which have a pronounced seasonal frequency. The ARIMA model allows to build specifications that take into account multiple seasonality. This generalization of the ARIMA model is sometimes called SARIMA (Seasonal ARIMA), and it is widely used to forecast prices in electricity markets.

In 1980, C. Granger proposed the ARFIMA model, which allows the existence of a non-integer parameter of the order of integration of the time series. This model allows to simulate the effects of long-term memory.

Exogenous variables (both predictive and retrospective) can be included in autoregressive models.

In the autoregressive models AR, ARMA, ARIMA and ARFIMA it is assumed that the data have the property of homoskedasticity. They do not take into account the changing over time volatility (heteroskedasticity), which is an important feature of price series in wholesale electricity markets.

In 1997, Campbell Lo and MacKinlay developed a general concept of a class of nonlinear processes that describe the nonlinear dependence of the current value of a given indicator on the current and lag values of random variables: The most popular among nonlinear models are ARCH, GARCH, which use them. to model and predict the volatility of financial series, and switching models to describe the different behavior of time series at different times.

ARCH / GARCH models belong to the class of nonlinear models with conditional variance that changes over time, which allows, in addition to the average value of the studied indicator, to simultaneously model the dynamics of its variance, and thus correctly describe phenomena such as volatility clustering, information asymmetry, etc. [56].

In 1982, R. Engle developed a model of autoregressive conditional heteroscadasticity (ARCH) [59]. The ARCH residue model is as follows (2.6):

$$\varepsilon_t = \sigma_t z_t, \tag{2.6}$$

where σ_t – the time-dependent standard deviation,

z_t – a random variable having a normal distribution, an average value equal to 0, and a standard deviation equal to 1;

$$\sigma_t^2 = \varsigma_0 + \sum_{j=1}^{j=k} \eta_j \varepsilon_{t-j}^2, \tag{2.7}$$

where ς_0 –the constant,

η_j –the j-th coefficient of the model.

The ARCH model is able to reflect the change in volatility over time and its clustering, as well as the heavy distribution tails observed in market data. In the future, a model of generalized autoregressive conditional heteroscadasticity (GARCH) appeared. In the GARCH model, the current conditional variance of a random error depends not only on the squares of the random errors, but also on the previous values of their variances [56]. The GARCH model (m, k) has the form (2.8):

$$\sigma_t^2 = \varsigma_0 + \sum_{i=1}^{i=m} \varsigma_i \sigma_{t-j}^2 + \sum_{j=1}^{j=k} \eta_j \varepsilon_{t-j}^2 \tag{2.8}$$

There are specifications of GARCH models that can capture asymmetric nonlinear effects, lever effects.

Achieving the adequacy of ARIMAX models, in turn, imposes restrictions on the number of external factors, which can also be a "barrier" to the use of these models for forecasting prices in the electricity sector. The application of parametric models for forecasting the market situation in the electricity market is considered in detail in [58].

2.4.5 A class of electricity price forecast models based on artificial intelligence and machine learning

Models based on artificial intelligence and machine learning (non-parametric, nonlinear statistical models) combine elements of learning, evolution and fuzzy to create approaches that can adapt to complex dynamical systems. These models can be considered "intelligent". In this sense, artificial neural networks [47, 60-61], fuzzy systems [60, 62] and the reference vector method (SVM) [44,63] are the main classes of models of artificial intelligence and machine learning. Their main advantage is the ability to cope with complexity and nonlinearity. Models based on artificial intelligence also belong to the group of time series prediction models. Models of this group, when forecasting the price of electricity, use retrospective price values and exogenous variables, allow to take into account the complex nonlinear relationship In general, artificial intelligence methods better model these features of electricity prices than statistical methods. At the same time, this flexibility is also their main weakness. The ability to adapt to nonlinear, abrupt behavior will not necessarily lead to better point or probabilistic predictions.

Artificial neural network (ANN) is a mathematical model, the principle of which corresponds to the principle of functioning of biological neural networks. The main elements of the ANN model are artificial neurons (the simplest processors), capable of sending the output signal obtained by processing a set of input signals [67].

An important stage of prediction based on ANN is the so-called network learning process, which consists in determining and "adjusting" the weight of each signal at the input of the neuron so that the value at the output of the network corresponds to the target (actual) value. In other words, learning is the process of solving an optimization problem to minimize the error between the values of the target (actual) parameter and the output parameter of the network.

It should be noted that the network parameters directly depend on the complexity of the task, ie there are no unambiguous ANN parameters (including their number) to solve different problems [64].

The following steps can be distinguished in the use of ANN models to solve forecasting problems:

1) determination of a set of factors influencing the target parameter;

2) formation of the network structure and its training (with further assessment of the network's ability to summarize information);

3) direct forecasting on a trained network [65]. It is important to emphasize that at the stage of forecasting only the input parameters are known, the supply of which to the network input allows to obtain the predicted values of the analyzed parameter.

The method of reference vectors, known in the English literature [66] as support vector machine (SVM), is a machine algorithm that is taught by example and used to classify objects. SVM is based on some mathematical essence - an algorithm for maximizing some mathematical function relative to the existing data set. The SVM method in tests beats other methods in terms of speed and accuracy of categorization. SVM can be successfully used to control complex electromechanical systems, it can ensure the adaptability of control algorithms, perform observer functions, identifier of unknown parameters, some reference model, it can be used to control complex nonlinear objects, as well as objects with stochastic parameters [63].

The support vector machine (SVM) method is used, for example, to predict market movements and electricity prices. The method is based on the classification produced by translating the original time series, represented as vectors, into a space of higher dimension and finding a separating hyperplane with the maximum gap in this space. The task of forecasting is solved in such a way that at the stage of training the classifier independent variables (external factors) are detected, the future values of which determine in which of the previously defined subclasses the forecast $Z\ (t)$ will get.

2.4.6 Class of hybrid models of electricity price forecast

Many of the approaches to price modeling and forecasting discussed in the literature are hybrid solutions that combine methods from two or more of the above groups. Their classification of the outfit is not possible. For example, the hybrid model AleaModel (AleaSoft) combines neural networks and the Box Jenkins model. The advantage of hybrid models is that the combinations of models give the best result in forecasting electricity prices and reduce the risks in practice of using such models, as well as take into account different price features compared to individual forecasting methods.

2.5 Statistical methods for estimating the error of the forecast of time series for the choice of the method of forecasting energy demand

Prediction accuracy is usually determined by comparing the values of the initial time series y_1, y_2, . .. with the corresponding values of the forecast $\hat{y}_1$, $\hat{y}_2$, …The error of the forecast is called the difference between the actual and forecast values.

The forecast error $e_t$for the time period *t* is the difference between the actual value and its forecast value determined by the formula (2.9):

$$e_t = y_t - \hat{y}_t \tag{2.9}$$

The final decision on the use of a particular method and method of forecasting is made after calculating the forecast error. If the application of this method gives sufficiently small errors, then this approach can be used in their research.

Today, it is possible to create a forecasting method that creates relatively small forecast errors on a regular basis.

Depending on the method by which forecasting is performed, there are different methods for estimating forecast error (2.9). The most commonly used methods of estimating forecast error, which involve the use of the average function of forecast error. These methods make it possible to:

- perform a comparative analysis of the accuracy of different forecasting methods;
- to investigate the expediency, adequacy and reliability of the application of a certain method or model of forecasting;
- help in finding the optimal method or model of forecasting.

Next consider the most typical methods for estimating forecast error, which are based on averaging [21].

2.5.1 Estimation of forecast accuracy by the value of the mean absolute deviation

Mean absolute deviation (MAD) is a method of estimating the accuracy of the forecast, which is used to estimate the value of the average absolute deviation of the actual and forecast values. MAD is calculated by the formula: If there is a data set consisting of n observations for which the forecast was calculated, then the mean absolute deviation is calculated by the equation (2.10):

$$MAD = \frac{1}{n}\sum_{t=1}^{n}|e_t| = \frac{1}{n}\sum_{t=1}^{n}|y_t - \hat{y}_t| \tag{2.10}$$

Where n is the number of observations for which the forecast was calculated.

This method does not reflect the change in the forecast variable relative to the actual one, because the mean absolute deviation MAD is the sum of the absolute values of the forecast errors divided by the number of time periods n used in the forecast.

2.5.2 Estimation of forecast accuracy based on the value of absolute percentage error

Mean absolute percentage error ($MAPE$) is another method that estimates the accuracy of the forecast in percent. The application of this method is especially relevant when the approach is especially useful when the values are large. The value of the average absolute percentage error $MAPE$ is determined by the formula (2.11):

$$MAPE = \frac{100\%}{n} \cdot \sum_{t=1}^{n} \frac{|y_t - \hat{y}_t|}{y_t} \qquad (2.11)$$

$MAPE$ is determined by finding the absolute error in each period and dividing this value by the actual value for this period, average these absolute errors for the observed period, and then multiply the result by 100%.

This method of estimating the accuracy of the forecast by the equation has the following characteristics:

– $MAPE$ is measured as a percentage;
– $MAPE$ can be used to compare forecast accuracy for the same and different forecasting methods applied to two completely different time series;
– $MAPE$ is not calculated in the case equal to zero.

2.5.3 Estimation of forecast accuracy based on the value of the average percentage error

Mean Percentage Error (MPE) is used to determine the level of the forecast value relative to the actual value (stable above or below). The forecast offset can be described as a tendency either to overestimate the forecast value (forecast more than the actual value) or to underestimate (forecast less than the actual value), which leads to forecasting error. The average percentage error of the forecast measures the "percentage shift" and is used to assess the accuracy of the forecasting method.

Formally, MPE is calculated by finding the error in each period, dividing it by the actual value for this period, and then averaging these errors and multiplying the result by 100%. The average percentage error is calculated by the equation (2.12):

$$MPE = \frac{100\%}{n} \cdot \sum_{t=1}^{n} \frac{e_t}{y_t} = \frac{100\%}{n} \cdot \sum_{t=1}^{n} \frac{y_t - \hat{y}_t}{y_t} \tag{2.12}$$

This method of estimating the accuracy of the forecast has the following characteristics:

- if the result MPE is close to zero, the prediction method is unbiased;
- if the result MPE is a large negative percentage, the forecasting method constantly overestimates the result;
- if the result MPE is a high positive percentage, the forecasting method constantly underestimates the result;
- MPE is determined as a percentage;
- MPE can be used to compare the accuracy of different methods, using completely different time series;
- MPE is not calculated in the case for the period t is zero.

2.5.4 Estimation of forecast accuracy according to the value of standard error

Mean squared error (MSE) is the most typical method for estimating the forecasting method. This error is calculated as follows: each error is squared, after which all errors are summed and the result is divided by the number of observations. The calculated formula for the standard error is as follows (2.13):

$$MSE = \frac{1}{n} \sum_{t=1}^{n} e_t^2 = \frac{1}{n} \sum_{t=1}^{n} (y_t - \hat{y}_t)^2 \tag{2.13}$$

This the method of estimating the accuracy of the forecast has the following features:

- MSE records the presence of large forecasting errors, as each error is squared;
- MSE is usually used to find very large errors of different forecasting models.

2.5.5 Estimation of forecast accuracy by the value of the square root of the root mean square error

Another method of estimating the accuracy of the prediction is the square root of the root mean square error ($RMSE$). The calculation of this estimate is based on the following equation (2.14):

$$RMSE = \sqrt{MSE} = \sqrt{\frac{1}{n}\sum_{t=1}^{n} e_t^2} = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2} \tag{2.14}$$

The method of estimating the accuracy of the forecast by equation (2.14) has the following features:

- $RMSE$ helps to determine the presence of large errors and has such units of measurement as the predicted series;
- $RMSE$ is used similarly to MSE to find very large errors of different forecasting methods.

Conclusions on the second section

The development of tools for short-term forecasting of the wholesale price of electricity at DAM can minimize the risks of buying and selling electricity for the day ahead, providing better forecasts at the system level.

