ISSN 2786-7102 (Online), ISSN 2786-7633 (Print)
https://doi.org/10.15407/srenergy2023.03.050

UDC 621.3:519.8

Viktor Denysov*, https://orcid.org/0000-0002-3297-1114
Vitalii Babak, Dr. Sci. (Engin.), Professor, https://orcid.org/0000-0002-9066-4307
General Energy Institute of NAS of Ukraine, 172, Antonovycha St., Kyiv, 03150, Ukraine
*Corresponding author: visedp@gmail.com

SOFTWARE AND INFORMATION SIMULATION COMPLEX OF MULTI-NODE INTEGRATED AND AUTONOMOUS POWER AND HEAT SUPPLY SYSTEMS

Abstract. *A software and information complex for modeling multi-node integrated and autonomous power and heat supply systems is proposed. The main difference of the proposed software and information complex is the possibility of a detailed consideration of the influence of economic and technological parameters contained in the power system of individual power units and nodes. These parameters can be presented both in the form of matrices on the sheets of the software and information complex, and in the form of separate attached files available for automated input by the software and information complex. The main advantages of the complex, which distinguish it from the known ones, include versatility, which makes it possible to study various models of energy systems in a short time. This versatility is ensured by the fact that the complex is developed using a combination of standard Microsoft Excel software and SolverStudio – an add-in for Excel 2007 and later versions on Windows, which allows you to explore a variety of optimization models using a large list of optimization modeling languages. With the SolverStudio add-in in the information package, the user can develop, edit, save, and debug an optimization model in an Excel workbook. The connection of source data, sets, parameters, constants and variables used in the model is conveniently organized. After editing the parameters and source data, the model is launched. Simulation results can be displayed both on model sheets and displayed as separate files. Another advantage of the software and information complex is the ability to conveniently compare many models, due to the fact that each of the worksheets can have its own model. The developed software and information complex makes it possible to calculate in detail the energy, technological and economic indicators of the optimal use of power system components, to determine the permissible limits of the operating parameters of power units of autonomous and integrated power systems. The results of these calculations make it possible to select appropriate measures for the future renewal of technologies for the production of electric and thermal energy. The ease of use and editing of both individual parameters and program texts used in modeling the development of power systems improves the quality of the resulting development scenarios. The proposed software and information complex can be used to study the prospects for short-term and long-term development of Ukraine, as well as the energy system integrated with the power systems of neighboring ENTSO-E member countries, which is relevant in these conditions.*
Keywords: software, information, complex, multi-node, integrated, autonomous, power, systems.

1. Introduction

The field of digital and industrial technologies progress [1] has a significant impact on all sectors of the economy, including energy. They lead to a change in approaches to assessing and modeling sustainable development and renewal paths. The grave challenges of recent years have shown the need to increase the stability and flexibility of both technological development and the improvement of methods for forecasting and modeling the modes of operation and renewal of energy systems. Given the global digitalization trend, it is necessary to support the modeling of technological innovations in key sectors of industrial ecosystems while maintaining their ability to develop safely and sustainably. European Commission, in its document "Updating the New Industrial Strategy 2020: Building a Stronger Single Market for Europe's Recovery" [2], supported the European Green Deal and the Action Plan on the Circular Economy, as well as the digital strategies "Shaping Europe's Digital Future", "Data", "White Paper on Artificial Intelligence", "Digital Decade of Communication".

Energy systems have complex structures and contain a large number of elements. This leads to difficulties in modeling, researching and managing the modes of their components. To overcome these difficulties, complex multifunctional software is required, with the help of which the tasks of assessing the current state and predicting the optimal operating modes of power units should be solved. To solve the described problems, the authors [3] proposed a multi-agent approach.

The correct approach to determining the energy efficiency of complex energy systems is quite problematic and requires the use of specialized methods [4]. Energy efficiency can be understood as the most complete compliance of the technical and economic essence of the system with the requirements of the consumer. The organization of the system of energy efficiency indicators can be carried out both on the principle of "bottom up" and on the principle of "top down" with gradual aggregation or de aggregation of macroeconomic indicators determined at each level of the system.

In [5] an economic and mathematical model of the production type is proposed. The use of the model makes it possible to predict a balanced supply of carbon-containing fuels, electricity and heat from fossil fuels and renewable energy sources. The model is built on the basis of open data sources and, unlike known ones, uses subsystems for the production of abstract products. Selective aggregation procedures are also used to construct various forms of interproduct balance matrices.

Integrated power systems with multiple energy carriers [6] provide high efficiency of power supply to consumers. The possibility of transforming energy systems under the influence of internal and external factors contributes to the expansion of their technological integration areas and the wider use of integrated multi-carrier energy systems. To simulate such systems, the authors [6] proposed a concept and developed a simulation model of the power unit. The implementation of this simulation model is made using Matlab/Simulink. An example of the application of the simulation model is given. The simulation results demonstrate the possibilities and prospects of using the simulation model of the power unit.

The task of energy management ILES [7], taking into account the energy balance and technological limitations for the operation of each power unit, is aimed at realizing the system economic efficiency. Mathematical model for solving the problem of energy management given. The use of it makes possible to optimize operating costs.

The paper [8] emphasizes that the relevance of modeling energy systems is becoming increasingly important in the process of planning the implementation of the "energy transition". At the same time, it is necessary to take into account both the issues of cogeneration and the problems of regional and temporal coordination. While in many modern reviews, models are grouped by type or energy carrier, the authors offer a classification according to the quality of expert assessments. The advantages of a dynamic model of cogeneration of heat and electricity are analyzed, in combination with traditional and advanced control schemes.

In [9], the authors presented a recently developed model called MESS – Multi Energy System Simulator and their assessment of the advantages and disadvantages compared to the optimization model (Calliope [10]). They believe that using their simplified method for modeling energy systems at urban scales gives satisfactory results. The advantage is that the simplified approach allows many alternative scenarios to be explored in a relatively short period of time. At the same time, the authors acknowledge that with an hourly modeling step, the use of an optimization approach seems more appropriate.

Paper [11] shows that existing models are inadequate to address grids with a high percentage of renewables, and there is a challenge in integrating short-term temporal changes due to model complexity and computational cost.

Given the rapid growth in renewable energy production, the authors of [12] devoted their review to two types of energy storage (ES), taking into account the need for their widespread use to ensure the flexibility and resilience of power grids. They distinguish between storage devices that use direct and reverse energy conversion (e.g., heat and electricity) (GIES) to store energy, and those where this conversion is not used. From their point of view, long-term models of electric power systems (LEPSM) are limited to consideration of power systems with one type of ES without taking into account the GIES. The authors believe that:

– existing models are inadequate for networks with a high percentage of renewables and ES;

– there is a problem of integrating short-term time changes into LEPSM due to model complexity and computational cost.

