Ministry of Education and Science of Ukraine

ODESSA NATIONAL ACADEMY OF FOOD TECHNOLOGIES

International Competition of
Student Scientific Works

BLACK SEA SCIENCE 2021

PROCEEDINGS

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4. POWER ENGINEERING AND ENERGY EFFICIENCY

INCREASING THE LEVEL OF ENERGY EFFICIENCY OF COMBINED POWER SUPPLY SYSTEMS

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Abstract. *The method of construction of the combined system of power supply of consumers from local sources is presented. The key function of the mathematical model of construction is to minimize financial investments in the construction and use of the local energy supply system using renewable energy sources. Recommendations for assessing the efficiency of use of fuel and energy resources by local energy supply systems and determining the conditions of positive economic effect and establishing the composition and basic technical parameters of energy institutions and devices of the local energy supply system are presented. At the same time, the conditions for ensuring the competitiveness of the local energy supply system to the centralized one should be applied. The source of the local power supply system is a biogas plant capable of producing biogas with the possibility of long-term storage, and at the same time being a storage battery and performing the function of highly maneuverable energy for other renewable sources within the united energy system of Ukraine.*

Keywords: *high-shunting power, renewable energy sources, mathematical model, bioenergy complex, energy saving, energy efficiency.*

I. INTRODUCTION

In the complex of energy supply tasks, the use of renewable sources (RES) is justified in many areas: saving energy resources, especially fossil fuels used for centralized energy supply; reducing the cost share of energy in the cost of agricultural products; reduction of ecological impact on the environment. Renewable energy has its own specific features that must be taken into account both in autonomous use and in the construction of combined energy supply systems. A combined power supply system is a system where the local renewable energy supply system (LRES) is connected in parallel to the centralized power supply system (SS) and the FIK consumer as shown in fig. 1. The SS acts as a battery for renewable sources and at the same time as a backup source for the consumer. But such systems require additional high shunting loads (HSL) [1].

In addition, the question of economic efficiency of construction of such energy supply systems in relation to the consumer does not subside. It is believed that the consumer is economically feasible to connect to the SS.

These judgments are based primarily on the fact that the unit cost of SS electricity is lower than, for example, the cost of electricity from wind or other power plants. Therefore, it is advisable for manufacturers and users of RES to build the system in the optimal version with the economic effect predicted in the early stages of design.

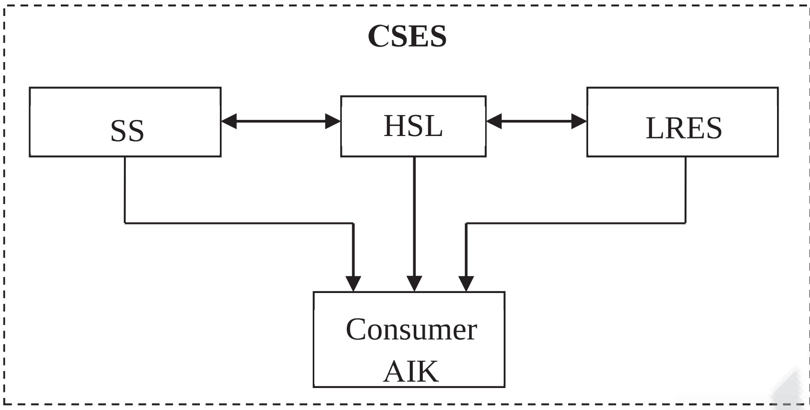

Fig. 1. Block diagram **CSES.**

Thus, the aim of the work is to determine the conditions of efficiency and develop a method to simplify the use of renewable energy sources in combined energy supply systems.

II. RESEARCH OF CONDITIONS OF USE OF ENERGY FROM RENEWABLE SOURCES IN THE UNITED ENERGY SYSTEM (UEC) OF THE WORLD AND UKRAINE

For the stable operation of the country's energy system, a balance between energy flows, high maneuverability and energy storage are needed. The system of accumulation of the electric power allows to postpone consumption and use of the electric power as long as it will be required by consumers. In the world, high-maneuverability is used for a long time and has great prospects for development. According to a forecast study by Bloomberg New Energy Finance (BNEF) (Fig. 2), the development of the global energy storage market by 2040 (excluding HSS) will reach about 942 GW with an investment of more than 1.2 trillion US dollars.