Various methods and ideas have been tested to forecast electricity prices, so there is a wide range of forecasting models that are currently used in liberalized electricity markets in different countries with varying degrees of success in order to obtain the highest possible forecast accuracy.

When classifying approaches to modeling the forecast of electricity prices, six classes of models are conditionally determined: multiagent models, fundamental (structural) models, quantitative stochastic models, statistical models and methods (econometric models), models based on artificial intelligence, machine learning, (nonparametric, nonlinear). statistical models), hybrid models;

When forecasting the price of electricity at DAM, economic agents of a competitive market must take into account specific factors that affect the price and volume of production: seasonality; configuration of network objects; features of industry regulation; high barriers to entry into the industry; underdevelopment of derivatives.

There are various methods for estimating forecast error. The most commonly used methods of estimating forecast error, which involve the use of the average function of forecast error. The most common errors are the Mean Absolute Deviation MAD, the root mean square error ко, the square root of the root mean square error процен, the Mean Percentage Error MPE, and the Mean Absolute Percentage Error $MAPE$.

3 STATISTICAL DATABASE ON WHOLESALE PRICE IN THE ELECTRICITY MARKET SEGMENT OF DAM

In determining the open sources for the formation of a database of wholesale price statistics in the segment of the electricity market DAM was used information on the results of bidding DAM according to the State Company "Market Operator", posted on the official website of the companyhttps://www.oree.com.ua.

The site contains detailed information on the results of tenders for the purchase and sale of electricity on the market "for the day ahead" and the intraday market for two trading areas - IPS of Ukraine and Burshtyn Energy Island. You can see information about the amount of electricity bought or sold at DAM, the hourly results of the auction on any of the days when the auction was held.

The generated statistical database consists of established indices and weighted average electricity prices. Indices are displayed in three time periods of the day.

BASE - the period of base load, the average value of the price for all day (all hours during the day) is displayed.

PEAK - peak load period (electricity supply from 08:00 to 20:00).

OFFPEAK - off - peak load period (electricity supply from 00:00 to 08:00 and from 20:00 to 24:00.

Participants have the right to submit their bids for the purchase or sale of electricity in any of these periods.

It should be noted that the Market Operator analyzes the DAM indices in different European countries during the BASE period, which is a universal trading period, to compare electricity prices in Ukraine.

To create a statistical database on the wholesale price in the segment of the electricity market of DAM and hourly weighted average prices of purchase and sale of electricity on DAM was used information on the results of trading DAM according to the State Enterprise "Market Operator" [68].

The statistical database on the wholesale price in the segment of the electricity market of DAM covers the time period 19.10.2020-21.10.2020. Detailed information is given below in Table. 2-7 on the dates of the auction.

The statistical database on hourly weighted average prices of purchase and sale of electricity at DAM on IPS of Ukraine is given as of 10.2020 in Table. 8.

3.1 Statistical database on the wholesale price in the segment of the electricity market DAM as of 19.10.2020

Table 3.1 — Information on the calculation of DAM, 19.10.2020

Date	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh	Weighted average price, UAH / MWh	Shopping area
10/19/2020	69540.7	69540.7	165888.7	69881.0	1305.17	IPS of Ukraine
10/19/2020	6201.6	6201.6	10033.5	8121.2	1828.16	BEI

Table 3.2 — Prices for DAM and volumes of purchase and sale of electricity at DAM, hourly results at DAM, 19.10.2020

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
01:00	744.00	2129.4	2129.4	6524.2	2159.7
02:00	939.00	2186.2	2186.2	6833.8	2217.5
03:00	799.00	2056.3	2056.3	6719.7	2086.8
04:00	799.00	2072.3	2072.3	6863.0	2102.7
05:00	760.00	2035.2	2035.2	6775.1	2065.6
06:00	848.00	2226.6	2226.6	6538.9	2257.1
07:00	1074.00	2532.5	2532.5	6053.0	2565.1
08:00	1225.00	2828.8	2828.8	6821.1	2860.5
09:00	1300.00	3029.1	3029.1	6809.3	3061.4

Continuation of Table 3.2

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
10:00	1445.00	3329.5	3329.5	7056.7	3333.2
11:00	1380.00	3278.7	3278.7	7630.9	3282.6
12:00	1320.00	3181.9	3181.9	8301.7	3185.9
13:00	1365.00	3177.4	3177.4	8577.9	3181.2
14:00	1380.00	3278.3	3278.3	8527.9	3282.5
15:00	1370.00	3200.6	3200.6	8230.7	3204.9
16:00	1400.00	3351.7	3351.7	7919.4	3356.1
17:00	1326.81	3399.8	3399.8	7547.7	3404.1
18:00	1445.00	3433.8	3433.8	6947.9	3438.1
19:00	1697.00	3222.0	3222.0	5808.9	3226.3
20:00	1697.00	3344.1	3344.1	5598.1	3347.7
21:00	1558.00	3160.7	3160.7	5617.0	3164.5
22:00	1543.00	3251.9	3251.9	6297.9	3256.3
23:00	1663.00	3174.8	3174.8	6276.0	3179.1
24:00	1112.00	2659.1	2659.1	5611.9	2662.1

3.2 Statistical database on the wholesale price in the segment of the electricity market DAM as of 20.10.2020

Table 3.3 — Information on the calculation of DAM, 20.10.2020

Date	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh	Weighted average price, UAH / MWh	Shopping area
10/20/2020	6794.7	6794.7	11515.2	8640.5	1612.89	BEI
10/20/2020	69529.9	69529.9	166240.1	70011.6	1259.98	IPS of Ukraine

Table 3.4 — Prices for DAMand volumes of purchase and sale of electricity at DAM, hourly results at DAM, 20.10.2020

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
01:00	959.12	166.8	166.8	288.8	518.1
02:00	959.12	160.4	160.4	282.4	368.1
03:00	959.12	163.7	163.7	285.7	341.8
04:00	959.12	164.3	164.3	286.3	244.3
05:00	959.12	164.5	164.5	286.5	210.0
06:00	959.12	163.7	163.7	285.7	249.9
07:00	959.12	204.4	204.4	326.4	354.6
08:00	1641.09	294.6	294.6	541.0	296.5
09:00	2048.23	313.8	313.8	435.8	373.4
10:00	2048.23	323.8	323.8	445.8	391.7
11:00	1820.00	372.5	372.5	512.6	372.5
12:00	1808.52	353.2	353.2	576.7	353.2
13:00	1620.45	334.9	334.9	695.8	334.9
14:00	1491.84	336.9	336.9	726.2	336.9
15:00	1434.56	337.6	337.6	727.2	337.6
16:00	1370.67	334.9	334.9	709.8	334.9
17:00	1448.59	340.3	340.3	712.3	340.3
18:00	1552.18	348.5	348.5	702.1	348.5
19:00	2048.23	360.6	360.6	482.6	369.7
20:00	2048.23	372.0	372.0	494.0	453.3
21:00	2048.23	370.3	370.3	492.3	448.6

Continuation of Table 3.4

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
22:00	2048.23	349.6	349.6	471.6	372.6
23:00	1820.00	315.6	315.6	477.8	315.6
24:00	959.12	147.8	147.8	269.8	573.5

3.3 Statistical database on the wholesale price in the segment of the electricity market DAM as of 21.10.2020

Table 3.5 — Information on the calculation of DAM, 21.10.2020

Date	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh	Weighted average price, UAH / MWh	Shopping area
10/21/2020	7218.8	7218.8	12643.7	8278.4	1595.38	BEI
10/21/2020	66438.9	66438.9	158860.9	66835.4	1159.11	IPS of Ukraine

Table 3.6 — Prices for DAM and volumes of purchase and sale of electricity at DAM, hourly results at DAM, 21.10.2020

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
01:00	959.12	105.4	105.4	240.4	453.4
02:00	959.12	160.8	160.8	295.8	245.4
03:00	959.12	162.5	162.5	297.5	237.0
04:00	959.12	188.9	188.9	323.9	216.6
05:00	959.12	212.2	212.2	373.4	212.2
06:00	959.12	223.3	223.3	358.3	230.9
07:00	959.12	265.7	265.7	400.7	306.9

Continuation of Table 3.6

Hour	Price, UAH / MWh	Sales volume, MWh	Purchase volume, MWh	Declared sales volume, MWh	Declared purchase volume, MWh
08:00	1500.17	309.2	309.2	721.8	311.1
09:00	1810.00	364.9	364.9	709.0	364.9
10:00	1820.00	379.1	379.1	677.3	379.1
11:00	1820.00	376.2	376.2	694.3	376.2
12:00	1705.63	366.7	366.7	731.6	366.7
13:00	1680.32	350.5	350.5	709.7	350.5
14:00	1660.37	356.4	356.4	654.5	356.7
15:00	1563.50	348.4	348.4	626.8	348.9
16:00	1820.00	343.0	343.0	597.2	343.6
17:00	1820.00	346.3	346.3	556.0	346.3
18:00	1820.00	353.0	353.0	540.0	353.0
19:00	1652.38	379.7	379.7	697.1	379.7
20:00	1820.00	417.7	417.7	569.5	417.7
21:00	1820.00	411.9	411.9	599.4	411.9
22:00	1820.00	376.1	376.1	564.4	376.1
23:00	1820.00	324.7	324.7	473.9	324.7
24:00	959.12	96.2	96.2	231.2	568.9

3.4 Statistical database on hourly weighted average purchase and sale prices of electricity at DAM

Table 3.7 — Hourly weighted average purchase and sale prices of electricity at DAM on IPS of Ukraine for 10.2020

Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Numbers	UAH / MWh																							
1	0.00	0.00	0.00	959.12	0.00	0.00	0.00	0.00	0.00	0.00	1,958.56	1,969.61	2,048.23	2,020.71	2,024.50	2,016.46	2,030.80	1,993.74	1,902.00	2,048.23	2,048.23	2,048.23	2,048.23	959.12
2	959.12	0.00	959.12	959.12	959.12	959.12	959.12	1,343.26	2,048.23	2,048.23	2,048.23	1,986.80	2,048.23	2,041.13	1,835.20	1,965.36	1,957.59	2,006.30	2,048.23	2,048.23	2,048.23	2,048.23	2,048.23	959.12
3	959.12	899.95	549.95	0.00	0.00	0.00	619.86	866.15	825.68	869.22	1,235.00	1,294.00	2,048.23	1,235.00	2,015.85	1,344.00	1,926.78	1,235.00	1,200.00	1,241.00	2,048.23	2,048.23	1,602.33	959.12
4	959.12	521.95	403.85	360.62	342.00	0.00	0.00	432.00	519.10	545.00	709.85	564.07	558.84	519.10	519.10	545.00	597.00	956.00	0.00	1,220.00	0.00	0.00	1,200.00	0.00
5	959.12	0.00	0.00	0.00	0.00	0.00	959.12	0.00	0.00	0.00	0.00	0.00	1,334.15	0.00	0.00	0.00	1,268.75	1,366.85	0.00	2,048.23	2,048.23	2,048.23	0.00	0.00
6	959.12	959.12	959.12	959.12	959.12	0.00	959.12	0.00	0.00	1,726.56	1,809.50	1,203.30	1,816.74	1,225.58	1,183.80	1,232.53	1,341.45	1,872.85	1,784.11	0.00	0.00	0.00	0.00	959.12
7	959.12	959.12	944.00	944.00	944.00	944.00	959.12	1,334.16	1,799.00	1,726.56	1,563.06	1,809.50	1,150.00	1,289.00	1,520.00	1,470.00	1,268.76	1,366.13	1,563.06	1,799.00	1,810.01	1,799.00	1,375.00	959.12
8	959.12	959.11	957.50	493.08	394.71	488.77	959.12	1,360.00	1,700.00	1,625.04	1,491.84	1,425.24	1,390.00	1,390.00	1,335.50	1,179.50	1,184.89	1,640.00	1,640.00	1,800.00	2,048.23	1,809.50	1,550.00	959.12
9	959.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,048.23	1,960.54	1,853.92	1,824.58	1,695.75	1,633.86	1,756.54	1,768.13	1,989.53	2,038.70	2,048.23	1,952.94	1,810.00	959.12
10	959.12	959.12	959.12	0.00	0.00	0.00	0.00	2,048.23	0.00	0.00	1,764.13	2,048.00	2,048.00	2,048.00	2,048.00	2,040.00	2,048.23	2,048.23	1,628.30	0.00	2,048.23	1,995.84	2,048.23	959.12
11	959.12	0.00	955.00	503.99	503.99	0.00	863.00	0.00	0.00	1,100.00	1,200.00	0.00	0.00	2,048.00	0.00	0.00	0.00	1,212.00	0.00	0.00	1,819.02	1,620.00	0.00	0.00
12	959.12	959.12	0.00	0.00	0.00	0.00	959.12	0.00	2,048.23	2,048.23	2,048.23	0.00	0.00	1,749.00	1,699.17	1,760.66	1,921.62	2,043.95	2,048.19	1,828.57	2,048.23	2,048.23	1,778.92	959.12
13	959.12	959.12	959.12	959.12	959.12	959.12	959.12	0.00	1,807.00	0.00	1,801.01	0.00	0.00	0.00	1,807.00	0.00	1,807.00	0.00	0.00	1,801.01	1,801.01	1,939.88	1,756.71	959.12
14	0.00	0.00	0.00	0.00	0.00	0.00	959.12	1,790.00	1,790.00	2,048.23	1,807.90	1,807.90	1,608.67	1,569.98	1,582.77	1,424.47	1,456.31	1,505.42	1,587.48	0.00	2,048.23	0.00	0.00	959.12
15	0.00	0.00	0.00	959.12	959.12	959.12	0.00	0.00	2,048.23	2,048.23	1,998.83	1,940.61	1,841.35	1,898.39	1,897.53	1,896.80	1,902.23	1,867.88	1,928.49	1,987.34	1,994.45	2,048.02	1,930.86	959.12
16	959.12	959.12	959.12	959.12	959.12	959.12	959.12	0.00	2,048.23	2,048.23	0.00	2,048.23	2,048.23	1,954.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,048.23	0.00	959.12
17	0.00	959.12	959.12	959.12	959.12	959.12	959.12	0.00	0.00	0.00	0.00	0.00	1,838.20	1,762.37	1,503.04	1,501.98	1,570.56	1,632.50	1,838.20	2,048.23	2,048.23	2,048.23	0.00	959.12
18	0.00	959.12	0.00	959.12	959.12	959.12	959.12	0.00	0.00	0.00	0.00	1,081.91	1,121.78	1,822.92	1,807.61	1,807.32	1,022.52	1,120.38	1,405.42	1,812.61	1,807.90	0.00	1,411.73	959.12
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,048.23	1,983.64	1,777.32	1,753.24	1,830.90	1,793.95	1,778.26	1,835.83	1,943.70	2,048.23	2,048.23	0.00	0.00	0.00
20	959.12	959.12	959.12	959.12	959.12	959.12	959.12	1,641.09	2,048.23	2,048.23	1,838.20	1,826.61	1,636.40	1,491.84	1,434.56	1,370.67	1,448.59	1,564.50	2,048.23	2,048.23	2,048.23	2,048.23	1,820.00	959.12
21	0.00	959.12	959.12	959.12	0.00	959.12	959.12	0.00	0.00	0.00	0.00	0.00	1,680.32	1,660.37	1,579.14	1,838.20	0.00	0.00	1,652.38	1,836.44	1,837.31	2,037.36	2,048.23	0.00
22	959.12	0.00	0.00	929.40	881.16	927.06	959.12	1,443.45	1,738.87	2,048.20	1,657.51	1,534.22	1,424.47	1,365.37	1,314.78	1,218.42	1,376.22	1,748.45	1,838.21	1,850.19	1,877.68	2,048.23	2,048.20	959.12
23	959.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,048.23	2,048.23	2,048.23	2,048.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,048.23	2,048.23	0.00	0.00	959.12
24	959.12	0.00	0.00	959.12	959.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	959.12

3.2 Factors influencing changes in electricity prices

Today, generators, distributors and consumers must be prepared for even a small and immediate change in the load and supply of electricity [69]. Every market participant must know the exact price of electricity to achieve maximum profitability. With the right forecast for the market price of electricity, generating companies and large enterprises as key market participants in decision-making can reduce their risks and maximize their profits in the future.

Electricity price forecasting has now become a necessity of the electricity market. To date, forecasting the demand and price of electricity has become one of the main areas of research [70]. Accurate load forecasts lead to lower operating costs, which contributes to savings in electricity.

Electricity price forecasting differs from load forecasting, as the former is characterized by high volatility, very rapid change in the frequency of the peak price, and high dependence on the season.

These characteristics arise for various reasons, which are due to the dependence of electricity prices on various factors, such as environmental factors, market factors and historical price and load data. Factors affecting electricity are shown in Figure 3.1 [71].

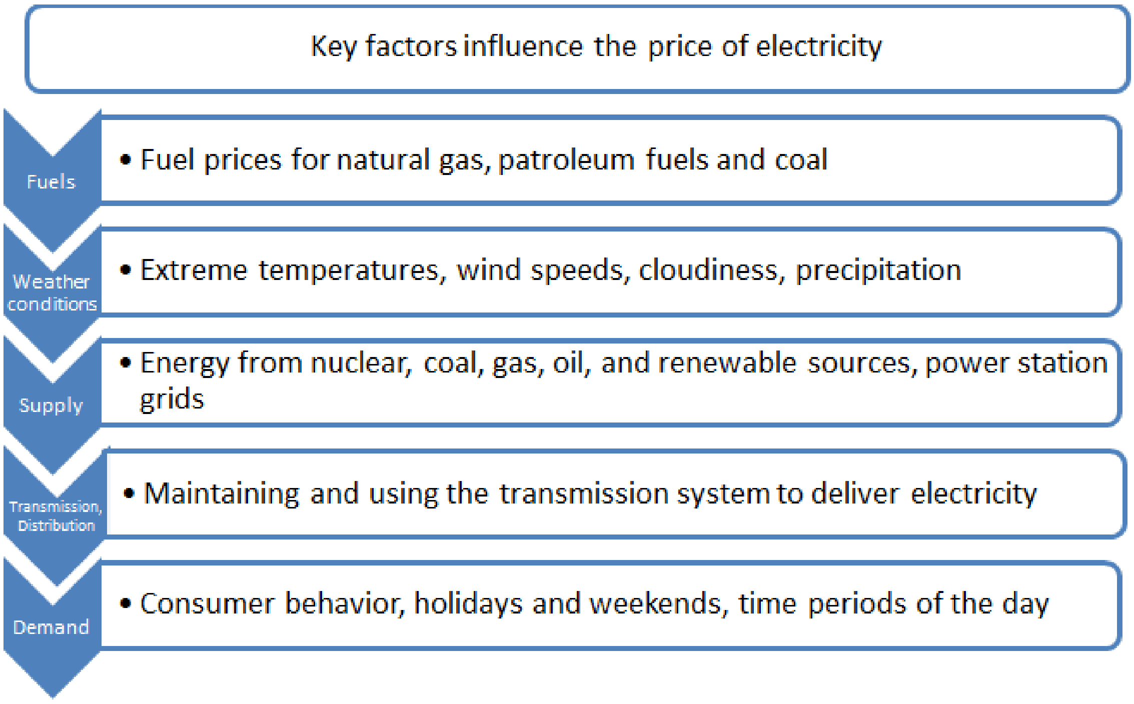


Figure 3.1: Factors affecting Electricity Price [69]

3.3 Comparative analysis of some of the most popular forecasting models

Forecasting includes conventional methods and new machine learning methods [72].

Among the most commonly used methods are autoregressive integrated moving average models (ARIMA) [73].

3.3.1 ARIMA and ARIMAX models

In the field of time series analysis, the autoregressive (AR) model and the moving average (MA) model are one of the most used.

In this model, the current value of the process is expressed as a finite linear set of previous values of the process and the pulse, which is called "white noise". More about this model is discussed in Section 2.

The development of the ARIMA model (p, d, q) is the ARIMAX model (p, d, q), which is described by the equation

$$Z(t) = \mathrm{AR(p)} + \alpha_1 \mathrm{X}_1(\mathrm{t}) + \cdots + \alpha_s \mathrm{X}_s(\mathrm{t})$$

Here $\alpha_1, \ldots, \alpha_s$ –coefficients of external factors $\mathrm{X}_1(t), \ldots, \mathrm{X}_s(\mathrm{t})$. In this model, most often the process Z (t) is the result of the model MA (q), ie the filtered values of the original process. Next, the autoregression model is used to predict Z (t), in which additional regressors of external factors $\mathrm{X}_1(\mathrm{t}), \ldots, \mathrm{X}_s(\mathrm{t})$ are introduced.

3.3.2 Fuzzy systems and artificial neural networks

The rapid development of computational intelligence has brought new methods of short-term forecasting [74]. They are based mainly on artificial neural networks (ANNs) and fuzzy systems, as well as on cluster methods and expert systems.

The multilayer perceptron (an artificial neural network most commonly used in short-term prediction) is an attractive tool for modeling nonlinear problems due to its universal approximation property. But learning ANN is not easy because of its complex structure and large number of parameters.

Structurally, such a network consists of three main layers:

1) input layer - a set of neurons that represent a set of input signals (output data);

2) hidden layer (or hidden layers) - a set of neurons that allow the network to learn to solve complex problems, consistently receiving the most important signs of signals from the input layer;

3) the output layer - a set of neurons that represent a set of output parameters. MLP is a network of direct propagation, ie the input signal propagates from layer to layer of the network in the forward direction. The neurons in the second and third layers can be connected by the same set of input signals, but not connected to each other [67].

Fuzzy systems allow you to enter input according to rules formulated orally by experts and describing the behavior of complex systems using linguistic expressions.

The structure of the neuro-fuzzy system is complex and the number of parameters is usually large (it depends on the size and complexity of the problem), so learning is difficult and does not guarantee convergence to the general minimum.

3.3.3 Random Forest

Random Forest is the latest method. It was developed by Braiman [76] as a way to obtain more accurate predictions without excessive data processing. A random forest is a collection of decision trees that is built using a whole set of data taking into account all the features, but in random forests a certain number of traits are randomly selected for training and a decision tree is built on this subset. In

Random Forest, a different subset of training data is selected, with a replacement for training each tree. The class is assigned by the number of votes from all trees and the average value of the results is used for regression.

The main difference is that Random Forest (RF) is a collection of numerous decision trees (DT).

Reasons for choosing a random forest among the decision tree:

1. Individual decision trees would lead to an overly applicable model if the data set is huge, just as one person can have their own view of everything.

2. However, if we introduce a voting system and ask different people to interpret the data, we could cover more features and patterns.

The RF principle is a combination of a set of binary decision trees (CART, created by Braiman - Classification And Regression Trees) [76], each of which is built using a sample of the initial load coming from the training sample and a subset of features (input variables), randomly selected on each node.

Thus, in contrast to the strategy of building the CART model, each tree in the overhead line is based on a subset of learning points and subsets of features considered in each node, which must be divided. Trees in the forest are grown to the maximum size.

The final decision is obtained by averaging the results for regression or by voting for the classification. This procedure, called beging (packing), improves the stability and accuracy of the model and reduces variance. The variance decreases due to a decrease in the correlation between the trees [77]. Random forests cannot be overfilled, but give the limit value of generalization error [78]. The overhead generalization generalization error is estimated using the out-of-bag (OOB) error, ie the errors for training points that are not contained in the initial boot training kits.

The OOB error estimate is almost identical to the estimate obtained by N-fold cross-checking. The great advantage of overhead lines is that they can be installed in the same sequence, while cross-checking is performed on the fly. Training may be terminated when the OOB error stabilizes.

The two main parameters of overhead lines are: the number of trees in the forest K and the number of input variables selected randomly at each division F. The number of trees can be determined experimentally. During the training procedure, we add consecutive trees until the OOB error stabilizes. The overhead line procedure is not very sensitive to the value of F.