The key feature of the new structure proposed by the authors is taking into account "agent-based modeling" of consumer behavior, thereby reducing the number of scenarios for the functioning of renewables.

All the above-mentioned works confirm the conclusion about the relevance of updating existing and developing new software and information complexes for modeling modern complex energy systems.

2. Software and information complex

The software and information complex (SIC) proposed in this paper is aimed at overcoming most of these difficulties. The main advantages of the complex, which distinguish it from the known ones, include versatility, which allows you to explore various models of energy systems in a short time. This versatility is ensured by the fact that the complex is developed using a combination of standard Microsoft Excel software and the SolverStudio add-in – an add-in for Excel 2007 and later versions on Windows, which allows you to explore a variety of optimization models using a large list of optimization modeling languages:

– PuLP – open-source COIN-OR modeling language based on Python;

– COOPR/Pyomo, which extends Pulp with abstract models, support for stochastic programming and a wider range of solvers;

– AMPL – modeling language that supports running models in the cloud;

– GMPL (GNU MathProg Language) – open-source analogue of AMPL, developed as part of the GLPK (GNU Linear Programming Kit). GMPL is part of SolverStudio;

– GAMS, – commercial modeling language;

– Gurobi, – commercial solver available in SolverStudio;

– CMPL, – an open-source COIN-OR modeling language.

– SimPy, – open-source Python modeling language that is included in the SolverStudio download.

Thanks to the presence of the SolverStudio add-in in the software and information package, the user can develop, edit, save and debug the optimization model in an Excel workbook. The connection of source data, sets, parameters, constants and variables used in the model is conveniently organized. It is possible to edit the parameters and source data, and then run the model. Simulation results can be displayed on model worksheets or output as separate files. Another advantage of the software and information complex is the ability to conveniently compare many models, due to the fact that each of the worksheets can have its own model.

The complex (Fig. 1) includes interacting blocks: service, control, information and analytical.

The *service unit* is designed to improve the convenience of working with SIC and user service. It includes internal interface and user interface programs, control and dialog forms, provides opportunities for: generating statistical reports on specified features, visualization of intermediate data, parameters of the current state, results of calculations on request in a form convenient for the developer and user.

The main functions of the *control unit* are to coordinate the processes of entering initial data, optimizing and monitoring the results obtained.

The *information block* is designed for collecting, storing and primary processing of data and includes a set of databases (DB) that provide permanent storage and replenishment of data necessary for the functioning of the SIC, supports standard data management functions:

– input and editing;

– organization of storage;

– connection (download) and disconnection (unloading) of databases necessary for modeling at the current stage of work.

The information block, in addition to storing elements of the working database, allows you to perform the functions of selecting modes and variable parameters of the optimization process.

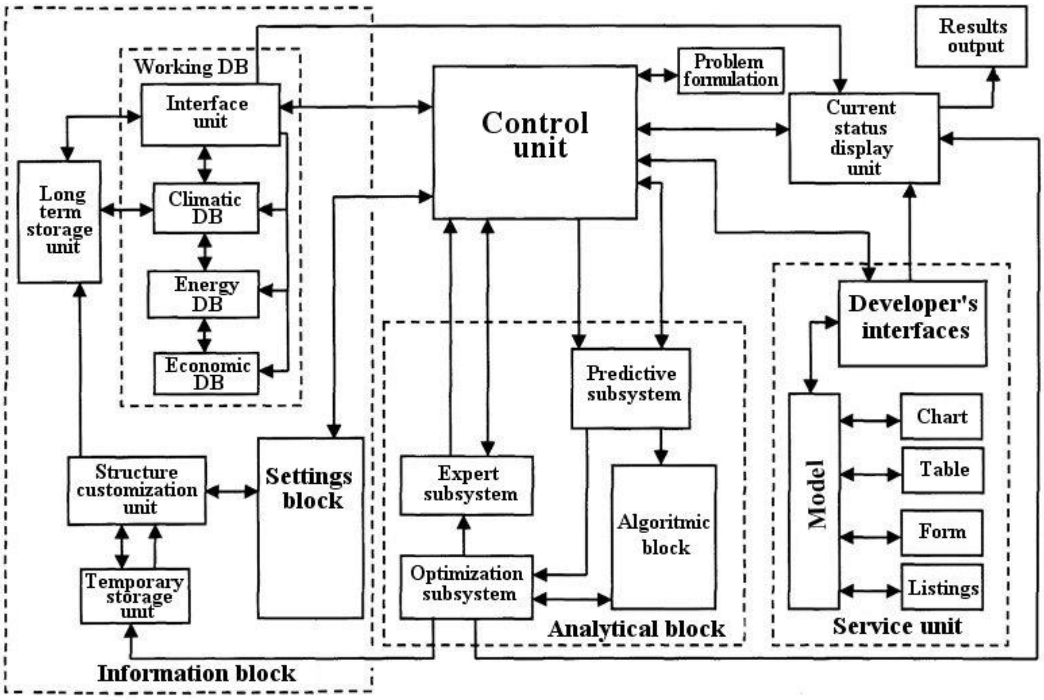


Fig. 1. The information and software complex's structure

The *analytical block* is designed to solve the problems of intelligent data processing and includes predictive and expert subsystems, as well as an optimization subsystem. The predictive subsystem allows estimating the consequences of different input effects on the hierarchical controlled energy system based on the scenario method. The optimization subsystem allows you to solve the problem of choosing the best control options under given restrictions.

2.1 Service unit

An example of the SIC title page with the dialog form of the service block is shown in Fig. 2. The dialog form of the service block (Fig. 3) allows you to select or modify possible the modeling process configuration.

