Information System for Decision-Making in the Management of Renewable Energy Sources in the Microgrid System

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Abstract

The researches of scenarios of dynamic energy management in local Microgrid networks, the mathematical instruments which a used for realization of algorithms are carried out. Various elements of the intelligent system of cost-effective scheduling of energy islands with a photovoltaic source, as well as the mechanisms of electricity price formation using different generation sources in Microgrid systems are analyzed. The analysis of the architecture of information systems and software in the management of renewable electricity systems are carried out as well. The algorithm and software interface of the decision-making information system for managing alternative energy sources are developed. The design of a database and software that calculates the efficient distribution of energy to the user, forecasts the efficiency of certain energy sources, building in real-time graphs is described.

Keywords [1]

Electricity, alternative sources, effective management, decision making, information system,database, forecasting.

1. Introduction

Currently, power plants using alternative energy sources, such as solar power plants, wind power plants, are becoming more common. The growing penetration of stochastic and uncertain distributed energy resources, such as wind and photovoltaic, has a significant impact on the dynamics of the power system, which raises concerns about reliability and sustainability. This requires innovation in modeling, operation and management of the power system to address these new challenges. In addition, coordinated control between different devices usually relies on communication systems. Connected control and communication systems bring both opportunities and challenges for the future development of renewable energy systems. The use of intelligent energy management systems can reduce consumption and thus save money for consumers. The need for energy consumption must be met and some benefits can be obtained if you use specific optimization algorithms. Thanks to the efficient use of renewable sources and energy imported from the grid, intelligent and adaptive control systems are able to meet the load needs and minimize all energy costs associated with the studied scenario. Based on the idea of intelligent network (SMART-grid and Microgrid-systems), this study it is planned to develop an intelligent scheme of renewable resources management in combination with the battery, implemented using a dynamic database, forecasting methods and decision-making algorithm. Computer simulation in the form of system testing confirms the effectiveness of this approach.

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2. The state of the issue

In the article of Russian researchers [1] the basic approaches to creation of control systems of complexes of alternative energy sources are considered, and also the algorithm of management of forecasting of states is described. Its feature is forecasting the state of the complex of objects, dynamic optimization of equipment operation modes, in addition, the authors analyze the needs of thermal consumers. The paper performs numerical simulation of the algorithm and compares it with the cascade algorithm.

In 2012-2013, scientists of the Volga branch of the Moscow Energy Institute (MEI) under the leadership of prof. V.S. Kuzevanova created a unique landfill, which is also called a green research landfill [2]. It allows us to study the efficiency of electricity and heat sources (non-traditional and renewable). Energy in this project is produced by a set of alternative energy sources - solar modules and wind turbines, it is used for hot water production, heating, air conditioning and electricity. At creation of this complex the Master SCADA software was used, it allows to collect and process information from various devices, and then displays data on technological processes and a condition of the equipment on mnemonics of the operator with their subsequent registration and archiving in a database.

Ukrainian researchers from the Kyiv Polytechnic Institute have proposed a new approach to choosing the optimal structure and characteristics of energy sources for a combined power supply system of an industrial enterprise, taking into account the profile of its needs for different types of energy resources [17]. This approach is based on modeling the optimal operating parameters of the elements of the combined power supply system operating in the power hub mode. This approach allows to assess the cost-effectiveness of different options for the structure of the system and choose the best option. As a result, the optimal decision is made regarding the choice of energy sources for your own power supply system. This will reduce the energy intensity of industry in the face of rising prices for traditional energy resources.

The work of Ukraine researchers N. Kiktev, V Osypenko and others. [6] also applies to this topic and is devoted to the grouping of meteorological data for further use in the control system of alternative energy sources. In the work of N. Kiktev, N. Chichikalo, H. Rozorinov and others. [7] considered decision-making algorithms to ensure the required ash content of coal and the creation of an info-communication system for managing this process.

The works of Ukrainian scientists V. Kaplun and V. Osypenko [3, 6] consider the formation of a specific conditional dynamic tariff (CDT), which is an integral indicator depending on time, taking into account tariffs from both the general grids and renewable sources.