Another parameter is the minimum node size m. The smaller the minimum node size, the deeper the trees. Many publications recommend m = 5. This value is set by default in many programs. VL show insignificant sensitivity to this parameter.

Using overhead lines, we can determine the importance of variables, which is useful for ranking variables and their selection, for interpreting data and understanding basic phenomena. The value of a variable can be estimated as an increase in the prediction error if the values of this variable accidentally intersect between OOB samples. The increase in error as a result of this permutation is averaged over all trees and divided by the standard deviation for the whole ensemble. The greater the increase in OOB error, the more important the variable.

3.4 Model selection and implementation of short-term electricity price forecasting

To model a non-stationary time series with a trend and several seasonal cycles usually require a complex model with many parameters. Finding such a model space is a difficult and time consuming process. Intelligent search methods are often used to find the optimal solution. The disadvantages of complex models are the poorer ability to generalize, unclear structure and uninterpreted parameters.

A one-dimensional model of short-term forecasting is a random forest model.The advantage of tree methods is that they are able to investigate and highlight complex or hidden relationships in the data, for this reason they are used to obtain models that very accurately reflect the behavior of the data and are especially useful for forecasting.

This method was used to make a short-term forecast of the wholesale price of electricity in Ukraine on the market "day ahead".

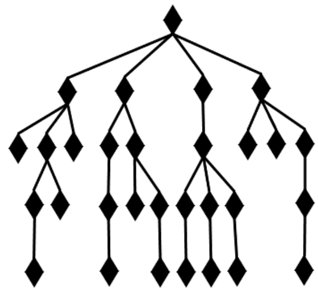


Figure 3.2 A model of decision tree

3.4.1 Pre-processing of data

The load string $\{z_l\}_{l=1,2,\ldots,L}$.is divided into daily cycles of length n. To eliminate weekly and annual fluctuations, daily cycles are pre-processed to obtain their patterns is a vector with components that are functions of the actual elements of time series. A pattern is a vector with components that are functions of the actual elements of time series. Two types of paterns are defined: input templates x and output (forecast) y. The forecast template $y_i = [y_{i,1}\ y_{i,2} \ldots y_{i,n}]^T$ encodes consecutive actual time series elements z_l in the predicted daily cycle i + τ: $z_{i+\tau} = [z_{i+\tau,1} + z_{i+\tau,2} + z_{i+\tau,n}]^T$, and the corresponding input patern $x = [x_{i,1}\ x_{i,2} \ldots x_{i,n}]^T$ displays the time series elements in the daily cycle i preceding the forecast cycle: $z_i = [z_{i,1}\ z_{i,2} \ldots z_{i,n}]^T$. Vectors y are encoded using the current process parameters from the recent past, which allows to take into account the current variability of the process and allows decoding. Some definitions of the mapping functions of the source space Z in the space of patterns X and Y, that is f_x: Z → X and: f_y: Z → Y, presented in [78]. The most popular definitions are:

$$f_x(z_{i,t}) = \frac{z_{i,t} - \overline{z_i}}{\sqrt{\sum_{j=1}^{n}(z_{i,j} - \overline{z_i})^2}} \qquad f_x(z_{i+\tau,t}) = \frac{z_{i+\tau,t} - \overline{z_i}}{\sqrt{\sum_{j=1}^{n}(z_{i,j} - \overline{z_i})^2}}$$

where: i = 1, 2,…, N — number of the daily period, t

, j = 1, 2,…, n — the number of the time series element in the period i,

τ — forecast horizon,

$z_{i,t}$ —time series of the t -th element of the time series in the period i,

$\overline{z_i}$ −the average value of the elements in the period i.

Function f_x expresses the normalization of vectors $\boldsymbol{z_i}$. After normalization, they have a unit length, zero mean and the same variance. Note that nonstationary and heteroskedastic time series are represented by regularities having the same mean and variance.

Prediction schemes y_i are determined using a function similar to that f_x, but the coding parameters are determined from the process history. This allows to decode the predicted vector $z_{i+\tau}$ after determining the regularity prediction y_i. To do this, use the inverse function $f_y^{-1}(y_{i,t})$.

From a set of pairs $\{(x_1, y_1), ..., (x_N, y_N)\}$, where y_i represents the load per hour*t* the next day (this *t*-th component of the patern y_i for τ= 1), a training set for a random forest is generated. For each query point (template x representing*k*-th daily period) training set is prepared individually from historical data. It contains*M*nearest neighbors of the query template, representing the same days of the week (Monday, ..., Sunday) as the query template. This is a restriction for*M* nearest neighbors due to the purpose of building a local model that matches the query pattern. Therefore, it makes no sense to use distance learning points to teach the model. Of course, this model is not suitable for other query points, and we need to create a separate model for each query point. But the cost and time of construction of the model in this case are not limiting factors.

3.4.2 Calculation of the price forecast for Random Forest

There are a large number of IT forecasting systems that help analytics. Risk management systems are used for risk forecasting and management. Functional systems help to make predictions in any values.

The MidOSS program by Transition Technologies has a lot of analytical functionality. One of such functionalities is the implementation of the forecast based on 6 mathematical models that help to make a forecast. Forecasting can be done for the price of electricity, the amount of electricity, network losses, and so on.Analytical system MidOSS, integrated with the computing environment, which allows you to implement and maintain various mathematical functions in the system - forecasting, risk analysis, modeling, etc.

An example of functionality is the implementation of forecasting using different models. In this case, the Random Forest model was used.

As initial data we accept hourly dynamics of pricesfor electricity for the IPS zone of the electricity market of the day-ahead market (DAM price) for the period from September 1, 2020 to September 15, 2020, a total of 360 observations.

The actual daily dynamics of electricity prices in the IPS zone from January 1, 2020 to September 30, 2020 were used to build a forecast model, and data for the period from September 1, 2020 to September 15, 2020, were used to assess its forecast results.

Figure 3.3 shows the dynamics of prices from January 1, 2020 (the beginning of the market "day ahead" to September 30, 20202.

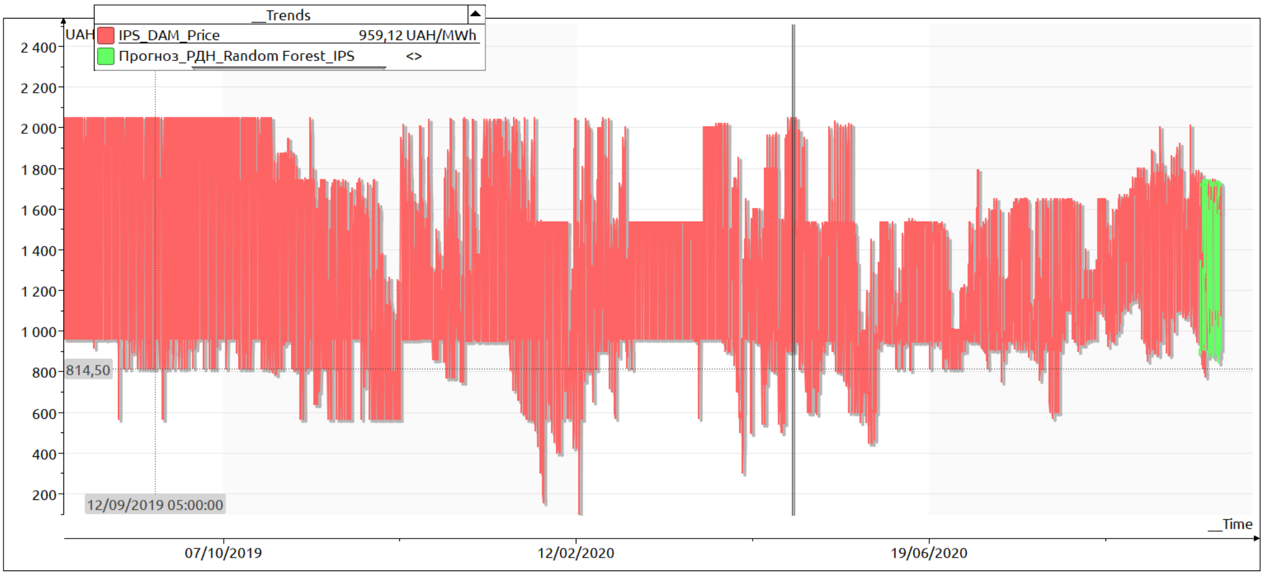


Figure 3.3. Daily dynamics of electricity prices in the UES zone from January 1, 2020 to September 30, 2020

The input parameters are:

- time of day;
- weekday;
- variable that relates the current day to a weekend or holiday;
- variable that relates the current day to the working day.

Figure 4 shows an example of the time dynamics of electricity prices as of September 1, 2020. All incomes were divided into: hour of the day, day of the week, sign "working (weekend) day".

Дата	Исторические данные
01.09.2020 0:00	1164
01.09.2020 1:00	1150
01.09.2020 2:00	1148
01.09.2020 3:00	1148
01.09.2020 4:00	1148
01.09.2020 5:00	1148
01.09.2020 6:00	1190
01.09.2020 7:00	1680
01.09.2020 8:00	1689
01.09.2020 9:00	1697
01.09.2020 10:00	1689
01.09.2020 11:00	1689
01.09.2020 12:00	1689
01.09.2020 13:00	1689
01.09.2020 14:00	1697
01.09.2020 15:00	1689
01.09.2020 16:00	1699
01.09.2020 17:00	1697
01.09.2020 18:00	1669
01.09.2020 19:00	1748
01.09.2020 20:00	1748
01.09.2020 21:00	1748
01.09.2020 22:00	1750
01.09.2020 23:00	1195
02.09.2020 0:00	1198

Figure 3.4. Timely dynamics of electricity prices as of September 1, 2020

Let's display the data on the graph of hourly price dynamics as of September 1, 2020 (Tuesday) and September 5 (Saturday).

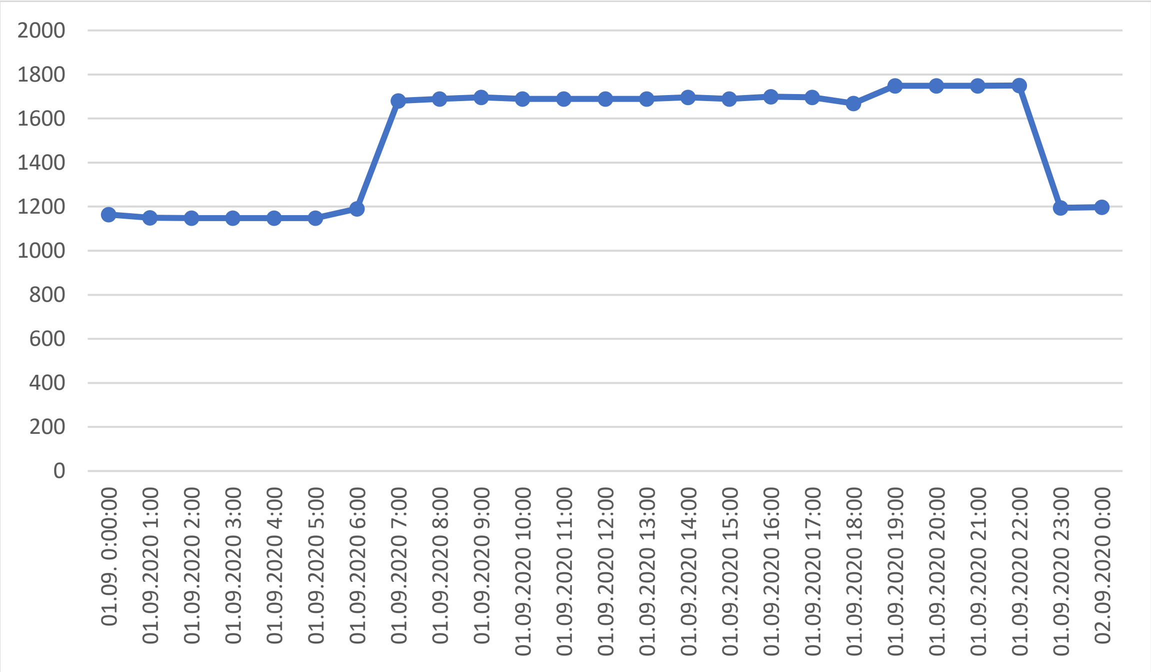


Figure 3.5. Timely price dynamics as of September 1 (Tuesday) 2020.