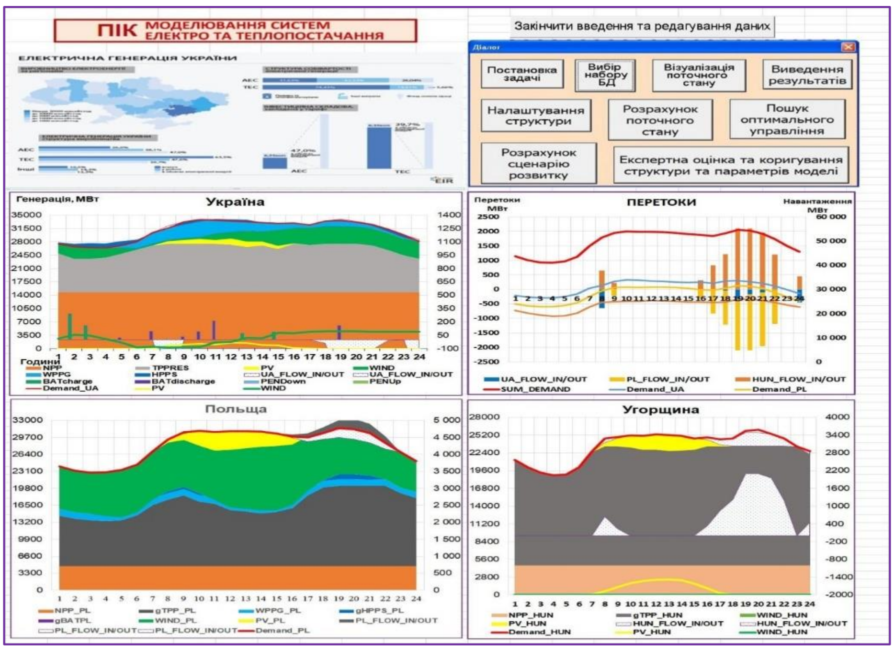


Fig. 2. SIC title page with the dialog form of the service block

Fig. 3. The dialog form of the service block

You can edit the model text and observe the optimization process using the panel (Fig. 4).

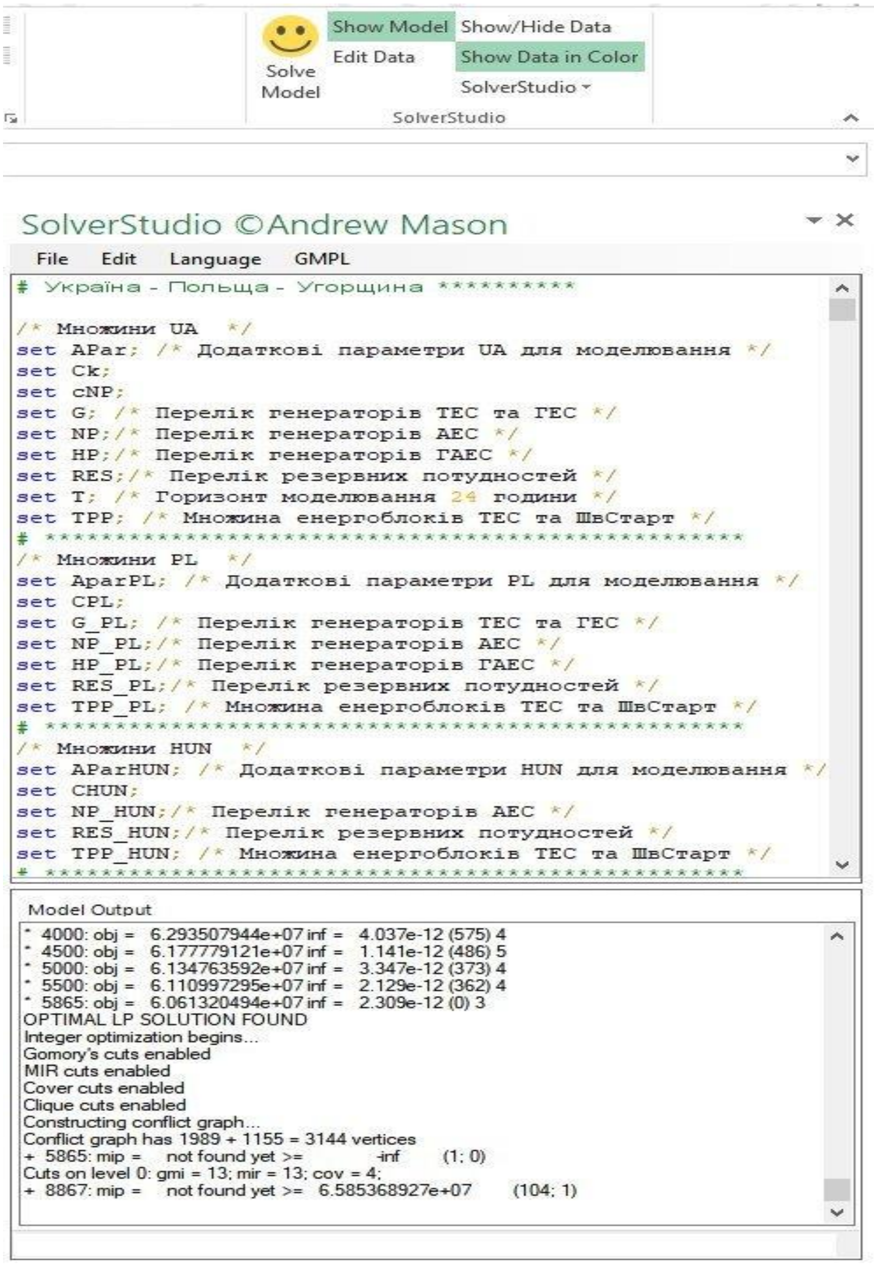


Fig. 4. Model text editing and optimization process observation panel

The parameters of the model processing program, which are specified with GMPL (GNU MathProg Language), if they need editing, can be changed using the form of Fig. 5. Or these parameters can be left unchanged if the user wants to leave the default values. For example, increasing the **mipgap** parameter, which determines how accurately a solution is found, can reduce the search time for an integer solution.

GMPLOptions	
cover	
clique	
gomory	
mir	
mipgap	0.05
m	

Fig. 5. Form for selecting the model processing program parameters

The parameters that are most often subject to change, for example, the modeling date, scaling factors and others, for ease of editing are placed in a separate form of parameters (Fig. 6).

Date	K_PV	K_WIND	MAX PV	MAX WIND
February 28, 2040	16.393	19.444	11000	7000

Fig. 6. Parameter editing form

In the form of parameters (Fig. 6):

– K_PV – PV generating capacity scaling factor for modeling forecast data;

– K_WIND – WPP generating capacity scaling factor for modeling forecast data;

– MAX PV – limitation of the maximum possible generating capacity of PV, (MW);

– MAX WIND – limitation of the maximum possible generating capacity WPP, (MW).

The service unit functions allow the developer to make changes to the optimization algorithms by changing the values and binary variables in the appropriate forms (Fig. 7). So, in Fig. 7a provides examples of import-export parameter management forms. Also on Fig. 7 presents the parameters for controlling the participation of power units of PSPs, HPPs, storage facilities and TPPs for redundancy and redundancy management using total generating and storage capacities.