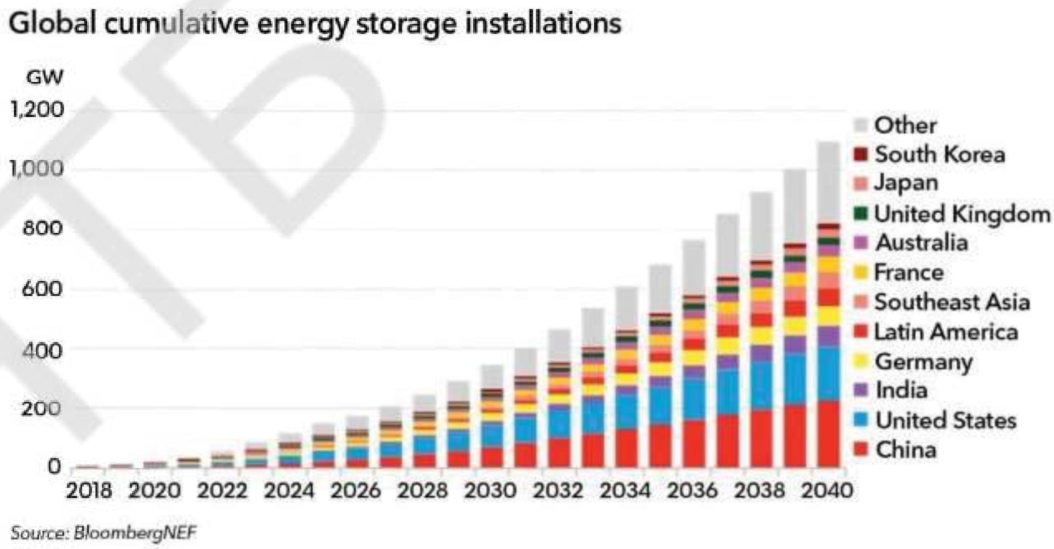

Fig. 2. BNEF forecast for the development of the market for highly maneuverable batteries in the world.

According to the forecast, nine countries - Britain, South Korea, Australia, France, Germany, Japan, India, the United States and China - by 2040 will own two-thirds of all energy storage capacity in the world.

Among the types of renewable energy, the most promising today are SES, WPPs and biomass. This is proved by analyzing the production of "green" energy in Europe, because in 2020 Europe managed to produce more energy from renewable sources than from traditional ones (Fig. 3) [2].

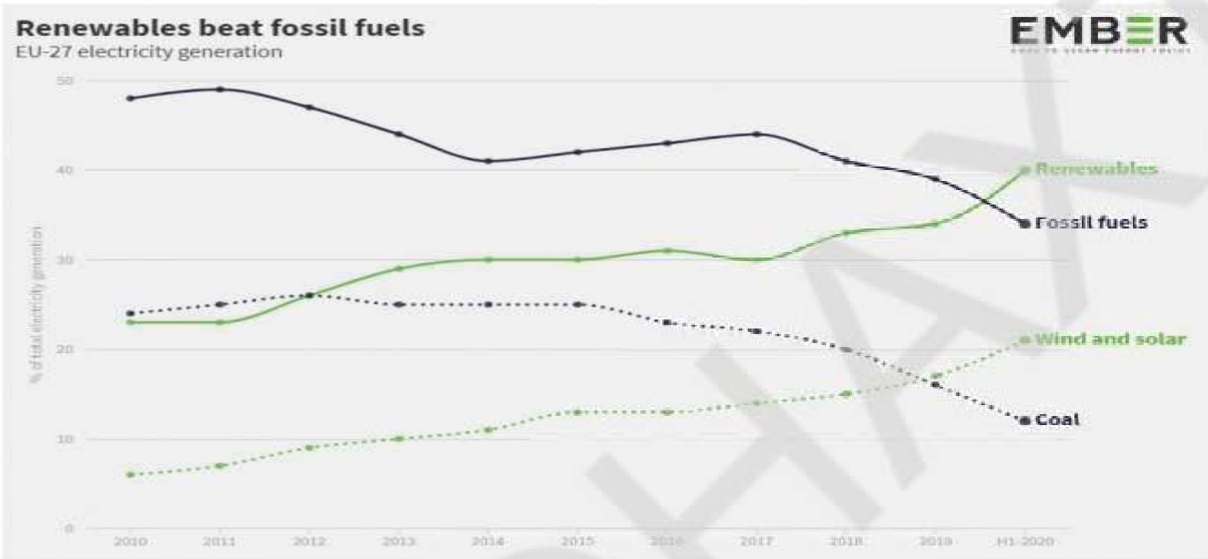

Fig. 3. Electricity generation in Europe as of the first half of 2020.