In [3] one of the approaches to solving the problem is presented, namely: intelligent modeling of dynamic energy management, strategies in polygeneration micronetworks using different elements of electricity supply, inductive system-analytical technologies. Modeling based on the collected statistical data using an inductive algorithm was also performed. The results of this study can be used in electricity pricing processes for microgrids or for dynamic management of smartgrid with renewable sources. To model scenarios of dynamic energy management in micronetworks, data grouping using a bicluster analysis algorithm is used [3].

In [4], modeling was performed on the basis of collected statistical data, the results of which can be applied in the processes (algorithms) of electricity pricing for dynamic management of intelligent networks with renewable sources. The authors of this innovative approach imply the further application of the initial data of the model (optimal clustering) to dynamically estimate the total cost of energy generated by its own components, taking into account the cost of the network involved in subsequent periods of the day.

This article can be considered as a development of work [3, 6] in the direction of software development of the described techniques, namely - a dynamic database and user interface.

An article by MIT researchers M. Roozbehani, M. A. Dahleh and S. K. Mitter [4] proposes a structure for modeling and analyzing the dynamics of supply, demand and clearing prices in power systems with real-time retail prices and information asymmetry. The study involves the transmission of wholesale electricity prices in real time to end users. Real-time pricing creates a feedback loop between the physical and market levels of the system.

The article [5] presents the concept of smart buildings in the context of the decarbonization of the energy system. The authors do not focus on one specific energy carrier, it is about convergence, alignment and synchronization between heat and electricity on the one hand and the developing energy system on the other. It explored how individual buildings can profit from existing or innovative energy-saving technologies.

The work of Indian researchers [13] describes methodologies for modeling the components of hybrid renewable energy systems, the designs of such systems and their assessment.

At the Swiss Federal Institute of Technology, a new concept, the so-called Energy Hub, has been developed to solve optimal energy flow (OPF) problems for integrated energy systems with multiple energy carriers [14]. In this document, the Energy Hub model is applied to the OPF problem, given the availability of multiple renewable energy sources in the mixed consumption zone. The creation of the energy hub was also carried out by Chinese scientists from the State Key Laboratory of Power Systems Department of Electrical Engineering Tsinghua University (Beijing) in collaboration with researchers from Denmark and the USA [15], in particular, in the electricity and heat distribution markets. They proposed a new approach - a mathematical model of equilibrium constraints (MPEC) program to study the strategic behavior of a profit-oriented energy center in the electricity and heat market against the background of grid integration.

Scientists from Iran and Spain presented a two-level model of the stochastic programming problem (BSPP) of decision making by an energy hub manager [16]. The two-level circuit is converted to an equivalent single-level circuit using the Karush-Kuna-Tucker optimality conditions, although there are two bilinear products related to electricity and heat. The bilinear product of heat is replaced by the heat price curve, and the bilinear product of electricity is linearized using the strong duality theorem. In addition, the notional value at risk is used to mitigate the adverse effects of uncertainties.

An article by British and American researchers [17] is devoted to the problem of managing the energy imbalance in the microgrid. The problem is investigated from the point of view of the electricity market. The study proposes a new pricing scheme that provides resilience to this intermittent supply of power. The proposed scheme takes into account possible uncertainties about the marginal benefits and marginal costs of the electricity market.

In the work of the Italian researcher P. Siano [18], an overview of smart electric grids is considered, which can deliver electricity in a controlled and intelligent way from generation points to active consumers. Demand Response (DR), by fostering customer engagement and responsiveness, can offer a wide range of potential benefits for system operation and expansion, as well as for market efficiency. This study examines the energy management system at the local level. The main task is to create information technology that could select such scenarios and provide recommendations for the most efficient use of a particular energy source in real time. Modern possibilities of using combined energy systems (COM) for local facilities with an installed capacity of up to 15 kW are based on the use of several sources (traditional and renewable with energy storage), including the main network (MN).