In the form of parameters (Fig. 7, a):

– MaxImpPower – the maximum possible import capacity limited by the existing or projected capacity of power lines (MW);

– MaxExpPower – the maximum possible export capacity limited by the existing or projected capacity of power lines (MW);

– MinImpPower – the minimum possible import capacity, which is set by technological constraints, (MW);

– MinExpPower – the minimum possible export capacity, which is set by technological constraints, (MW);

– ImportPrice – unit cost of imported electricity, taking into account the market situation, ($ / MWh);

– ExportPrice – unit cost of exported electricity, taking into account the market situation, ($ / MWh);

– DailyBalanceExpImp – binary variable that determines whether the simulation will fulfill the condition: 1 – zero balance of flows, 0 – do not comply with the condition of zero balance of flows.

In the form of parameters (Fig. 7, b):

– EachHydroPump – binary variable that determines whether the simulation will fulfill the condition: 1 – each hydraulic unit of the PSP must be started once, 0 – the condition is not met;

– PumpGenBalance – binary variable that determines whether the simulation will fulfill the condition: 1 – each hydraulic unit of the PSP must use all the accumulated water for the current day, 0 – the condition can be ignored;

– MaxSumPumpPower – the maximum allowable level of power consumption for injection by all PSPs, (MW);

– MaxSumGenPower – the maximum allowable level of power generation by all PSPs, (MW);

– PumpGenOperate – binary variable that determines whether the simulation will fulfill the condition: 1 – cannot be simultaneously pumped and generated, if in a certain period of time the hydraulic unit pumps then all niches of the hydraulic aggregate cannot generate, 0 – it is possible;

– On_Off_HPPS_Reserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use PSP capacities in common redundancy, 0 – do not use;

– Include_HPPS_UpReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use PSP capacities in reserve for load, 0 – do not use;

– Include_HPPS_DownReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use PSP capacities in redundancy for unloading, 0 – do not use;

– Up_HPPS_ReserveLevel – the maximum possible capacity of participation of PSPs in reserve for load, (MW);

– Down_HPPS_ReserveLevel – the maximum possible capacity of participation of PSPs in reservation for unloading, (MW).

MaxImpPower	650
MaxExpPower	650
MinImpPower	0
MinExpPower	0
ImportPrice	200
ExportPrice	200
DailyBalanceExpImp	0

a)

EachHydroPump	1
PumpGenBalance	1
MaxSumPumpPower	1100
MaxSumGenPower	1100
PumpGenOperate	1
On_Off_HPPS_Reserve	**1**
Include_HPPS_UpReserve	1
Include_HPPS_DownReserve	**1**
Up_HPPS_ReserveLevel	3 500
Down_HPPS_ReserveLevel	**180**

b)

On_Off_WPP_Reserve	**1**
Include_WPP_UpReserve	1
Include_WPP_DownReserve	1
Up_WPP_ReserveLevel	**500**
Down_WPP_ReserveLevel	**250**

c)

On_Off_BUT_Reserve	**1**
BatteryBalance	**1**
BatChargePrice	**37**
BatDisChargePrice	**37**
DailyMaxStorage	**3 000**
Max_CHARGE_SumStoragePower	**680**
Max_DISCHARGE_SumStoragePower	**3 060**

d)

On_Off_TPP_Reserve	1
Include_TPP_UpReserve	1
Include_TPP_DownReserve	1
RampUp_TPP_ReserveLevel	**300**
RampDown_TPP_ReserveLevel	**200**

e)

On_Off_ALL_Reserve	**1**
Include_ALL_UpReserve	0
Include_ALL_DownReserve	0
RampUp_ALL_ReserveLevel	**1 000**
RampDown_ALL_ReserveLevel	**500**

f)

Fig. 7. Forms of the import-export parameters management. And also, the parameters for controlling the participation of power units of WPP, HPPS, storage facilities and TPPs in redundancy
a) import-export; b) HPPS; c) WPP; d) BUT;
e) TPP; f) total reservation

In the form of parameters (Fig. 7, c):

– On_Off_WPP_Reserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use HPP capacities in common redundancy, 0 – do not use;

– Include_WPP_UpReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use HPP capacity in reserve for load, 0 – do not use;

– Include_WPP_DownReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use HPP capacity in redundancy for unloading, 0 – do not use;

– Up_WPP_ReserveLevel – the maximum possible capacity of participation of hydroelectric power plants in the reservation for loading, (MW);

– Down_WPP_ReserveLevel – the maximum possible capacity of participation of hydroelectric power plants in reservation for unloading, (MW).

In the form of parameters (Fig. 7, d):

– On_Off_BUT_Reserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use the capacity of the drives in the general redundancy, 0 – do not use;

– BatteryBalance – binary variable that determines whether the simulation will fulfill the condition: 1 – battery charge must be greater than the discharge in the previous hours, 0 – battery charge must be greater than zero;

– BatChargePrice – unit cost of battery charge, ($/MWh);

– BatDisChargePrice – unit cost of battery discharge, ($/MWh);

– DailyMaxStorage – the maximum possible amount of charge-discharge of drives, (MWh per day);

– Max_CHARGE_SumStoragePower – the maximum possible total power consumed when charging the drives (MW);

– Max_DISCHARGE_SumStoragePower – the maximum possible total power given by all drives to the system (MW).

In the form of parameters (Fig.7, e):

– On_Off_TPP_Reserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use TPP capacities in general redundancy, 0 – do not use;

– Include_TPP_UpReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use TPP capacities when reserving for load, 0 – do not use;

– Include_TPP_DownReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use the capacity of TPPs when reserving for unloading, 0 – do not use;

– RampUp_TPP_ReserveLevel – minimum permissible capacity of TPP participation in load redundancy, (MW);

– RampDown_TPP_ReserveLevel – minimum permissible capacity of TPP participation in reservation for unloading, (MW).

In the form of parameters (Fig. 7, f):

– On_Off_ALL_Reserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use the power system capacity in redundancy, 0 – do not use;

– Include_ALL_UpReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use the power of the system when redundant for the load, 0 – do not use;

– Include_ALL_DownReserve – binary variable that determines whether the simulation will fulfill the condition: 1 – use the capacity of the system when redundant for unloading, 0 – do not use;

– RampUp_ALL_ReserveLevel – minimum permissible capacity of general reserve for load, (MW);

– RampDown_ALL_ReserveLevel – minimum permissible capacity of the total reservation for unloading, (MW).