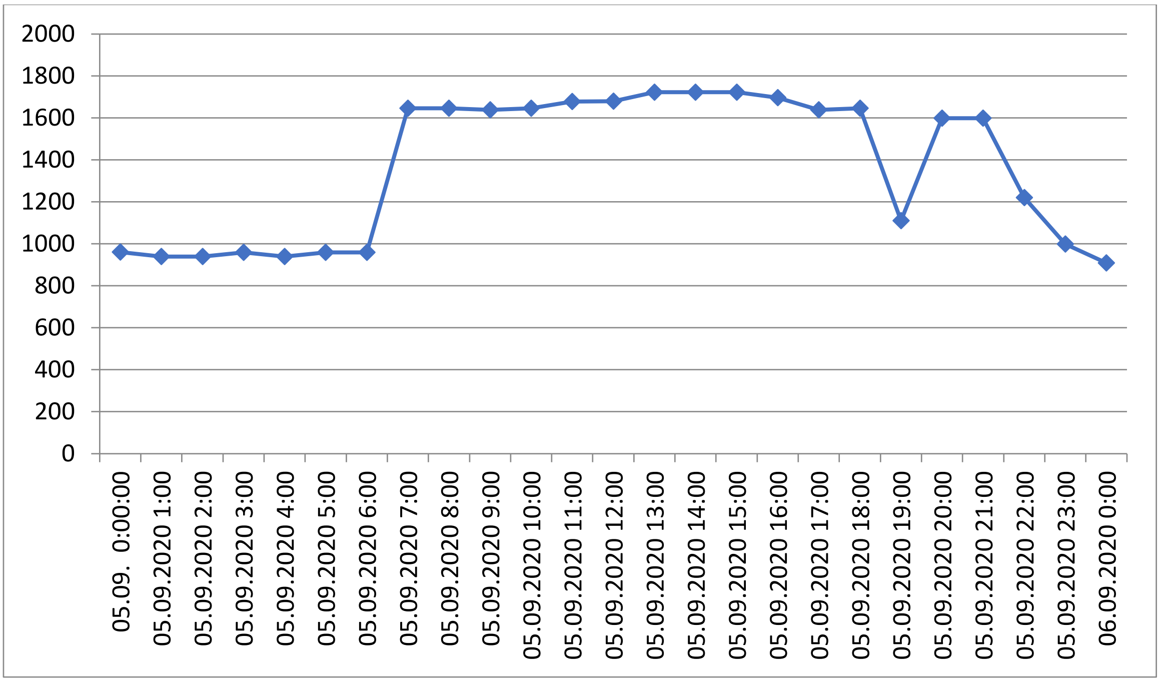


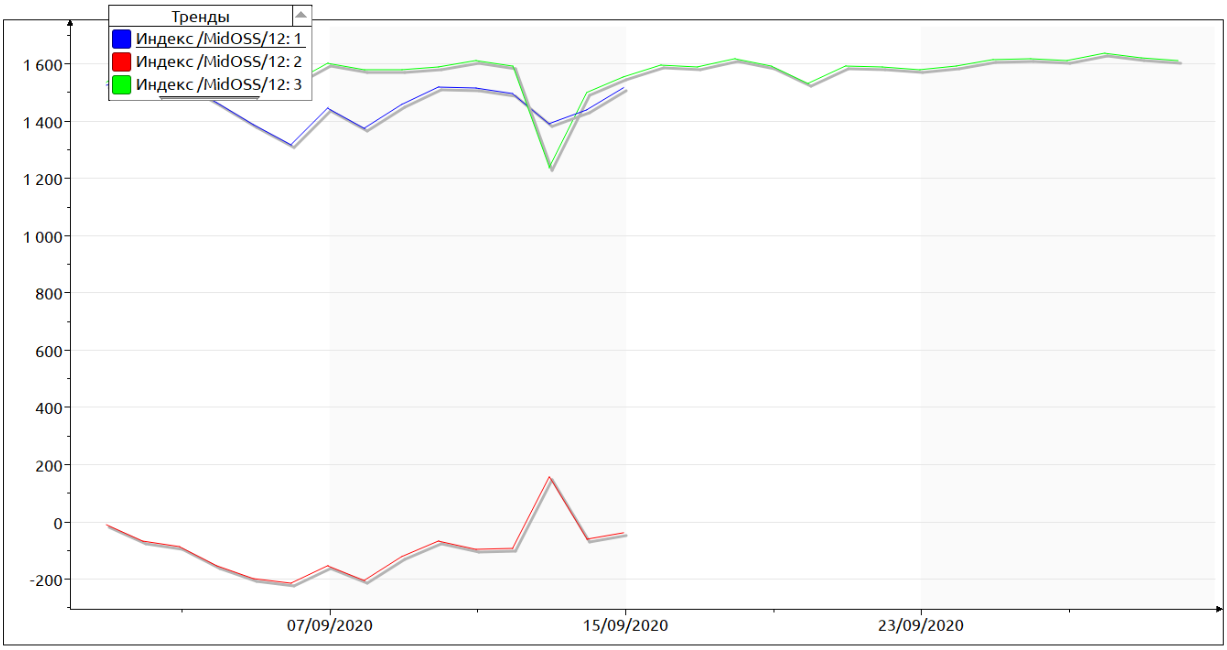
Figure 3.6. Timely price dynamics as of September 5 (Saturday) 2020.

Figure 3.7. Timely dynamics of electricity prices on weekends and working days as of November 2020

The price of electricity on DAM during the day is higher compared to the night period, similarly, we can note the excess of the price of DAM on weekdays over this figure on holidays and weekends. This fact is associated with an increase in demand during the day compared to night and similarly - on weekdays compared to weekends and holidays. The latter is largely related to the workload (work) of large industrial consumers.

Statistics on such parameters as network load, outside air temperature, composition of the included generating equipment, river water content were not taken into account when forming the model, as they were absent. Such data reflect the peculiarity of the functioning of the electricity market and affect the accuracy of seasonality.

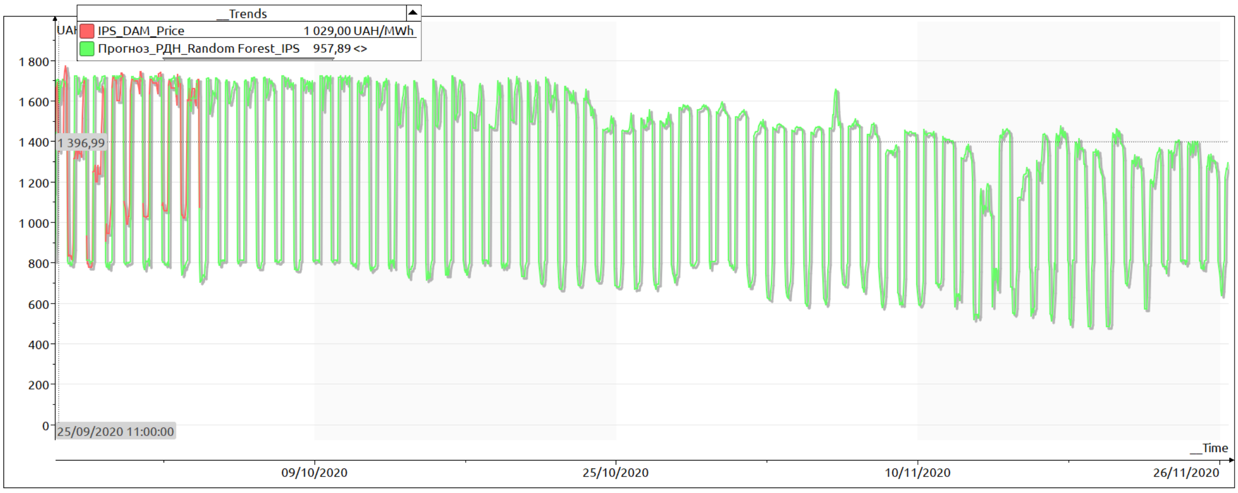
Figure 9 shows the result of the forecast in daily granulation in the period from September 16, 2020 to September 30, 2020, ie each point on the graph is one day, not one hour.



forecast value of the price; historical significance; error

Figure 3.8. Forecast for the period from September 16, 2020 to September 30, 2020

The result of the forecast for the period from September 25, 2020 to November 26, 2020 is shown in Figure 9.



forecast value of the price; error

Figure 3.9. Forecast of electricity prices in the period from September 25, 2020 to November 26, 2020

The results of the calculations - the values of errors in the forecast of the price of DAM are given in table. 9.

Table 3.1 - Error forecasting the price of DAM on the forecast horizon of two weeks

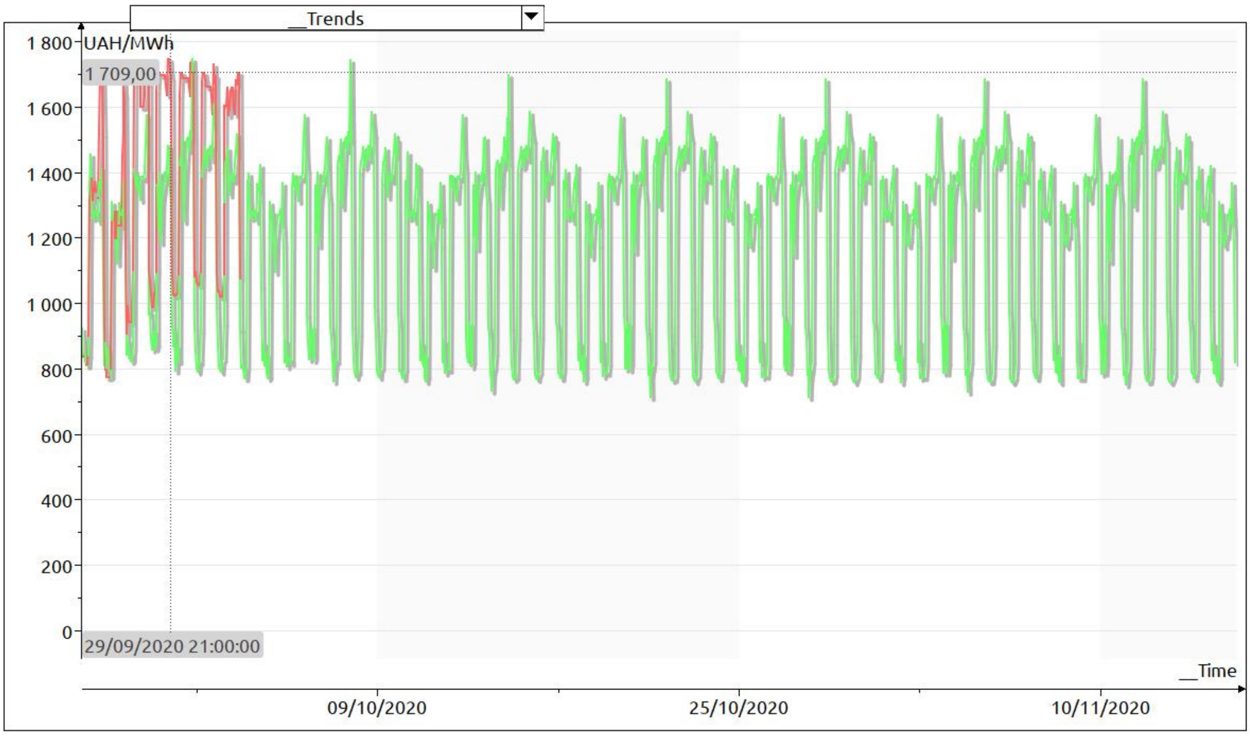
MAP	MAD, UAH / MWh	MPE
6,62%	0,77	6,62%

We can conclude that the forecast is made qualitatively. The MAPE error is less than 10%. The value of the MPE error is close to zero, that is this prediction method is unbiased. The average absolute deviation is also quite small, which may indicate the implementation of a fairly accurate forecast of electricity prices.