The mathematical apparatus that can be used for decision making and control in energy facilities is described in [12, 19, 22-25]. In particular, the method of group accounting of the relative advantage of alternatives in decision-making problems is proposed by Yu. Samokhvalov [12].

Some problems of intellectualization of decision support systems for smart electrical grids and in the design of others have been considered in in articles by scientists from Jordan and Iran [21, 25]. The research of scientists from Taras Shevchenko Nationality University of Kyiv is devoted to the choice of alternatives in decision-making. The article [19] considers the form of forming the procedure for the dynamic equilibrium of an alternative in a multi-agent environment when making decisions by a majority of votes on the basis of Markov chains. The derived method for the formation of matrices "state - probability of choice." was described The proposed model includes several parameters, one of which affects the spread of values between the best and worst values, and the other is the degree of agent's decisiveness. The Markov chain is used to model changes in agents' preferences.

A number of scientists have been involved in mathematical support of renewable energy sources. Researcher from Cairo (Egypt) Hussein. A. Attia compiled a mathematical formulation of the demand management problem (DSM) and outlined the ways of its optimal solution [22].

3. Statement of the problem

The purpose of this study is to create an information and control system for the implementation of the algorithm for the most efficient use of all possible energy sources in the microgrid system.

Research objectives:

- determine the input and output information on the management of renewable energy sources;
- using previous research to develop an algorithm for determining the most efficient source of electricity;
- to create a dynamic database of electricity parameters for a certain period of the year;

- using forecasting methods to estimate the cost of using different types of electricity sources for the next period;
- issuing recommendations to the user to determine the source that should be used in a certain period of time.

4. Materials and methods

Research is based on mathematical methods, modeling of energy processes, as well as the use of modern information technology for information processing and decision making. The study was based on the idea described in the works of Ukrainian scientists V. Osypenko and V. Kaplun [3].

This innovative approach can be applied in the future in complex energy systems. The results of this project can be widely and effectively used in small energy facilities (farms, cottages, industrial plants)in climatic zones with different natural conditions, which involve the use of solar energy, wind or other sources of distributed generation, forming combined systems.

To control the production, accumulation and consumption of electricity in microgrid systems, a deterministic daily schedule of electricity consumption is compiled from several sources - external power system, wind and solar power plants, static sources with energy storage and autonomous power plants with an internal combustion engine. They use management principles based on a conditional dynamic tariff [3].

4.1. Calculation of electricity indicators.

The formula for calculating wind energy [1]:

$$P = \frac{kRV^3S}{2} \tag{1}$$

Here k is the efficiency of the turbine, which takes into account the impossibility of installation at 100 %; R - air density, kg / m^2; V - wind speed, m / s; $S = \pi D^2 / 4$ - wind flow area, m². Formulas for calculating solar energy [1]:

$$E_1 = \frac{E_2 P_1 y}{P_2} \tag{2}$$

where E_1 - energy production using solar panels;
E_2 is insolation per square meter;
P_1 is rated power of the solar cell;
η is the total efficiency of electric current transmission;
P_2 is maximum solar power per square meter of the earth's surface.

The calculation of the cost of generated electricity is carried out according to the formula for the specific dynamic tariff [3]:

$$CDT = \frac{C}{P_t} \tag{3}$$

where P - the amount of energy produced;
C - the cost of maintenance of the wind or solar panel;
t -the number of time intervals.

Table 1 shows the formation of the initial conditions for calculating the efficiency of using certain energy sources and the formation of a database. The formation of the numerical results of the efficiency of using wind generators and solarbatteries is presented in table 2.

Decision-making on the use of this energy source is carried out in accordance with the formula:

$$Dec = \{R, C; CDT \rightarrow min\}$$

where R is the amount of energy produced;

C is the ability of the system to satisfy the consumer;CDT is the cost of electricity. It is proposed to use the ARIMA model to analyze and predict time series data. It will be better than other methods to be able to track daily trends in the distribution of energy from its sources, which will allow you to more accurately predict increased loads and level them during peak hours.