Ways of displaying initial parameters and calculation results can be varied by editing the model text (Fig. 4). For the convenience of visualization of input data and the results obtained, respectively, the software blocks of visualization and output of results are responsible.

2.2 Information block

As mentioned above, the information block is designed for collecting, storing and primary processing of data and includes a set of databases (DB) that provide permanent storage and replenishment of data necessary for the functioning of the SIC. It supports standard data management functions: their input and editing; organization of storage; connection (download) and disconnection (unloading) of databases necessary for modeling at the current stage of work. Depending on the problem being solved, the type of power system to be modeled (electrical, thermal, autonomous, integrated), the necessary databases from the database set are connected or disconnected (Fig. 8).

TIME_ALL	DATE_ALL	DEMAND_ALL_PL	DEMAND_ALL_HUN	DEMAND_ALL_ROM	PV_PL	WIND_PL	PV_HUN
1392	27.02.2018 23:00	21106	5589	7779	0	0	0
1393	28.02.2018 0:00	20025	5333	7457	0	1935	0
1394	28.02.2018 1:00	19365	5049	7271	0	1888	0
1395	28.02.2018 2:00	19063	4840	7183	0	1879	0
1396	28.02.2018 3:00	19106	4731	7164	0	1987	0
1397	28.02.2018 4:00	19474	4762	7273	0	2150	0
1398	28.02.2018 5:00	20350	5058	7457	0	2168	0
1399	28.02.2018 6:00	22455	5675	7969	11	2178	13
1400	28.02.2018 7:00	24431	6184	8661	176	2205	75
1401	28.02.2018 8:00	25582	6252	9273	507	2138	169
1402	28.02.2018 9:00	25806	6306	9511	845	2147	252
1403	28.02.2018 10:00	25604	6297	9509	1061	2243	298
1404	28.02.2018 11:00	25759	6350	9366	1063	2611	327
1405	28.02.2018 12:00	25766	6322	9453	979	2752	335
1406	28.02.2018 13:00	25700	6296	9297	913	2882	313
1407	28.02.2018 14:00	25387	6191	9011	722	2893	243
1408	28.02.2018 15:00	24903	6227	8842	576	2739	143
1409	28.02.2018 16:00	24737	6161	8820	188	2470	37
1410	28.02.2018 17:00	25435	6192	8894	18	2383	2
1411	28.02.2018 18:00	26258	6497	9385	0	2452	0
1412	28.02.2018 19:00	26081	6537	9606	0	2497	0
1413	28.02.2018 20:00	25439	6374	9449	0	2348	0
1414	28.02.2018 21:00	23893	6183	9037	0	1946	0
1415	28.02.2018 22:00	22307	5875	8389	0	1604	0
1416	28.02.2018 23:00	20934	5686	7823	0	1404	0

Fig. 8. Element of the working DB, actual capacities (MW) of Poland, Hungary, Romania power systems

In Fig. 8 in the columns are displayed:

– TIME_ALL – hour number since the beginning of the year;

– DATE_ALL – date and hour.

The following columns reflect the actual hourly values [13]:

– DEMAND_ALL_PL – actual hourly load schedule of the EC in Poland;

– DEMAND_ALL_HUN – actual hourly load schedule of the Hungarian EC;

– DEMAND_ALL_ROM – actual hourly load schedule of the EC in Romania;

– PV_PL – actual hourly schedule of capacity of PV in Poland;

– WIND_PL – actual hourly capacity schedule of wind farms in Poland;

– PV_HUN – actual hourly capacity schedule of Romanian PV.

The information block, in addition to storing elements of the working database, contains matrices of economic, energy and climatic parameters of modeled power systems (Fig. 9–11). Changing the values of the elements of the matrices of economic, energy and climatic parameters allows you to perform the functions of selecting modes and parameters of the optimization process.

TPP	pTPP Units	pTPP InstCap	pTPP UnitMax	pTPP UnitMin	pTPP Unit Ramp	pTPP Unit Ramp Max	pTPP ProdCost	pTPP NumStart	pTPP MinUnits	pTPP MaxUnits	pTPP Time Operate
TPP800	1	800	750	500	20	100	55	1	1	1	24
TPP100	2	100	96	76	10	20	65	1	0	1	24
TPP150	2	150	139.5	96	10	40	63	1	0	1	24
TPP200	24	200	190	110	10	50	60	2	0	1	24
TPP300	22	300	280	175	10	100	58	2	5	12	24
FBCoal	0	1500	290	140	20	100	80	1	0	0	24
QSGas	0	0	9.43	0.1	9	9	95	1	0	0	24

Fig. 9. Matrix of economic and energy parameters of TPPs of Ukraine

In the columns of the economic and energy parameters matrix of TPPs of Ukraine Fig. 9:
– TPP – list of types of power units of TPPs of Ukraine;
– pTPP Units – number of power units of each type;
– pTPP InstCap – installed capacity of the unit, (MW);
– pTPP UnitMax – maximum possible power that the power unit gives to the system (MW);
– pTPP UnitMin – minimum possible power that the power unit gives to the system (MW);
– pTPP Unit Ramp – accepted for calculations permissible change in the capacity of a TPP power unit when it is operating (MW);
– pTPP Unit Ramp Max – the maximum possible change in the capacity of a TPP power unit when it is operating (MW);
– pTPP ProdCost – the cost of supplying electricity to the grid by a TPP unit, ($/MWh);
– pTPP NumStart – the number of starts of TPP power units during the day;
– pTPP MinUnits – minimum number of TPP power units involved in covering the load schedule;
– pTPP MaxUnits – the maximum number of TPP power units that can participate in covering the load schedule;
– pTPP Time Operate – the permissible number of hours of operation of a TPP power unit during a day.

NP	pNPP InstCap	pNPPT	pNPP ProdCost	pNPP MinUnits	pNPP MaxUnits
NPP1000	1000	24	22	3	13
NPP440	440	24	24	0	2

Fig. 10. Matrix of economic and energy parameters of NPPs of Ukraine

In the columns of the economic and energy parameters matrix of NPPs of Ukraine Fig. 10:
– NP – list of types of power units of Ukrainian NPPs;
– pNPP InstCap – installed capacity of the unit, (MW);
– pNPPT – number of hours of continuous operation of NPP units;
– pNPP ProdCost – the cost of supplying electricity to the grid by a nuclear power unit, ($ / MWh);
– pNPP NumStart – number of NPP power units starts during the day;
– pNPP MinUnits – minimum number of NPP power units involved in covering the load schedule;
– pNPP MaxUnits – the maximum number of NPP power units allowed to participate in covering the load schedule.