As a result of a significant increase in renewable energy and a reduction in the use of traditional energy, carbon emissions in Europe's energy sector have been reduced by almost 25%.

While demand for electricity in the EU fell by 7% due to COVID-19, electricity generation from renewable sources increased by 11%, mainly due to new wind and solar installations, which produced a record fifth of electricity in Europe. In Denmark, 64% of electricity was generated from wind and solar.

The steady trend of increasing the share of renewable energy sources (RES) in the structure of generating capacity of different countries is one of the hallmarks of the conceptual provisions of the "philosophy" of innovative development of carbon-free energy and "smart" grids (Smart Grid) in particular.

2.1. Analysis of the current state of the unified energy system of Ukraine.

Given the rapid growth of generation from RES (Fig. 4), the need to solve one of the main problems - increasing the flexibility of Ukraine's energy system has increased. According to the forecast, by the end of 2020 the capacity of alternative energy may increase to 7.4 GW, and in 2030 - to 11.2 GW.

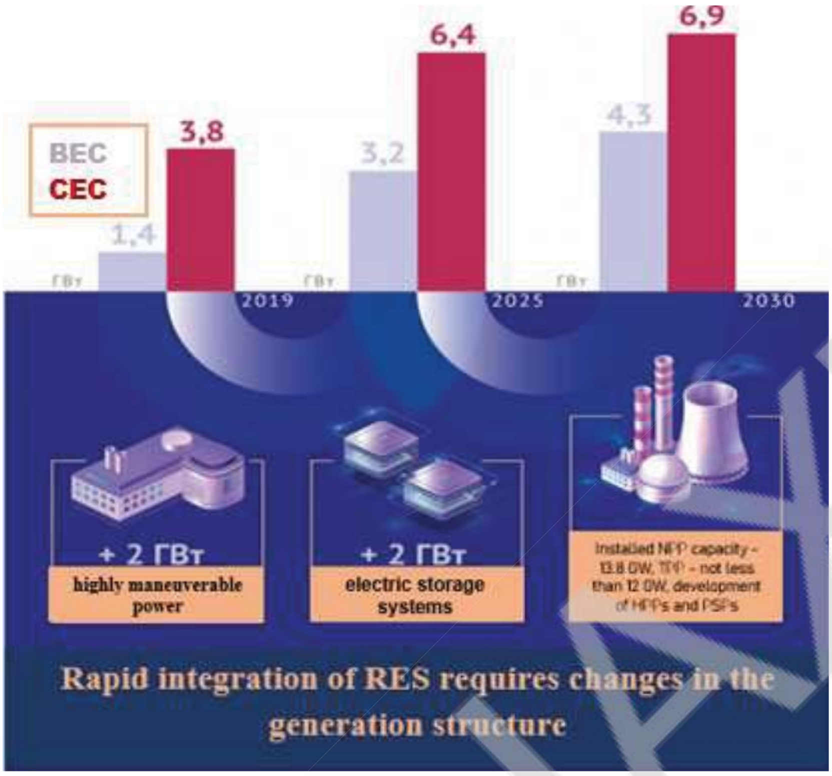

Fig. 4. Target scenario for the development of UEC of Ukraine until 2030.

Therefore, in 2021, 2 GW of new high-maneuvering capacities with a control range of at least 80% of the installed and capable of up to 8 times a day to start and stop with a time of reaching the rated capacity of not more than 15 minutes. The current generation is incapable of this. In the absence of primary regulation reserves, by 2021 it is necessary to introduce at least an additional 200 MW of electricity storage systems to provide frequency maintenance reserves.

NCERUC approved the Report on Conformity Assessment (Sufficiency) of Generating Capacities, developed by NEK Ukrenergo. This strategic document has been approved for the first time since its first development, namely in 2017. The report has a recommendatory character and is formed on the basis of studying a number of scenarios of development of energy and economy of Ukraine.

The report is developed in accordance with the Law of Ukraine "On Electricity Market", the Transmission System Code, forecast electricity balances, Energy Strategy for 2035 and other strategic documents, taking into account the recommendations and comments of NCERUC, ENTSO-E, market participants and the public.