Table 1

Formation of conditions reports

Field name	**Report number**	**Time**	**Air density**	**Wind speed**	**Activetime**	**Fuelcost**	**Fuelcost**	**Consumerenergy**	**Day**
Notation	#	t	R	V	ta	η	$	P	day
Units of Measure	Integers	Minu-tes	kg/m2	m/s	Minu-tes	Ratio	USD	W	day
Limits	1-∞	0:00-23:30	200-2000	0-100	0-30	0.00-1.00	0-100	0-10 000	1-31
Task	Automatically by database	Determined by recording time	Measured by hydrometer onobject	Measured by anemometer onobject	Measured by pergeliometerofsolar panel	Determined by the angle of thepanel	Taken from the market value offuel price	User-defined	Record time

Table 2

Formation of efficiency results of wind and solar generators

Field name	**Total number ofthe result**	**Wind generator result number**	**Time**	**Day**	**the amount of energy produced**	**Cost of electricity**	**Decisionmade**
Designation	#	#	t	day	P	CDT	Dec
Unit of measurement	Integers	Integers	Minuts	Days	W	USD	A set of possible solutions
Limits	1 - ∞	1 - ∞	0:00-23:30	1-31	0-10 000	0-100	Used, saved
Tasks	Automatic ally bydatabase	Automatic ally bydatabase	Determi ned by recording time	Deter-mined by recording time			Dec = {R,C;CDT→min}

ARIMA model - is expressed by the equation [19]:

$$Y_{t-1} = \beta_1 Y_{t-2} + \beta_2 Y_{t-3} + \ldots + \beta_0 Y_0 + \varepsilon_{t-1}$$

where, Y_{t-1} is the lag of 1 row, β_1 is the lag coefficient 1, which estimates the model, and βp is the interception time, also estimated by the model.

ARIMA model in words:

Predicted Y_t = Constant + Linear combination Lag from Y (up to p lags) + Linear combination of lagging forecast errors (up to q lags). The decision-making algorithm of the renewable energy management system is presented in Fig.1.

4.2. Database architecture

Among the most typical databases (MySQL, PostgreSQL, MongoDB, Microsoft SQL Server, SQLite) implementations differ in the organization of data at different levels. Currently, SQLite is the most used database in the world, it will be used during the task. SQLite is a C-language library that implements a small, fast, stand-alone, highly reliable, full-featured SQL database engine.

The structure of the database of the management system of renewable energy sources includes 9 tables:

1) Handbook of wind turbines;
2) reference solar panels;

3) handbook of diesel generators;
4-6) results of calculations of electricity and its cost for wind turbines, solar panels and diesel generators;
7) initial conditions;
8) general dynamic database;
9) forecast for the next period.