HP_number	HP	pP	pG	pHPGV	pHPPV	pHPT	pHPS	pHPVol
1	KHPS1	43	37	28.5	19	3	1	111
2	KHPS2	43	37	28.5	19	3	1	111
3	KHPS3	43	37	28.5	19	3	1	111
4	DHPS1	421	324	22.5	15	3	1	972
5	DHPS2	421	324	22.5	15	3	1	972
6	DHPS3	421	324	22.5	15	3	1	972
7	THPS1	216.5	151	25.5	17	3	1	453
8	THPS2	216.5	151	25.5	17	3	1	453

Fig. 11. Matrix of economic and energy parameters of HPSs of Ukraine

In the columns of the economic and energy parameters matrix of HPs of Ukraine Fig. 11:
– HP_number – serial number of the hydraulic unit of the HPS of Ukraine;
– HP – list of types of hydraulic units of HPSs of Ukraine;
– pP – power consumed by the HPS hydraulic unit in pumping mode;
– pG – power of the HPS hydraulic unit in generation mode;
– pHPGV – the cost of operation of the HPS hydrogenerator in the generator mode;
– pHPPV – the cost of operation of the HPS hydrogenerator in pumping mode;

– pHPT – number of hours of continuous operation of HPS hydraulic units in pumping and generating mode;

– pHPS – permissible number of starts of HPS hydraulic units in pumping and generating mode;

– pHPVol – maximum amount of energy that can be accumulated by the HPS hydraulic unit in pumping mode, (MWh).

2.3 Analytical block

Due to the joint use and interaction of the service unit, control unit and information unit, the user prepares a variety of information for the operation of the analytical unit. The analytical unit uses an optimizer built into the Solver Studio platform [14]. The optimization subsystem allows solving the problem of choosing the best options for controlling the power system under given constraints. After all the initial information is prepared, the user presses the button "Finish data input and editing" (Fig. 13) and the control unit forms a working data file and starts the optimization process. If the data is prepared correctly, the optimizer finds an analog solution at the first stage, and then, taking into account the integrity and binarity of individual variables, the optimal solution. The results of calculations are displayed by blocks of visualization and output of results on worksheets (Fig. 13–15) of the software and information complex. Otherwise, the optimizer displays a message stating that the solution does not exist (Fig. 12).

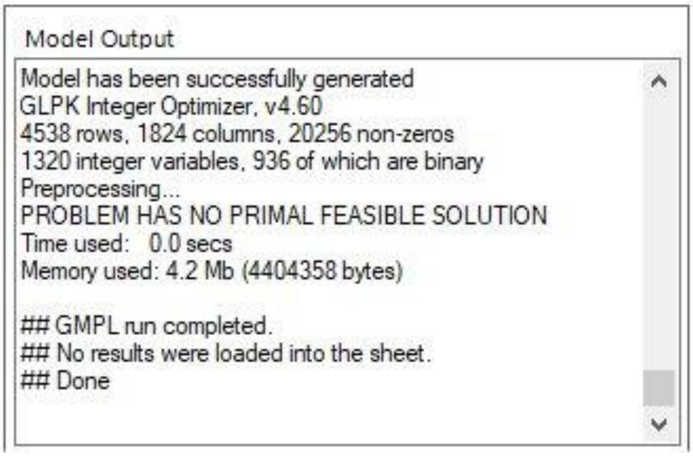
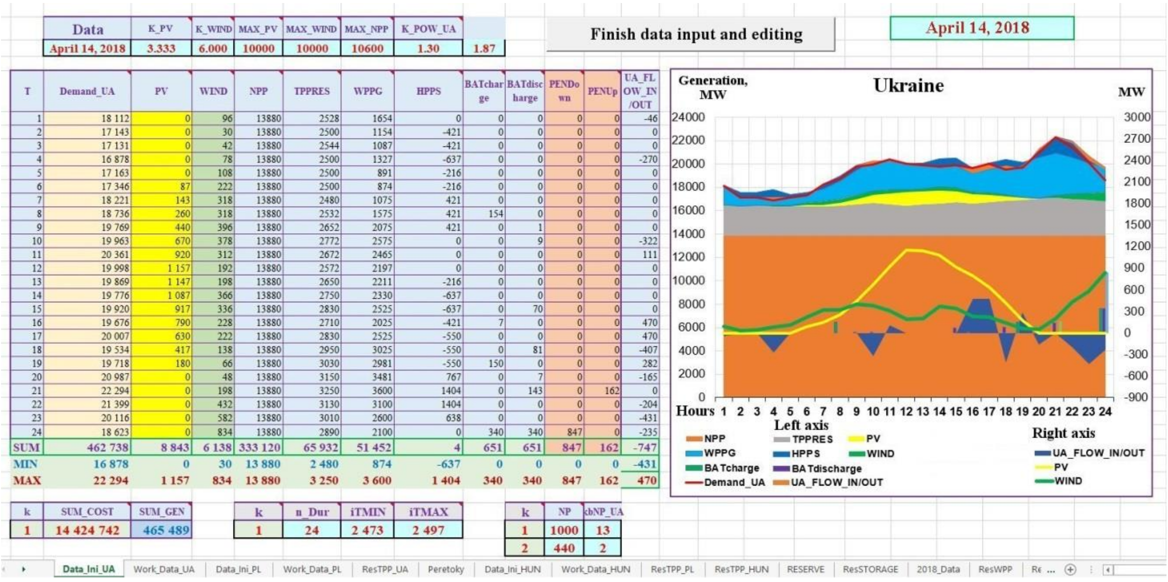