Another example of a short-term forecast is the ANN and ARIMA test models.

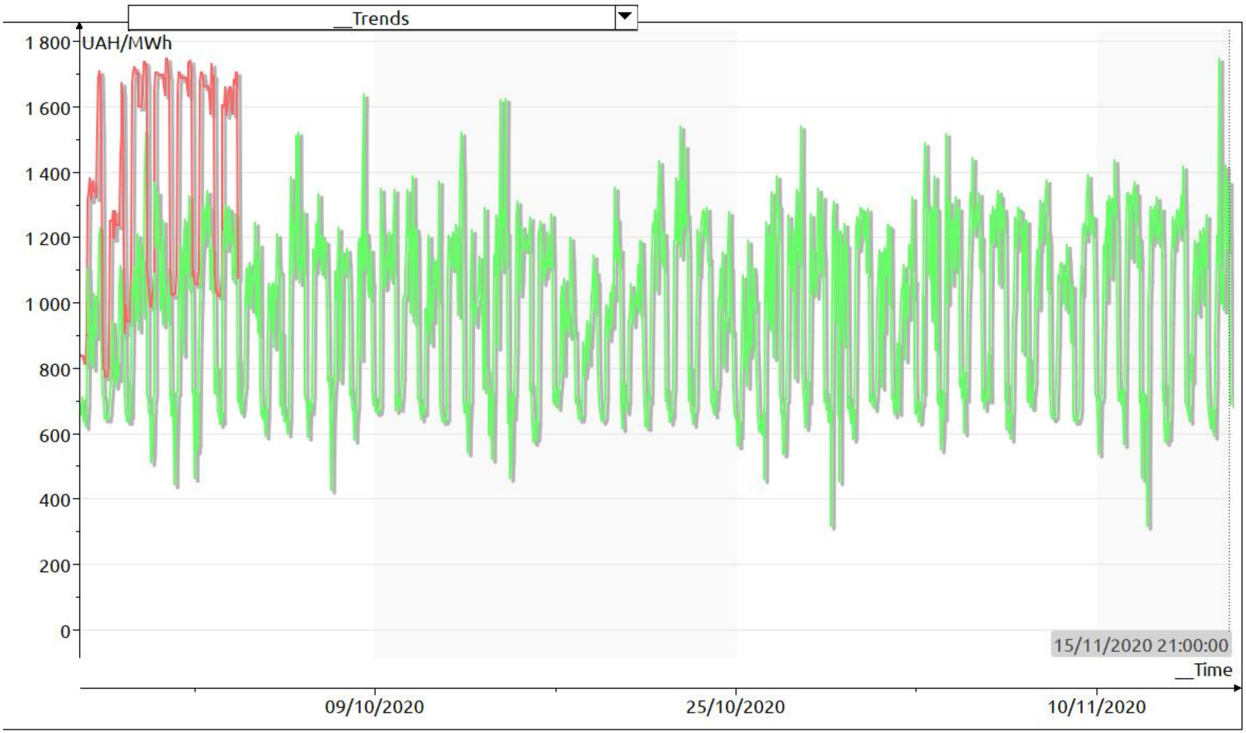
All incoming were similarly divided into: hour of the day, day of the week, sign "working (weekend) day". Data for the period from September 25, 2020 to October 2, 2020, were used to assess its forecast results.

Statistics on such parameters as network load, outside air temperature, composition of the included generating equipment, river water content were not taken into account when forming the model, as they were also absent.



—forecast value of the price; — error

Figure 3.10. Forecasting of electricity prices by the ARIMA model for the IPS of Ukraine in the period from 25.09.2020 to 15.11.2020

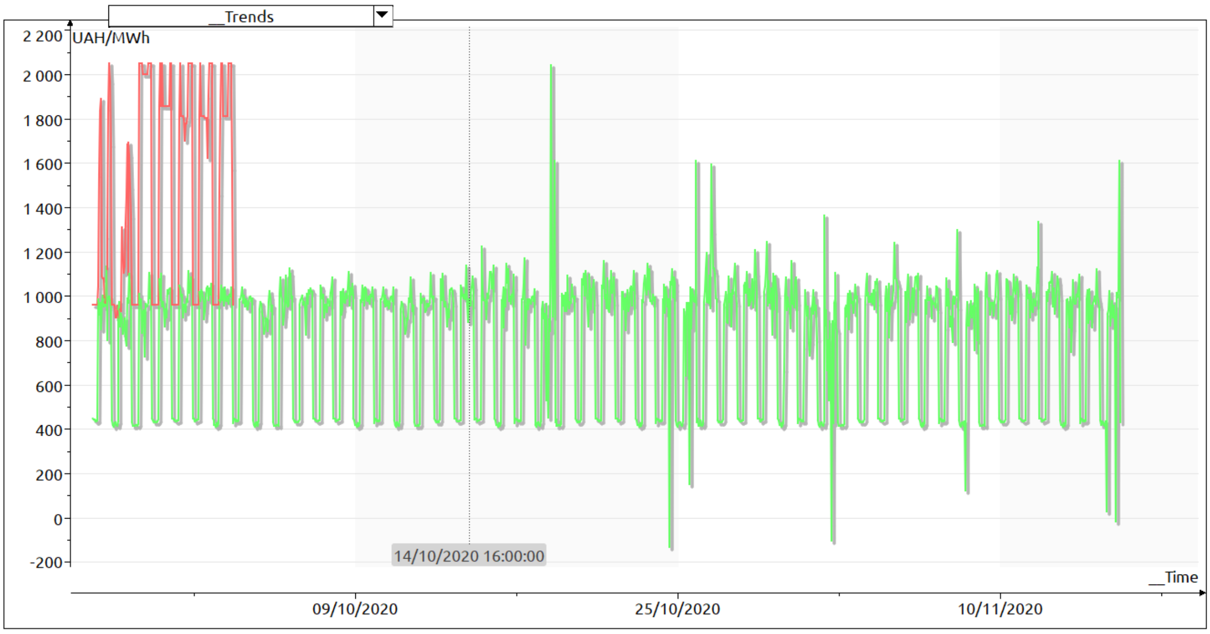


forecast value of the price; error

Figure 3.11. Forecasting of electricity prices by the ANN model for the IPS of Ukraine in the period from 25.09.2020 to 15.11.2020

forecast value of the price; error

Figure 3.12. Forecasting of electricity prices by the ARIMA model for BEI of Ukraine in the period from 25.09.2020 to 15.11.2020



forecast value of the price; error

Figure 3.13. Electricity price forecasting model ANN for BEI of Ukraine in the period from 25.09. 2020 to 15.11. 2020

Let’s plot the actual hourly dynamics of electricity prices on weekdays and weekends as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the UES zone, which was used for the ARIMA and ANN methods.

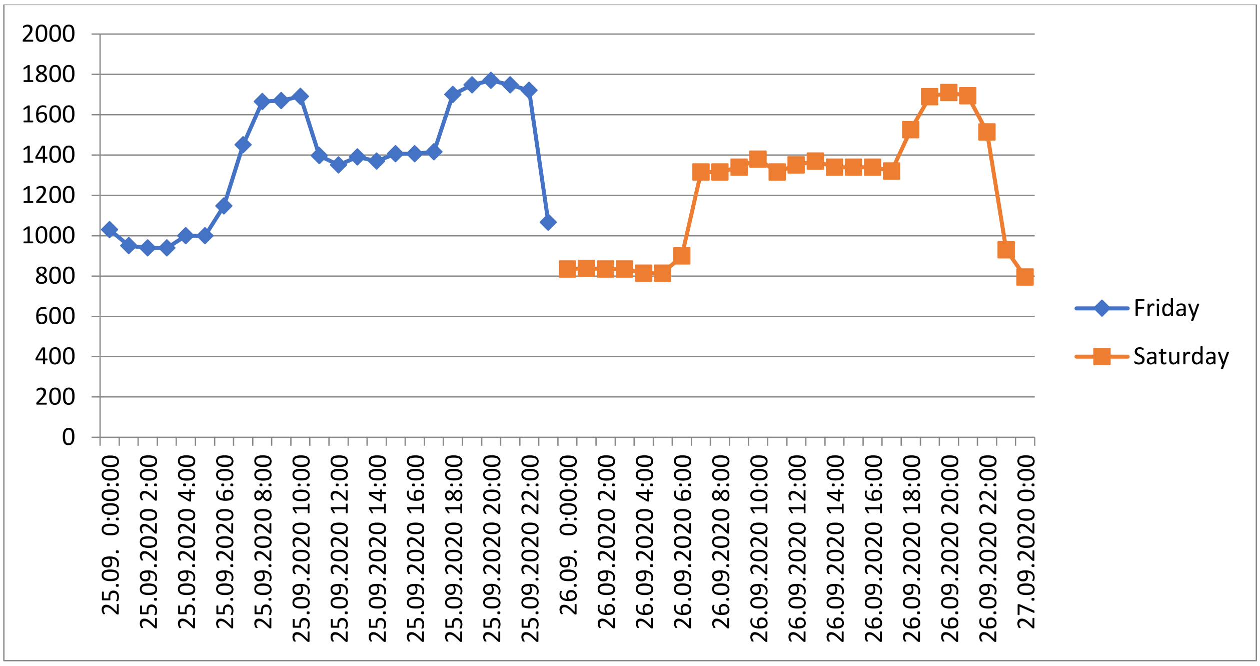


Figure 3.14. Actual hourly dynamics of electricity prices as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the IPS zone.

Let's plot the actual hourly dynamics of electricity prices on weekdays and weekends as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the BEI zone, which was used for the ANN and ARIMA method.

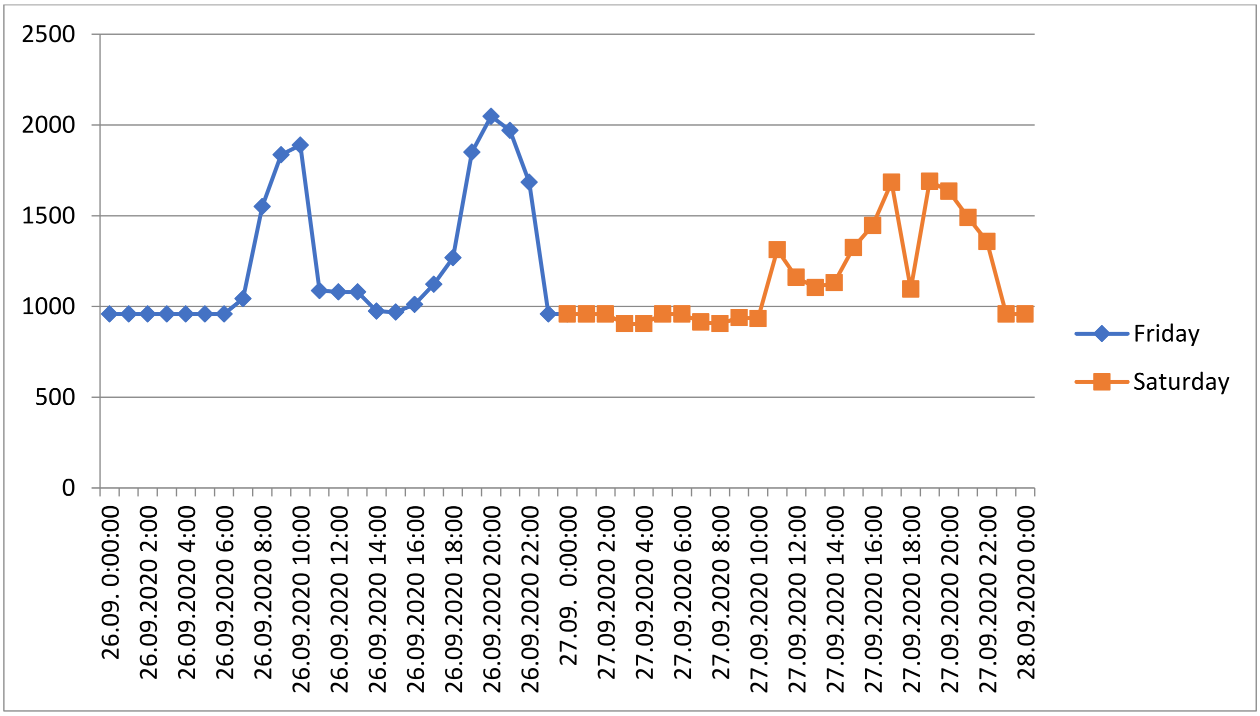


Figure 3.15. Actual hourly dynamics of electricity prices as of September 25, 2020 (Friday) and September 26, 2020 (Saturday) for the BEI zone

The figures show that the ARIMA model is more accurate in this case for the short-term forecast.