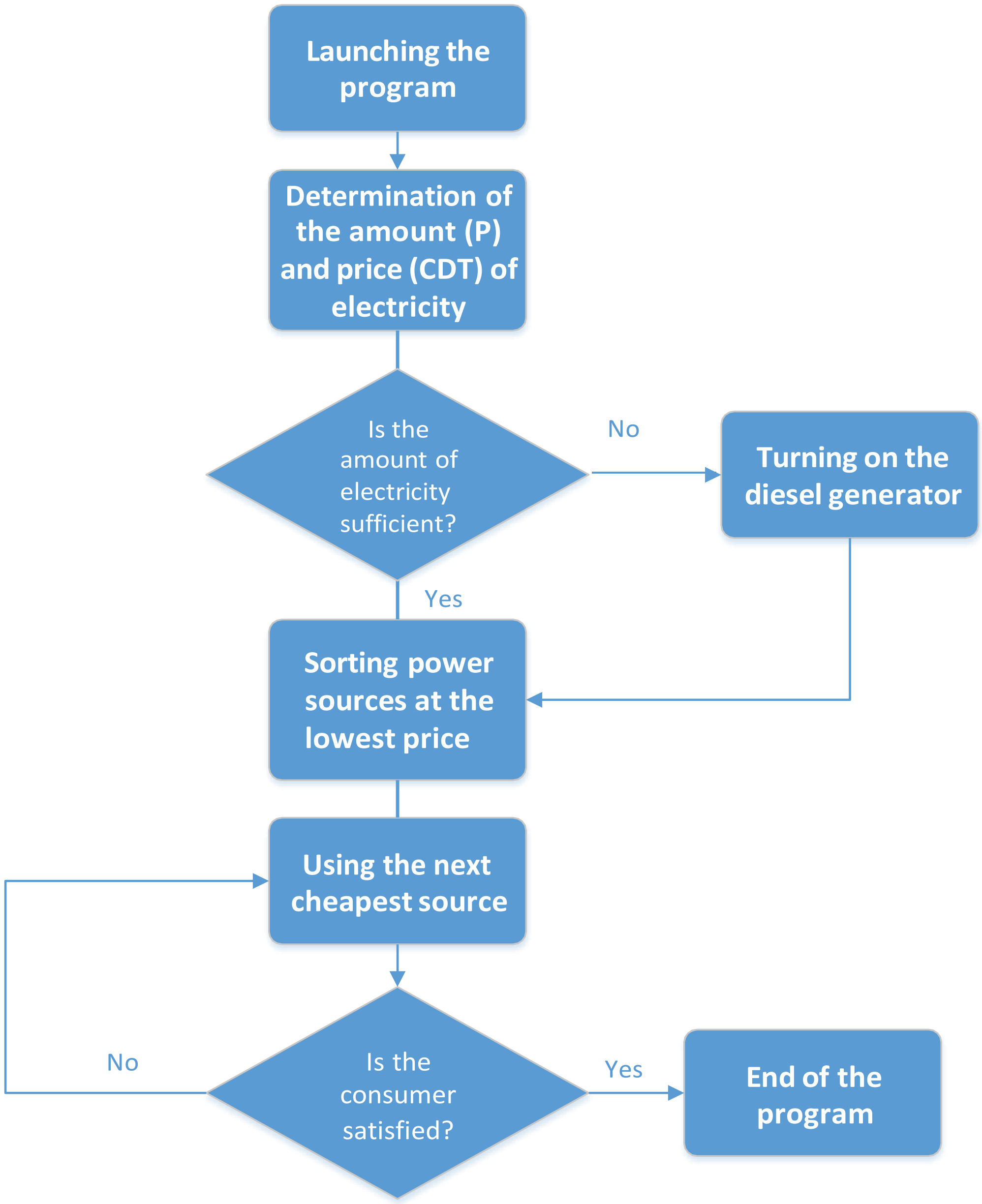

Figure 1: Block diagram of energy use decision making

To demonstrate the system and user convenience, a graphical interface of the software application was created using html with javascript and python elements (fig. 2). This form contains buttons, each of which is responsible for part of the functionality used.

4.2. Software application development.

To develop the software product used:

- object-oriented Python programming language;
- PyCharm environment;
- SQLite Server database management system.

The main modules that perform certain functions of the software application contain the prefix "main":

- main_client.py - interacts with the user interface
- main_graphics.py - builds graphs of calculated data
- main_output.py - displays the results of calculations to the user
- main_predict.py - performs forecasting
- main_sql.py - interacts with the database
- main_system.py - performs basic calculations of the software application