Fig. 12. Optimizer notification that a solution does not exist



Data	K_PV	K_WIND	MAX_PV	MAX_WIND	MAX_NPP	K_POW_UA	
April 14, 2018	3.333	6.000	10000	10000	10600	1.30	1.87

T	Demand_UA	PV	WIND	NPP	TPPRES	WPPG	HPPS	BATcharge	BATdischarge	PENDown	PENUp	UA_FLOW_IN/OUT
1	18 112	0	96	13880	2528	1654	0	0	0	0	0	-46
2	17 143	0	30	13880	2500	1154	-421	0	0	0	0	0
3	17 131	0	42	13880	2544	1087	-421	0	0	0	0	0
4	16 878	0	78	13880	2500	1327	-637	0	0	0	0	-270
5	17 163	0	108	13880	2500	891	-216	0	0	0	0	0
6	17 346	87	222	13880	2500	874	-216	0	0	0	0	0
7	18 221	143	318	13880	2480	1075	421	0	0	0	0	0
8	18 736	260	318	13880	2532	1575	421	154	0	0	0	0
9	19 769	440	396	13880	2652	2075	421	0	1	0	0	0
10	19 963	670	378	13880	2772	2575	0	0	9	0	0	-322
11	20 361	920	312	13880	2672	2465	0	0	0	0	0	111
12	19 998	1 157	192	13880	2572	2197	0	0	0	0	0	0
13	19 869	1 147	198	13880	2650	2211	-216	0	0	0	0	0
14	19 776	1 087	366	13880	2750	2330	-637	0	0	0	0	0
15	19 920	917	336	13880	2830	2525	-637	0	70	0	0	0
16	19 676	790	228	13880	2710	2025	-421	7	0	0	0	470
17	20 007	630	222	13880	2830	2525	-550	0	0	0	0	470
18	19 534	417	138	13880	2950	3025	-550	0	81	0	0	-407
19	19 718	180	66	13880	3030	2981	-550	150	0	0	0	282
20	20 987	0	48	13880	3150	3481	767	0	7	0	0	-165
21	22 294	0	198	13880	3250	3600	1404	0	143	0	162	0
22	21 399	0	432	13880	3130	3100	1404	0	0	0	0	-204
23	20 116	0	582	13880	3010	2600	638	0	0	0	0	-431
24	18 623	0	834	13880	2890	2100	0	340	340	847	0	-235
SUM	462 738	8 843	6 138	333 120	65 932	51 452	4	651	651	847	162	-747
MIN	16 878	0	30	13 880	2 480	874	-637	0	0	0	0	-431
MAX	22 294	1 157	834	13 880	3 250	3 600	1 404	340	340	847	162	470

k	SUM_COST	SUM_GEN
1	14 424 742	465 489

k	n_Dur	iTMIN	iTMAX
1	24	2 473	2 497

k	NP	kbNP_UA
1	1000	13
2	440	2

Fig. 13. Worksheet with the results of calculating the optimal parameters of the IPS of Ukraine

t	SUM_DEMAND	UA_FLOW_IN/OUT	PL_FLOW_IN/OUT	HUN_FLOW_IN/OUT	SUM
1	23 403	-46	46	0	0
2	22 327	0	0	0	0
3	21 930	0	0	0	0
4	21 710	-270	270	0	0
5	21 878	0	0	0	0
6	21 905	0	-17	17	0
7	23 001	0	0	0	0
8	24 476	0	0	0	0
9	25 980	0	0	0	0
10	26 538	-322	557	-235	0
11	26 842	111	-346	235	0
12	26 634	0	0	0	0
13	26 443	0	-7	7	0
14	26 151	0	0	0	0
15	25 715	0	0	0	0
16	25 391	470	-705	235	0
17	25 325	470	-705	235	0
18	24 935	-407	642	-235	0
19	25 017	282	-517	235	0
20	26 172	-165	400	-235	0
21	27 765	0	235	-235	0
22	26 633	-204	439	-235	0
23	24 874	-431	431	0	0
24	23 063	-235	0	235	0
SUM	594 110	-747	723	24	0
MIN	21 710	-431	-705	-235	
MAX	27 765	470	642	235	

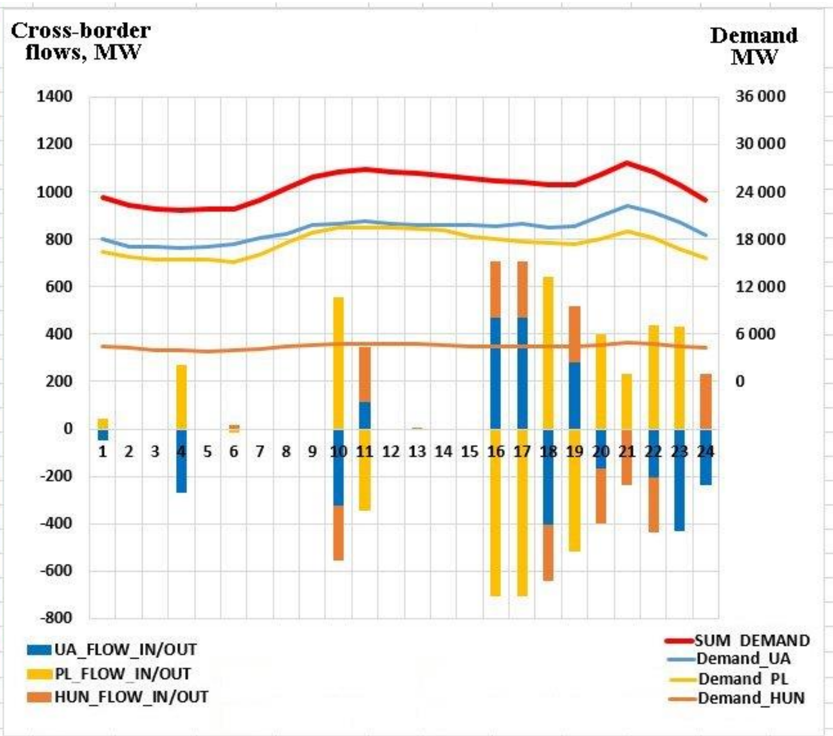


Fig. 14. Optimal values of cross-border flows during synchronous operation of power systems of Ukraine, Poland and Hungary

Time	Demand/10	BATcharge	BATdischarge	AllBATCharge	BATUpReserve	BATDownReserve	
1	1 811	0	0	0	0	680	
2	1 714	0	0	0	0	680	
3	1 713	0	0	0	0	680	
4	1 688	0	0	0	0	680	
5	1 716	0	0	0	0	680	
6	1 735	0	0	0	0	680	
7	1 822	0	0	0	0	680	
8	1 874	154	0	0	154	680	
9	1 977	0	1	154	154	681	
10	1 996	0	9	153	153	689	
11	2 036	0	0	144	144	680	
12	2 000	0	0	144	144	680	
13	1 987	0	0	144	144	680	
14	1 978	0	0	144	144	680	
15	1 992	0	70	144	144	750	
16	1 968	7	0	74	81	680	
17	2 001	0	0	81	81	680	
18	1 953	0	81	81	81	761	
19	1 972	150	0	0	150	680	
20	2 099	0	7	150	150	687	
21	2 229	0	143	143	143	823	
22	2 140	0	0	0	0	680	
23	2 012	0	0	0	0	680	
24	1 862	340	340	0	340	1020	
SUM		651	651		2 207	16 971	
	1 688			0	0	680	MIN
	2 229			154	340	1 020	MAX
	1 928			65	92	707	AVE