Electricity price forecasts on the stock exchange are difficult to predict by mathematical models. What affects the price arises spontaneously.

In this case, the calculation of errors could not be done due to inability to access all data.

Conclusions on the third section

To develop models for forecasting the wholesale price in the DAM electricity market segment and conducting a comparative analysis of the accuracy of the forecast, a statistical database on the wholesale price in the DAM electricity market segment was created according to the SC Market Operator.

The generated statistical database consists of established indices and weighted average electricity prices. Indices are displayed in three time periods of the day: BASE, PEAK and OFFPEAK.

To create a statistical database on the wholesale price in the segment of the DAM electricity market and hourly weighted average purchase and sale prices of electricity on the DAM, information on the results of the DAM bidding was used according to the State Enterprise Market Operator.

Factors that primarily affect the change in electricity prices are: price on fuels, weather conditions, supply, distribution and transmission, demand.

Forecasting includes conventional methods and new methods of machine learning.

Among the most commonly used methods are autoregressive integrated moving average models (ARIMA).

In the field of time series analysis, the autoregressive (AR) model and the moving average (MA) model are one of the most used. The development of the ARIMA model is the ARIMAX model.

The rapid development of computational intelligence has brought new methods of short-term forecasting. They are based mainly on artificial neural networks (ANNs) and fuzzy systems, as well as on cluster methods and expert systems.

The Random Forest model was chosen for short-term forecasting. Random Forest is a collection of decision trees, which is built using a whole set of data taking into account all the features, but in random forests a certain number of traits are randomly selected for training and a decision tree is built on this subset.

It was determined that the price of electricity on DAM during the day is higher compared to the night period, similarly, we can note the excess of the price of DAM on weekdays over this figure on holidays and weekends. This fact is associated with an increase in demand during the day compared to night and similarly - on weekdays compared to weekends and holidays. The latter is largely related to the workload (work) of large industrial consumers.

The MAPE error is less than 10% (6,67%), which confirms the qualitative forecast of electricity prices. The value of the MPE error is close to zero, ie this prediction method is unbiased. The average absolute deviation is also quite small, which may indicate the implementation of a fairly accurate price forecast.

A comparative analysis of the ARIMA and ANN test models showed that the ARIMA model is more accurate in this case for the short-term forecast.

4 INNOVATIVE SOLUTIONS IN THE LIBERALIZATION OF THE ENERGY SECTOR

4.1 The urgency of implementing innovative solutions in the liberalization of the energy sector

In the long run, the development of production and society will depend mainly not on resource opportunities, but on the innovative nature of production and services in a competitive environment. Analysis of the development of the energy sector in developed countries shows that they are based on a wide range of innovations embodied in new or upgraded products, services, technologies, methods of organizing production and marketing, and so on. For the domestic economy, it is innovation and innovative development of the energy sector that is the driving force that can ensure the economic independence of Ukraine and bridge the gap with developed countries. The acceleration of innovation waves, which is associated with the rapid development of science, creates the preconditions in the energy sector for the emergence of various innovations related to the creation of new or improvement of existing energy technologies or services, methods of production process. Due to the need to increase the informatization and intellectualization of energy facilities, modeling the process of making managerial decisions is the intensive development of innovative decisions related to the field of energy software [79-81].

The general rule when creating innovations is to focus on the market, ie to meet the specific needs of a potential consumer of goods or services. A competitive electricity market is no exception to this rule. Liberalization of the domestic energy sector and introduction of a new competitive model of organization of the electricity market of Ukraine requires the study of European and world experience in innovative approaches, in particular to overcome obstacles to the functioning of the "market for the day ahead" DAM. The volatility of electricity prices and the unpredictability of the conditions in which energy market participants are to operate in future periods, significantly complicate their management decisions in the future.

In this context, the urgent task of developing economic relations of the competitive model of electricity market organization should be to study the existing opportunities for innovative approaches in the form of software products or provide appropriate services for forecasting the wholesale price of electricity generated on DAM. Compared to other market segments, the risks of participants in this segment are often associated with the fact that the price of electricity generated on DAM is more prone to volatility under the influence of both exogenous and endogenous factors of the market environment [67,80,82] .

Based on this relevance of innovative approaches in the energy sector as a whole and in the context of the introduction of a competitive electricity market in Ukraine, this section identified the purpose and objectives of undergraduate practice.

The purpose of this section is to study the existing possible innovative solutions related to the creation or application of software products for forecasting the price of electricity on DAM to improve the accuracy of the forecast and reduce the risks of economic agents involved in this market segment.

To achieve this goal, the following tasks were identified:

– to characterize the general definition of the content of the concept of "innovation";

– provide a classification of innovations, the spread of which is possible in the energy sector, by type and degree of novelty;

– provide proposals for innovative solutions in the context of liberalization of the energy sector.

4.2 Definition of the concept of "innovation"

The basis of the theory of innovative economic development is the concept of innovation, innovation, which can be understood as various activities of new elements that increase the effectiveness of this activity. In the modern sense, innovation under different conditions is defined as a process and as the end result of innovation, embodied in the form of a new or incremental product; new services that have market demand or socio-economic significance for society; the latest or improved technological process used in practice; regulatory innovation, etc. [79-80, 83-85].

J. Schumpeter in his scientific work "Theory of Economic Development" (1911) formulated a holistic theory of innovative development, the central place of which was the introduction of the economic category of "innovation" as a necessary production function due to changes in factors of production, resources or a combination. J. Schumpeter identifies the following components of innovation [79-81]:

– introduction of new products, goods, services, new types or unknown to the consumer;
– application of new production technology, introduction of an unknown method (method) of production for a certain industry;
– use of new materials, types of raw materials, as well as its sources;
– opening and development of a new market for product consumption;
– undermining the monopoly of competitors or monopolizing the market through the production of its own, previously unknown products;
– introduction of a new organization of production, management process, organizational structure or their improvement.

According to the Law of Ukraine "On Innovation", innovation has a very universal definition: "innovation - newly created (applied) and (or) improved competitive technologies, products or services, as well as organizational and technical solutions of production, administrative, commercial or other nature, that significantly improve the structure and quality of production and (or) the social sphere "[85].

The modern methodology of systematic description of innovations in a market economy is based on international standards. To coordinate the collection, processing and analysis of information on science and innovation within the Organization for Economic Co-operation and Development (OECD), a group of experts on science and technology was created and developed the Frascati Manual (1963) - “Standard Practice Proposed for the survey of research and experimental development. This document got its name due to the fact that its first version of the guidelines was adopted in the city of Frascati (Italy). The regulations are periodically updated, which is due to changes in the strategy of scientific and technical policy at the national and international levels in the organization of research and development. The last edition of the "Frascati Manual" was adopted in 1993, it defines the basic concepts relating to research and development, their composition and limits. The methodology for collecting data on technological innovation is based on the recommendations adopted in Oslo in 1992 and is called the "Oslo Guide".

According to these international standards, innovation is defined as the end result of an innovation activity embodied in the form of a new or improved product or technological process used in practice or in a new approach to social services. A necessary sign of innovation is scientific and technical novelty and industrial use. According to the modern international standard enshrined in the documents of the European Commission, innovation is seen as the end result of creative activity, embodied in the form of the latest or improved products sold on the market, or new or improved technological process used in practice [79-80,86].

4.3 Classification of innovations in the energy sector by types and degree of novelty

To establish the value of a particular innovative product, service or process, to identify the degree of its impact on production efficiency, changes in society, as well as for comparative qualitative and quantitative assessment of innovations, their classification is important. There are different views on the classification of innovations, depending on the features and criteria used as a basis for typology.

When considering innovations, the spread of which is possible in the energy sector, the types of innovations and the degree of their novelty were chosen as the basis of the typology.

4.3.1 Classification by types of innovations

In international practice, the classification of innovations based on the "Oslo Guide" is used [79-80,86]. It distinguishes four types of innovation: product, process, marketing and organizational.

Product innovation is the introduction into use (introduction) of a product or service with new or significantly improved properties or methods of use. *For example, significant improvements in specifications, composition or materials, the availability of firmware, improvements in ergonomics and ease of use, or other functional characteristics.* Product innovations ensure the maintenance of the main factor of competitiveness in the modern market, ie the level of product innovation. They form the company's position in the external environment, in the consumer environment. Product innovations as a method of differentiation are characteristic of the stage of specialization, when innovations allow to distance oneself from the pressure of leaders on price. Product innovations are most tangible from a domestic point of view, because they appear to the consumer in the form of a new or improved product, this is something that relates to material production or production. Product innovations dominate the high-tech sector, such as the automotive and aerospace industries, the production of electrical machines, renewable energy technologies, SMART devices and SMART technologies, the manufacturing industry, the medical device industry, and more.

Process innovation is the introduction of a new or significantly improved method of production or delivery of a product. Basic production technology and business processes are formed and modernized by investing in process innovations. This includes significant changes in technology, production equipment and (or) software. Process innovations as a method of increasing productivity and reducing costs are relevant in the consolidation of the industry, company or enterprise at the stage of "growth", when major market players are struggling to minimize price and cost, seek to capture maximum market share. Economically process innovation is revealed as a new way of arranging productive forces, objects and tools. A significant share of process innovations is observed in low-tech industries: metallurgy, textile production, woodworking, mining and more. The category of process innovations also includes the service sector, for example, a new method of cargo delivery, the provision of consulting services improves processes that do not relate to the material component; introduction of ICT systems; digital technologies; system software, application software for market players, etc.

Product and process innovations are combined into a group of **technological innovations** for the key investment sector of the economy - industry.

Marketing innovation is the introduction of a new method of marketing, including significant changes in the design or packaging of the product, its placement, marketing or destination chain. Marketing innovations strengthen and promote the company's position in the external environment by finding optimal ways to communicate with its customer. Marketing innovations are gaining importance due to the decline in the effectiveness of commercial communications, traditional for the late twentieth century: advertising, direct mail, industrial exhibitions, direct sales, workshop and other tools. A defining feature of modernity is the growing role of the Internet in domestic and professional communications, especially the segment of social networks (Facebook, etc.), as well as the growing demands of consumers to technical aesthetics in all areas of consumption. Marketing innovations are implemented at the stages of "growth" and "specialization" of innovation, but with different goals. **At the stage of "growth"** develop mechanisms for market penetration and retention within the objective purpose of the stage - to maximize market share. **At the stage of "specialization"** marketing innovations are considered as tools for product differentiation due to the original technical aesthetics, appearance, design. Today, marketing innovations are becoming a key tool for market development in both the traditional consumer and industrial sectors.

Organizational innovation is the introduction of a new organizational method in the business practice of the enterprise, in the organization of jobs or external connections. Organizational innovations ensure the sustainable development of the enterprise through continuous optimization of the organizational structure and management system of the enterprise. For the purpose of sustainable development the enterprise should realize all kinds of innovations in the proportions defined by type of branch. Organizational innovations are effective in a period when the potential of product and process innovations is exhausted - the technology platform loses relevance under the influence of new discoveries and inventions. They allow you to optimize the management system, reducing overhead costs of the organization, while maintaining its profitability. Organizational innovations have been highlighted recently, but investment in them is becoming relevant in the context of interest in cognitive and information technologies, which open the potential to increase productivity, increase the efficiency of organizations, management systems of enterprises and organizations. One of the important features is the level of novelty in innovation. This level shows the knowledge that is embodied in the innovation. There is a common view of two levels of novelty.