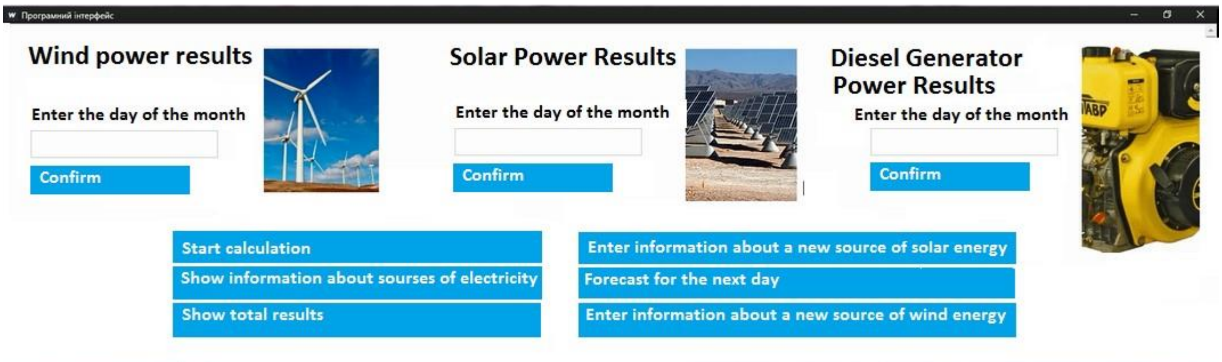

Figure 2: The form of the graphical interface

4.3. Testing the system.

When you click on the "Start calculations" button:

- a system is launched that will calculate the generated electricity;
- the source of energy which will be used first of all is chosen;
- it is determined whether there is enough energy to meet the needs of the user;
- if necessary, the diesel generator is started.

After that, the residual energy will be transferred to the batteries for use in the next time period. All considered data are recorded in the database for further analysis. On the basis of the received data schedules for each executed day are constructed (for example, 1stday, fig. 3).

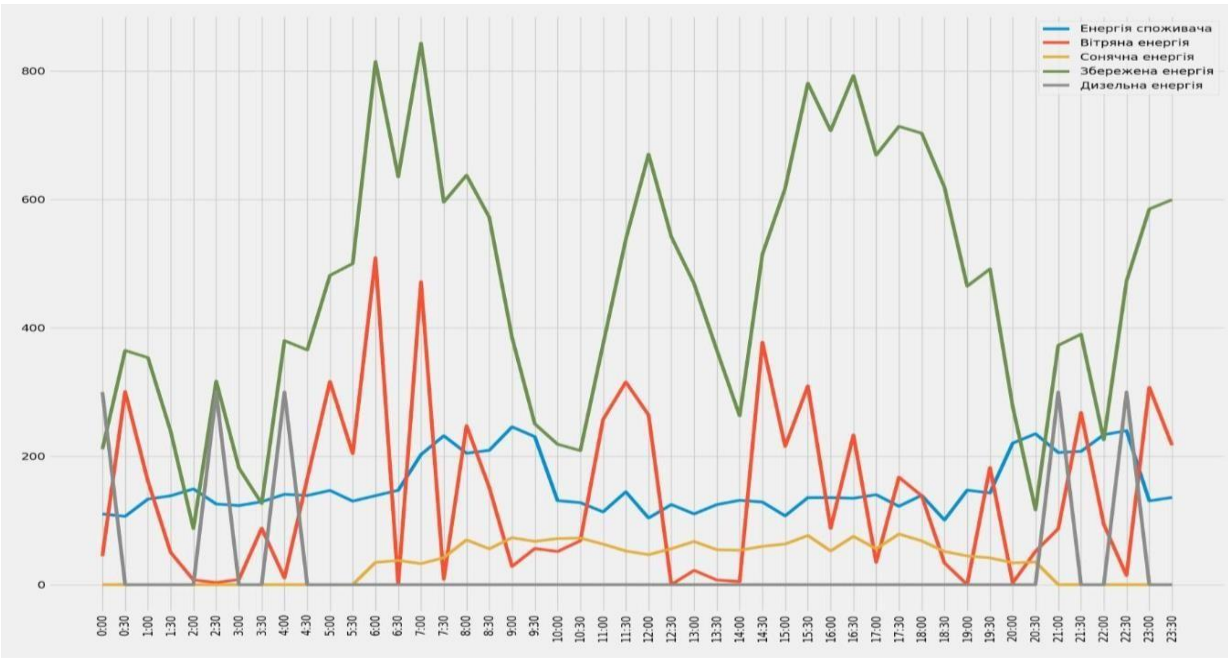

Figure 3: Schedule for the 1st day

The graphs show: blue - the required amount of energy to the consumer, green - the amount of energy on batteries, red - the energy produced by wind power plants, yellow - the energy produced by solar power plants, gray - energy produced by a diesel generator. Based on the results obtained, we obtain a graph of the price of each watt of energy for a wind farm (fig.4). The Solar Panel Results menu section displays the results of the calculations for each solar panel for a given day, where you can see the amount of energy produced, its price per watt of energy, and information about whether the energy was used by the user or stored on batteries. The menu section of the program "Forecast for the next day" based on previous results from the database displays the forecast based on the ARIMA model (fig. 5).