In addition, the main feature of WPPs and SES is poor predictability of their capacity even in the short term and stochastic mode of operation with the possibility of rapid capacity changes, as well as significant differences in their electricity production schedules on different, even adjacent days.

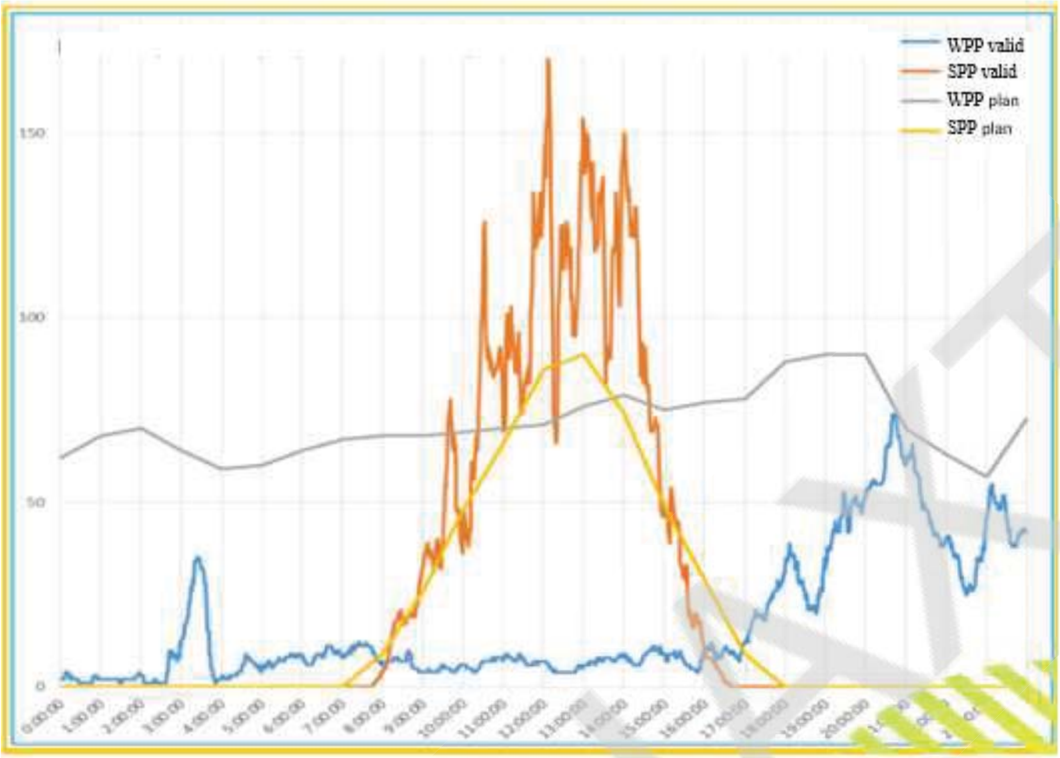

Fig. 5. Planned and actual generation of SPP and WPP of Ukraine according to the results of research by EDS-Development.

The situation, taking into account a number of bills and amendments, has grown into the introduction in 2021 of a system of penalties for RES producers for errors in generation forecasting. One solution for future and existing facilities is to use batteries in industrial solar and wind power plants. Taking into account the recommendations of EDS-Development, shunting drives should be connected in parallel to the generating unit and UEC in parallel (Fig. 6). In this case, the process of operation of the generating station in conjunction with UEC should be controlled with the implemented automatic control and management system of power supply (APMCS), taking into account the concept of SmartGrid. SmartGrid systems should be tasked with forecasting and linking weather data, traditional energy sources, they should accumulate arrays of data on solar and wind activity. All this is analyzed, and based on the analysis, decisions are made regarding the modes of operation.

In 2020, DTEK signed a contract with the American company Honey well for the supply of a lithium-ion energy storage system (SNE) with a capacity of 1 MW and a capacity of 1.5 MWh. DTEK and Honey well have started detailed design of the system and its manufacture in order to launch the first largest battery of Ukraine at the Zaporizhzhya TPP site (Energodar) by the end of the year.