4.3.2 Classification of innovations by degree of novelty

According to the depth and comprehensiveness of changes, the impact on the nature of the innovation process and the degree of risk, there are basic (radical) and improving innovations, as well as pseudo-innovations [79-80].

Basic (radical) innovations are innovations based on new knowledge, created on the basis of knowledge of new laws and patterns, which can radically change various activities of society. Basic innovations require a full cycle of research and development work and the availability of a developed base to perform a significant amount of applied NDDKR. The introduction of basic innovations requires the restructuring of a number of related industries, the introduction of new methods of organization of the production process, labor organization, management structure, they change the activities and life of society as a whole.

Improving innovations are innovations that are created on the basis of already existing knowledge and known laws and principles, which are aimed at improving existing products and technologies. Improving innovations promote the development of new generations of already known products with improved quality characteristics or known products with qualitatively new properties.

Pseudo-innovations are innovations that are involved by firms in a technological process or product in order to delay the decline in profits and extend the life cycle of goods. Pseudo-innovations are aimed at changing the design of the product, the ways of its packaging or packaging to attract the attention of the consumer, to create a certain emotional state. Such innovations are carried out in the process of operational management of innovation activities and do not require significant investment.

There are also other classifications, including multicomponent, which distinguish the species according to 8-16 criteria. But at the same time they are more scientific in nature to express or emphasize the specifics of innovation in a particular industry or national innovation system.

4.4 Existing obstacles to the functioning of the DAM market in the context of liberalization and ways to address them

Speculation and manipulation. Electronic bidding provides an opportunity to speculate. The consequence of such actions is the failure of electricity prices and an increase in market imbalances.

An example of such manipulations is the recent situation at DAM on October 19-25, 2020. There was a significant reduction in the price of electricity due to a sharp reduction in electricity purchases on the market for the day ahead. "

The situation has been exacerbated by the emergence of additional volumes of electricity from trading companies. These companies sold electricity at discounted prices, which led to an immediate reaction from other sellers to lower bids.

Such an anomalous fall in market prices is usually due to the behavior of large market participants, who artificially regulate market demand "day ahead", which allows you to manipulate prices.

Large-scale speculation is quite systemic. Therefore, in order to reduce market abuse "24 hours a day", PR should make observations at a very high level. The market operator should take measures to minimize market risks and control all processes so that manipulations do not occur. To regulate the MO process, systems should be introduced to regulate all processes. Thanks to such systems, high-quality market monitoring is carried out.

Settlement procedure. It is known that to conduct a transaction for the purchase or sale of electricity, you must have the appropriate amount of funds in the account. The current account changes after each such transaction. The solution to avoid multiple penalties from bank commissions and reduce the single price of commodity transactions on DAM and IDM is the introduction of clearing and netting.

According to the Strategic Development Plan of the Market Operator, one of the short-term goals is the introduction of netting and clearing settlements. These are financial methods for recalculating mutual settlements and requirements.

Therefore, the advantages of the new system are:

1) reduction of accounting (fewer payment orders);

2) accelerating the turnover of funds in the electricity market;

3) reduction of the total cost of all operations in the markets of DAM and IDM;

4) reduction of the bank commission during the purchase and sale of electricity.

The next stage of SC "Market Operator" is the introduction of such calculations in related markets, such as natural gas, coal, etc.

Transparency and availability of data. The need for continuous operation of the DAM and IDM markets 24/7 creates the need to implement high requirements for server equipment in terms of reliability. To perform this task, you need to create a data backup and a high-quality software service.

The PR should provide all the conditions for regular and uninterrupted bidding, provide timely information on prices and volumes of electricity on the DAM , ensure maximum simplicity and availability of data.

Since July 2019, SC "Market Operator" publishes daily information on operating activities, financial indicators, and socially important events on the official website of the company www.oree.com.ua, Prozorro and other open platforms. In accordance with the Rules of DAM and IDM, the price and volumes of purchase and sale of electricity for each settlement period are published based on the results of the auction. Daily, decadal and monthly in-depth analysis of the work of DAM and IDM is also published.

Large producers are obliged to report all events (accidents, repairs of generating equipment) in order to purchase the necessary amount of electricity for consumers in advance.

The solution to this issue is to regulate the market at the legislative level, the introduction of such a new law as, for example, for heat generation. The National Commission for Regulation of Economic Competition has obliged the heat producer to notify Ukrenergo of coal residues, the specific cost of electricity generation, equipment repairs, etc. In the event that heat producers submit their applications for BAM with larger volumes than the actual fuel capacity available, Ukrenergo rejects the registration of such applications.

Therefore, the market must be filled with the maximum amount of data to prevent obstacles to the functioning of the entire market.

***Efficiency and continuity of the trading system*.** The introduction of high-quality uninterrupted information systems (platforms), timely and proper support by development companies and the provision of their own reliable infrastructure is the key to the smooth operation of the trading system.

Because accidents and interruptions in work lead to the impossibility of buying and selling electricity in this segment.

Conclusions on the fourth section

Increasing (improving) process innovations in the form of software for forecasting the wholesale price of electricity at DAM using hybrid forecasting models will increase forecasting accuracy and reduce the impact of risks for economic agents who are participants in this market segment.

The proliferation of such software for forecasting the wholesale price of electricity on DAM as a service for players in this segment of the electricity market will increase the ability of companies to effectively manage risks in conditions of competition in the electricity market.

Based on the study, it was determined that in the context of reforming the energy sector of Ukraine and the introduction of a competitive electricity market, the following proposals for innovative developments can be provided. A promising innovation direction is the introduction of incremental (improving) product innovations in the field of digital technologies and application software. For electricity market participants, the most attractive are innovative solutions for the provision of services using software for forecasting the wholesale price of electricity at DAM.

CONCLUSIONS

According to the results of the research conducted within the framework of undergraduate practice on the formation of the wholesale price in the segment of the electricity market "day ahead market" (DAM) and the implementation of the objectives of the practice, the following conclusions can be drawn.

1. The study of the regulatory framework of Ukraine on the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM showed that starting from 2019 to ensure the functioning of a competitive wholesale electricity market since the introduction of a new model of the electricity market . Regarding DAM during this time, the principles of organization of purchase and sale of electricity at DAM by the state enterprise "Market Operator" were determined. There is a significant improvement in data disclosure compared to previous market models. DAM is the most transparent segment of the electricity market in Ukraine: data are published regularly and there is regular reporting. There have also been changes in the regulatory framework regarding the procedure for determining the price of electricity and the volume of purchase and sale of electricity at DAM. In particular, normative and legal documents concerning the rule of determining the cost of electricity sold at DAM by a participant of DAM/IDM have come into force. A number of legal documents have been adopted on the special responsibilities of electricity market participants to ensure the public interest. However, despite the existence of regulatory changes, the existing mechanism of special obligations restricts competition, imposes restrictions on state-owned producers and allows private companies to take advantage of imperfections in the DAM and IDM Rules. Household consumers, regardless of their income, do not pay the full cost of electricity. The difference between the market price and the price for household consumers makes it possible to obtain volumes of electricity declared for the population at a price below the market price.

2. The study of the existing methodology and methods of forecasting models of wholesale electricity prices on DAM showed that the development of tools for short-term forecasting of wholesale electricity prices on DAM can minimize the risks of buying and selling electricity for the day ahead, providing better forecasts at the system level. Various methods and ideas have been tested to forecast electricity prices, so there is a wide range of forecasting models that are currently used in liberalized electricity markets in different countries with varying degrees of success in order to obtain the highest possible forecast accuracy. When classifying approaches to modeling the forecast of the price for the electric power conditionally define six classes of models: multiagent models, fundamental (structural) models, quantitative stochastic models, statistical models and methods (econometric models), models on the basis of artificial intelligence, machine learning, (nonparametric, nonlinear). statistical models), hybrid models. When forecasting the price of electricity at DAM, economic agents of a competitive market must take into account specific factors that affect the price and volume of production: seasonality; configuration of network objects; features of industry regulation; high barriers to entry into the industry; underdevelopment of derivatives.

3. Identification of open sources for the formation of a database of wholesale price statistics in the segment of the electricity market DAM showed that the best option for such sources is the data of the SC "Market Operator". To develop models for forecasting the wholesale price on the DAM electricity market segment and conducting a comparative analysis of the accuracy of the forecast, a statistical database on the wholesale price on the DAM electricity market segment was created according to the State Company Market Operator.

The generated statistical database consists of established indices and weighted average electricity prices. Indices are displayed in three time periods of the day: BASE, PEAK and OFFPEAK.

To create a statistical database on the wholesale price in the segment of the electricity market of DAM and hourly weighted average prices of purchase and sale of electricity on DAM, information on the results of DAM bidding was used according to the State Company "Market Operator".

The main factors influencing electricity prices were identified: price on fuels, weather conditions, supply, distribution and transmission, demand.

The most commonly used are autoregressive integrated moving average models (ARIMA).

In the field of time series analysis, the autoregressive (AR) model and the moving average (MA) model are one of the most used. The ARIMA model is a development of the ARIMAX model.

The rapid development of computational intelligence has brought new methods of short-term forecasting. They are based mainly on artificial neural networks (ANNs) and fuzzy systems, as well as on cluster methods and expert systems.

4. The Random Forest model was chosen for short-term forecasting. The input parameters were the time of day, day of the week, the variable that relates the current day to the weekend or holiday and the variable that relates the current day to the working day. Statistical data on such parameters as network load, outdoor air temperature, composition of the included generating equipment, river water content were not taken into account when forming the model, as they were absent.

As initial data we accept hourly dynamics of pricesfor electricity for the IPS zone of the electricity market of the day-ahead market (DAM price) for the period from September 1, 2020 to September 15, 2020, a total of 360 observations. The actual daily dynamics of electricity prices in the IPS zone from January 1, 2020 to September 30, 2020 were used to build a forecast model, and data for the period from September 1, 2020 to September 15, 2020, were used to assess its forecast results.

It was determined that the price of electricity on DAM during the day is higher compared to the night period, similarly, we can note the excess of the price of DAM on weekdays over this figure on holidays and weekends.

The MAPE error is less than 10% (6.67%), which confirms the qualitative forecast of electricity prices. The value of the MPE error is close to zero, is this prediction method is unbiased. The forecast offset is described as a tendency to overestimate the forecast value (the forecast is greater than the actual value). The mean absolute deviation, which estimates the value of the average absolute deviation of the actual and forecast values, is also quite small (0.77 UAH / MWh), which may indicate the implementation of a fairly accurate price forecast.

Another example of a short-term forecast is the ANN and ARIMA test models. All incoming were similarly divided into: time of the day, day of the week, sign "working (weekend) day". Data for the period from September 25, 2020 to October 2, 2020, were used to assess its forecast results.

A comparative analysis of the ARIMA and ANN test models showed that the ARIMA model is more accurate in this case for the short-term forecast. In this case, the calculation of errors could not be done due to inability to access all data.

5. The study of European experience regarding innovative approaches to overcoming obstacles to the functioning of DAM in the context of liberalization has shown that incremental (improving) process innovations in the form of software for forecasting the wholesale price of electricity on DAM using hybrid forecasting models will increase forecasting accuracy and reduce economic agents who are participants in this market segment. The proliferation of such software for forecasting the wholesale price of electricity on DAM as a service for players in this segment of the electricity market will increase the ability of companies to effectively manage risks in conditions of competition in the electricity market.

Based on the study, it was determined that in the context of reforming the energy sector of Ukraine and the introduction of a competitive electricity market, the following proposals for innovative developments can be provided. A promising innovation direction is the introduction of incremental (improving) product innovations in the field of digital technologies and application software. For electricity market participants, the most attractive are innovative solutions for the provision of services using software for forecasting the wholesale price of electricity at DAM.

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