4. Results of the studies

The scientific novelty of this study is to use the ARIMA method to predict the cost of electricity produced by alternative sources, and to develop an algorithm for deciding on the use of a particular source of renewable energy. The practical value of the study is to create a dynamic database of technical and economic indicators of energy and combine it with the algorithm of decision-making and forecasting in a single software application.

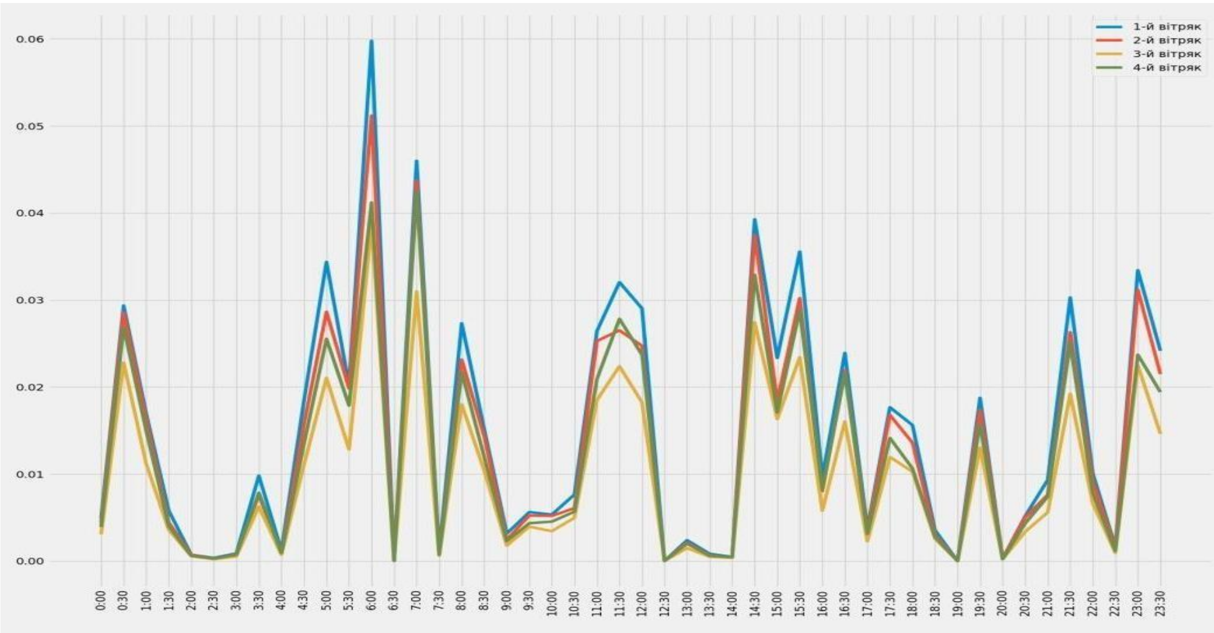

Figure 4: Schedule of the price of electricity for W

5. Discussion

The article examines the dynamic management of electricity using an intelligent component - decision making, this is an innovative approach to load management on the demand side by the criterion of the minimum cost of using a particular source in a given period of time.

This approach incorporates traditional energy management principles, representing all levels of energy distribution, integrating them into a structure for optimal demand management to reduce peak loads on the energy system. The study selected half-hour time intervals of samples for one day. Modeling based on the collected statistical data, the results of which can be applied in the processes (algorithms) of electricity pricing for Smart Grid dynamic management with renewable sources.