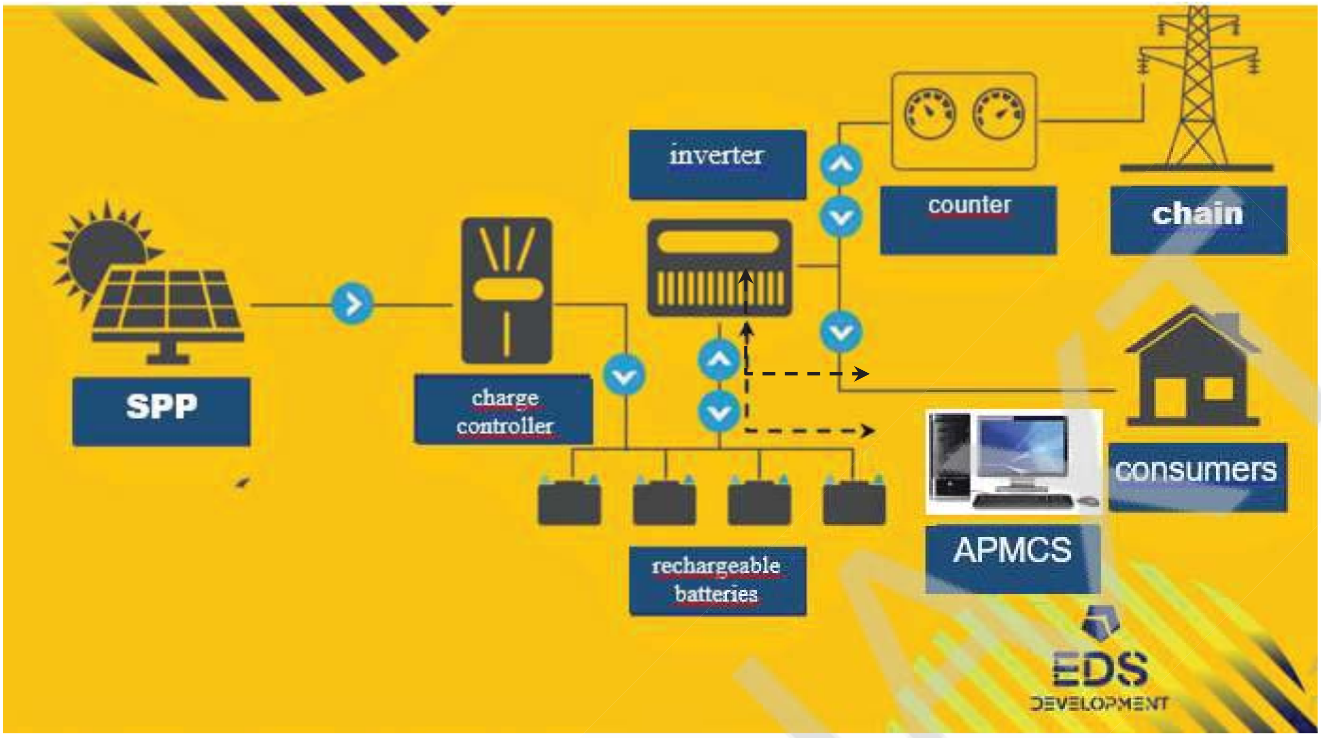

Fig. 6. Scheme of connection of accumulator batteries and shunting capacities to generating stations from renewable sources and UEC.

This will be the first industrial-scale SNE in Ukraine to become a DTEK pilot project to develop optimal operating models in various segments of the country's energy market. But the cost of shunting batteries today ranges from 1.5 to 6 thousand US dollars per 1 kW of installed capacity, which exceeds the cost of generating capacity of power plants operating from renewable sources. Thus, when building combined energy supply systems, it is advisable to determine at the first stages of design the conditions under which the consumer will have a positive economic effect.

III. SUBSTANTIATION OF THE STRUCTURE OF ALGORITHMS FOR THE DESIGN OF COMBINED POWER SUPPLY SYSTEMS WITH RENEWABLE SOURCES

The use of AES by AIC consumers depends on a large number of factors, some of which can be considered constant, while others may have a probabilistic nature. In addition, it should be borne in mind that the creation of the LSRES system requires significant capital investments, which must be returned for the period stipulated by the investor.

According to [3], the main criterion for assessing the effectiveness of an investment project, without taking into account the discount rate, is the value of the current annual income:

$$P = I - E, \quad (1)$$

Where *I* am - the annual revenue from the sale of energy, $;

E - annual estimated costs, *$*.

Equating the positive value of DEI to income, $\Delta D_t \approx$ I, then the period for the return of investment (Pp) is determined by the formula taking into account [3]:

$$P_p = \frac{E}{\Delta D_t} = \frac{\tau \cdot K + C_o}{\Delta D_t}, \tag{2}$$

Where *К* - capital investments for the creation of CSES, $;
τ – Constant discount rate, *r.u.;*
C_o – Annual recurrent costs, *$*.