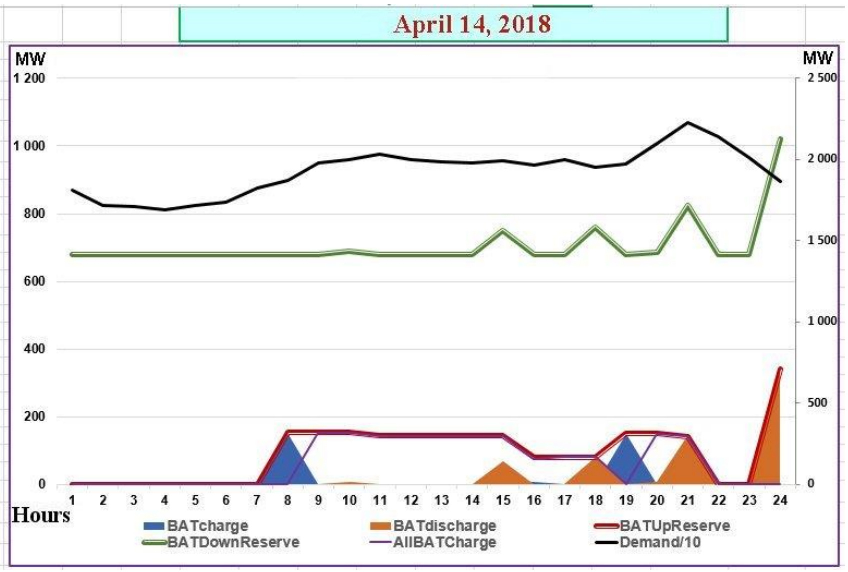


Fig. 15. Optimal values of battery operation

3. Results and discussion

The developed SIC [15]–[19] allows you to calculate in detail the energy, technological and economic indicators of the optimal use of components of energy systems, to determine the permissible limits of the parameters of operation of power units of autonomous and integrated power systems. Based on the results of these calculations, appropriate measures for the prospective renewal of technologies for the production of electricity and heat could select.

The possibility of incorporating software implementations of diverse models of the power systems' life cycle into the system allows for the collection of comparative characteristics of the most efficient technical, financial, and environmental parameters of technologies for all permitted modes of their operation in power systems. It also allows for comparisons of how efficient technologies are in operation and how they need to be updated, which is important for building new power systems' development scenarios.

4. Conclusions

A software and information complex for modeling multi-node integrated and autonomous systems of electricity and heat supply is proposed. The main difference of the proposed software and information complex is the possibility of detailed consideration of the influence of economic and technological parameters contained in the power system of individual power units and nodes. These parameters can be presented both in the form of matrices on software and information complex worksheets, and in the form of separate attached files available for automated input by the software and information complex.

The ease of use and editing of both individual parameters and program texts used in modeling the development of power systems improves the quality of the resulting development scenarios. The proposed software and information complex can be used to study the prospects for short-term and long-term development of the energy system of Ukraine, as well as the energy system integrated with the power systems of neighboring ENTSO-E member countries, which is relevant in these conditions.

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ПРОГРАМНО-ІНФОРМАЦІЙНИЙ КОМПЛЕКС МОДЕЛЮВАННЯ БАГАТОВУЗЛОВИХ ІНТЕГРОВАНИХ І АВТОНОМНИХ СИСТЕМ ЕЛЕКТРО- І ТЕПЛОПОСТАЧАННЯ

Віктор Денисов*, https://orcid.org/0000-0002-3297-1114
Віталій Бабак, д-р техн. наук, професор, https://orcid.org/0000-0002-9066-4307
Інститут загальної енергетики НАН України, вул. Антоновича, 172, м. Київ, 03150, Україна
*Автор-кореспондент: visedp@gmail.com

Анотація. *Запропоновано програмно-інформаційний комплекс для моделювання багатовузлових інтегрованих та автономних систем електро- і теплопостачання. Основною відмінністю запропонованого програмно-інформаційного комплексу є можливість детального розгляду впливу економічних і технологічних параметрів окремих енергоблоків і вузлів енергосистеми. Ці параметри можуть бути представлені як у вигляді матриць на аркушах програмно-інформаційного комплексу, так і у вигляді окремих прикріплених файлів, доступних для автоматизованого введення програмно-інформаційним комплексом. До основних переваг комплексу, які відрізняють його від відомих, можна віднести універсальність, що дає можливість вивчати різні моделі енергетичних систем в короткі терміни. Така універсальність забезпечується тим, що комплекс розроблений з використанням комбінації стандартного програмного забезпечення Microsoft Excel і SolverStudio – надбудови для Excel 2007 і пізніших версій. Це дозволяє досліджувати різноманітні моделі з використанням великого переліку оптимізаційних мов моделювання. За допомогою надбудови SolverStudio в інформаційному комплексі користувач може розробляти, редагувати, зберігати та налагоджувати модель оптимізації у книзі Excel. Зручно організувати зв'язок вихідних даних, множин, параметрів, констант і змінних, використовуваних в моделі. Після редагування параметрів і вихідних даних запускається модель. Результати моделювання можуть відображатися як на аркушах програмно-інформаційного комплексу, так і у вигляді окремих файлів. Ще однією перевагою програмно-інформаційного комплексу є можливість зручного порівняння багатьох моделей завдяки тому, що кожен з робочих аркушів може мати свою модель. Розроблений програмно-інформаційний комплекс дає можливість детально розрахувати енергетичні, технологічні та економічні показники оптимального використання компонентів енергосистеми, визначити допустимі межі робочих параметрів енергоблоків автономних та об'єднаних енергосистем. Результати цих розрахунків дають можливість обрати відповідні заходи щодо майбутнього оновлення технологій виробництва електричної та теплової енергії. Простота використання і редагування як окремих параметрів, так і програмних текстів, використовуваних при моделюванні розвитку енергосистем, підвищує якість одержуваних сценаріїв розвитку. Запропонований програмно-інформаційний комплекс може бути використаний для дослідження перспектив короткострокового і довгострокового розвитку енергосистеми України, а також інтегрованої з енергосистемами сусідніх країн-членів ENTSO-E, що є актуальним у сучасних умовах.*

Ключові слова: програмно-інформаційний, комплекс, багатовузлові, інтегровані, автономні, енергосистеми.

Надійшла до редколегії: 19.07.2023