Energy storage technologies are identified as key elements for the development of electricity generation using renewable energy sources. In this study, they were illustrated through two cases of modeling, how they can help eliminate technical constraints that limit the contribution of renewable energy sources to electricity grids. Examples of the use of wind and solar energy are offered. The considered methods can be implemented in the real sector of photovoltaic power generation taking into account the preliminary processing of data on solar insolation and photovoltaic production. The simulation results are presented in a clear and easy to understand form of graphs and tables that demonstrate the effectiveness of the proposed method. Remote control of alternative power sources using the Internet of Things technology is also promising. To do this, you can apply the development of the authors of the article using this technology in the agricultural sector.

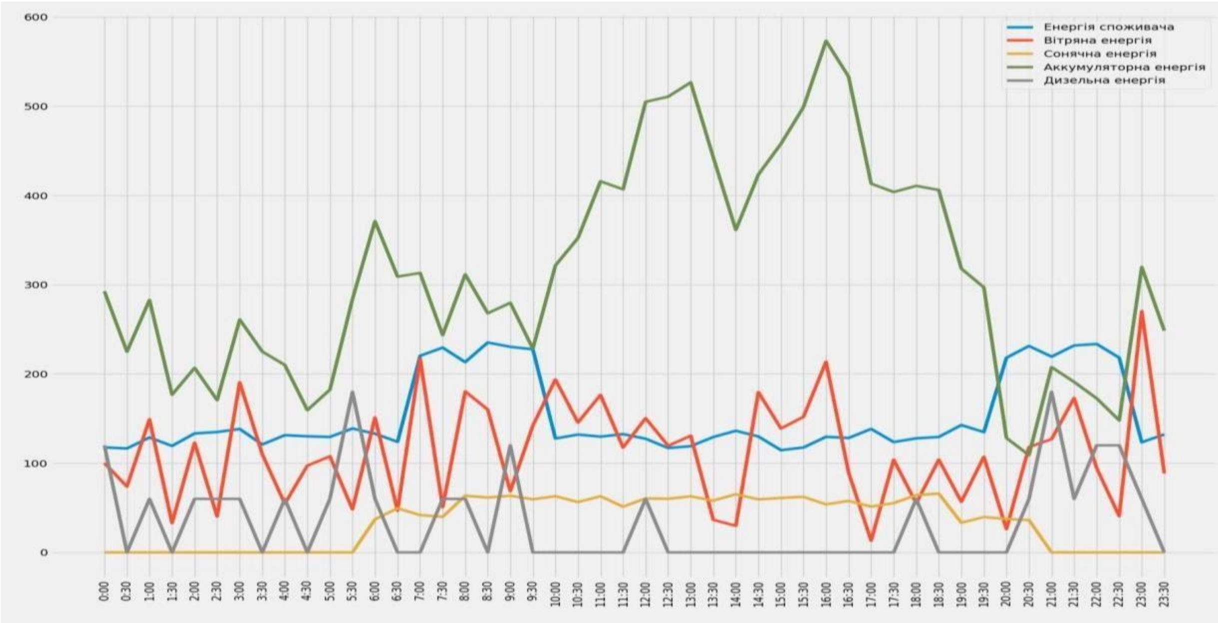

Figure 5: Forecast of energy use the next day based on preliminary data

6. Conclusion

The energy storage technology segment needs new solutions every day. Coming to the electric car market greatly contributes to such innovations. The aim of the article was to show that a dynamic approach to charge and discharge management at the energy storage system level provides good quality of service (energy efficient power reduction, power smoothing and uncertainty reduction) withreduced storage capacity. The results of this study allow further application of the initial data of the model (optimal clustering) to dynamically estimate the total cost of energy generated by its own components of the program, taking into account the cost of the network, in our case within one day. Further implementation of the research results will contribute to the improvement of mathematical and information support of decision support processes in the management of hybrid power grids. Further research can be aimed at improving the user-friendliness of the interface, the use of more efficient mathematical methods for grouping (clustering) data and forecasting technical and economic indicators.

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