To implement CSES or its individual components, annual capital investments should not exceed the values:

$$K < \frac{P_p \cdot \Delta D_t - C_o}{\tau}, \tag{3}$$

Taking into account (1, 2), the annual calculated expenses should be less than the following:

$$E < \Delta D_t - P_p, \tag{4}$$

In expanded form, the dependence (1) can be represented in the form of the matrix equation (5).. According to the analysis of equation (5), the value of the annual use efficiency of CSES is functionally dependent on the volume of production of various types of energy by the local system and the difference in the monetary costs of obtaining the corresponding types of energy from centralized and local systems.

$$\Delta P_{t\,к} = B_{цр} - B_{кр} = B_{цр} - (\Delta B_{цр} + \Delta B_{мр}) = \overbrace{\begin{vmatrix} \frac{Енергії}{Сезон} & \underline{елекрична} & \underline{теплова} & \underline{паливо} & \underline{добрива} \\ Зима & K_{11}qW & K_{12}bQ & K_{13}aV & K_{14}dG \\ Весна & K_{21}qW & K_{22}bQ & K_{23}aV & K_{24}dG \\ Літо & K_{31}qW & K_{32}bQ & K_{33}aV & K_{34}dG \\ Осінь & K_{41}qW & K_{42}bQ & K_{43}aV & K_{44}dG \end{vmatrix}}^{B_{ЦС}} - \tag{5}$$

$$- \left[\overbrace{\begin{vmatrix} \frac{Енергії}{Сезон} & \underline{елекрична} & \underline{теплова} & \underline{паливо} & \underline{добрива} \\ Зима & Z_{11}qW & Z_{12}bQ & Z_{13}aV & Z_{14}dG \\ Весна & Z_{21}qW & Z_{22}bQ & Z_{23}aV & Z_{24}dG \\ Літо & Z_{31}qW & Z_{32}bQ & Z_{33}aV & Z_{34}dG \\ Осінь & Z_{41}qW & Z_{42}bQ & Z_{43}aV & Z_{44}dG \end{vmatrix}}^{\Delta B_{ЦС}} + \overbrace{\begin{vmatrix} \frac{Енергії}{Сезон} & \underline{елекрична} & \underline{теплова} & \underline{паливо} & \underline{добрива} \\ Зима & N_{11}q_aW & N_{12}b_aQ & N_{13}a_aV & N_{14}d_aG \\ Весна & N_{21}q_aW & N_{22}b_aQ & N_{23}a_aV & N_{24}d_aG \\ Літо & N_{31}q_aW & N_{32}b_aQ & N_{33}a_aV & N_{34}d_aG \\ Осінь & N_{41}q_aW & N_{42}b_aQ & N_{43}a_aV & N_{44}d_aG \end{vmatrix}}^{\Delta B_{АД}} \right] =$$

$$= \Delta W_a(\Delta q) + \Delta Q_a(\Delta b) + \Delta V_a(\Delta a) + \Delta G_a(\Delta d).$$

where $K_{ij}, Z_{ij}, N_{ij} = \frac{W_i}{W}; \frac{Q_i}{Q}; \frac{V_i}{V}; \frac{G_i}{G}$ - Accordingly, the coefficients that characterize the degree of use by the consumer of the j-type energy *(Wu, Qi, Vi, Gi*) In the i-th season, relative to the annual volume of consumed j-type energy (W, Q, V, G) from CS, CS to CSES, LSRES to CSES*, р.у.;*

ΔW_a, ΔQ_a, ΔV_a, ΔG_a – Respectively the volumes of electricity, heat, fuel for vehicles and fertilizers from LSRES, *кВт·год, Гкал, т*;

Δq, Δb, Δa, Δd – Respectively, the difference in the cost of electricity, heat, fuel, fertilizer, the volumes of which are bought from SS (q, b, a, d), and the cost of the same types of energy generated by LSRES (q_a, b_a, a_a, d_a): $\Delta q = q - q_a$, $\Delta b = b - b_a$, $\Delta a = a - a_a$, $\Delta d = d - d_a = d - d_a$., *\$./кВт·год, \$./ГДж, \$./т, \$./м*^{3}*;*

q_a, b_a, a_a, d_a – Respectively the tariff value of electricity, heat, fuel for vehicles and fertilizers from LSRES, *\$/кВт·год, \$/Гкал, \$/t*;

q, b, a, d - Respectively, the tariff value of electric, Thermal energy, fuel for vehicles and fertilizer from the CA, *\$/кВт·год, \$/Гкал, \$/т*;

Depending on the factors that generate inflation for energy carriers, the value of DEI may change towards positive growth, or a negative decrease. Under the expected inflation, DEI calculation requires adjustments, for example, by using coefficients that are calculated by theories of economic science. In order to investigate possible alternative solutions for determining the annual monetary effect in both real and predicted time for AIC consumers using AES in the combined power supply system, the represented matrix equation (5) has a number of solutions for the year t with a positive or negative result.

From the analysis (2 - 5) it follows that with the help of DEI, it is possible to eliminate or significantly weaken the uncertainty in justifying the allowable costs. But for this it is necessary to carry out its research in dynamics with the help of the developed algorithm of economic justification, Fig. 7, and in the future other interrelated economic indicators (volumes of capital investments, terms of return of monetary investments, etc.). At the same time, in order to ensure that the consumer will have money profit from the use of LSRES, the cost limit should not be less than the "zero" level.

To solve the problem posed by studying the changes ΔDt from input values in dynamics, we use the graph-analytical method of calculation in accordance with the developed program, the generalized block diagram of the algorithm is shown in Fig. 7 and adapted for the processing of computer data in the software package MATLAB version 6.5. The algorithm of the program consists of three main stages:

1 - Data input, characterizing: the amount of consumed period of the year of different types of energy from LSRES (W_a, Q_a, V_a, G_a); Tariffs for various types of energy SS (*a*, *b*, *q*, *d*); The cost of various types of energy LSRES (q_a, b_a, a_a, d_a)

2 – Calculation of DEI expenses, depending on the share of energy use and energy tariffs for LSRES;

3 – Calculation of basic technical parameters of LSRES devices

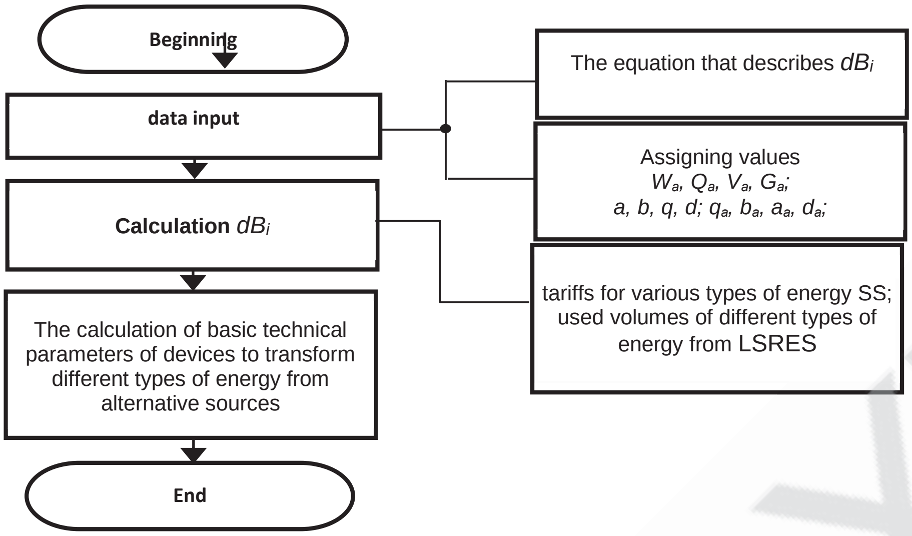

Fig. 7. Structural diagram of the algorithm for calculating the change in the cost limits $C_i^{/}$.

It is worth noting that the above parameters (6) are variable quantities having either a continuous probabilistic character, for example, the consumption of electrical energy (If there are no short-term interruptions in electricity supply), Or discrete, for example: The introduction of fertilizers into the soil, which is carried out mainly in the autumn season, or the use of thermal energy - only mainly in the heating season.

This greatly complicates the issue of determining the monetary benefit to the consumer and the share of LSES energy carriers in CSES, the volumes of which depend on local climatic and geographical conditions and the mass of waste of vegetable and animal origin. To eliminate the conditions of uncertainty, we equate the value of ΔD_t (1) to the cash cost limit $C_i^{/}$, the volumes of which, depending on the cost of energy produced by the local energy system, can have both positive and negative values. Consider three possible cases:

1. $dB_i<0$ – The consumer should abandon the CSES construction, or take the necessary measures to reduce the cost of produced energy;
2. $dB_i=0$ – Energy costs from LSRES will equal the purchase of energy from the SS. No funds are available to repay the loan. In the absence of conditions for subsidies from the state, the consumer should abandon CSES construction;
3. $dB_i>0$ – The consumer will profit from the introduction of CSES. The cost of generating energy from LSRES will be less than the purchase of energy from the SS. The introduction of CSES is proposed when the consumer has a positive economic effect, that is, if the following conditions are met:

$$dB_i > C_i, \tag{6}$$

Where C_i - is the cost of implementing and using CSES.

The ratio between dB_i and C_i is:

$$C_i = dB_i - P_i \tag{7}$$

Where P_i – is the net profit from the introduction of CSES for the i-th year, *$*.

The economic feasibility of implementing CSES is characterized by the definition of the allowable cost limit (C_l) for its construction and operation, in which the consumer will have a net positive economic effect Eee for the i-th year, taking into account [4, 5]:

$$Ee_i = dB_i - C_i, \tag{8}$$

Where C_i - is the cost of implementing and using CSES for the i-th year, *$*:

$$C_i = E_i + rK_i, \tag{9}$$

E_i – The cost estimate of depreciation charges for renovation, operational and other costs in LSRES for the i-th year, *$*;

r – Bank interest rate, *r.u.*;

K_i – Capital investments in the LSRES project for the i-th year, *$*.

To make a decision to determine the cost of building CSES, it is necessary to construct a nomogram of cost boundary changes from $dB_i = 0$ to dB_i = max, depending on the cost and volumes of produced and used energy types LSRES. In the future, with the known volumes of the cost of produced energy, the local system, according to the nomogram, establishes the limits of costs.

IV. Results of the study

To verify the developed program (Fig. 7) we will use the factual information of the private agricultural enterprise "Tavolzhanskoe" of the Dvurechansky district of the Kharkov region. According to the reporting data on energy carriers and information, which is concentrated in the company's energy passport, we establish that the agricultural consumer purchased energy from the SS for the period 2020 at tariffs: diesel fuel – a = 889 *$/t*, thermal energy — b = 48 *$/Gcal or (11,5 $/Gj)*, Electric Energy — q = 0,07 *$/kWh*.

The range of the change in the cost price of the produced energy by the local system will be taken as: diesel fuel a_a = *[0-1400] $/t*, thermal energy b_a = *[0-100] $/Gcal*. Fertilizers at the enterprise "Tavolzhanskoe" are planned to be introduced to areas where potatoes are grown. The recommended volume of application of liquid high-quality organic fertilizers from BGP, in which the potato has the highest yield, is *H – 5 t/ha* [6]. Average potato yield in Ukraine $У_c$ *– 16 t/ha.* Complex mineral nitrogen-phosphate-potassium fertilizers, which were purchased at a price of *Pf – 500 $/t* at a consumption of *250 kg/ha*, are planned to be replaced by high-quality fertilizers from BGP.

Taking into account the manure manure waste, the volume of the BGP reactor is $V_{BGP} = 200\ m^3$, Which theoretically will make it possible to produce: thermal energy Q_a = *388,8 Gj/year*; Fuel for vehicles and agricultural machinery N_a = *23,8 t/year*; Revenues related to the reduction of monetary investments for the purchase of mineral fertilizers for the introduction of arable land for potatoes into the appropriate area: $G_a = I_f$ = *4500 $/year (*Suppose that this quantity is constant*).*

Taking into account (6) for the proposed CSES, the dB_i index for the *i-th* year will be:

$$dB_i = W_{ai}(\Delta q_i) + Q_{ai}(\Delta b_i) + V_{ai}(\Delta a_i) + I_{fi} + I_{si}, \quad (10)$$

To simplify the calculations, suppose that the income from the use of If energy will be constant, and the total amount of additional revenues from the use of innovative Is technologies will not be taken into account.

To solve the problem in dynamics, we use the developed program (10), the generalized structural scheme of the algorithm is shown in Fig. 1 and is adapted for computer data processing in the mathematical software package MATLAB version 6.5. Based on the results of the calculation, the area of eligible costs *dB* is determined, which correspond to a set of possible estimates of the economic effect from the introduction of CSES (Fig. 8).

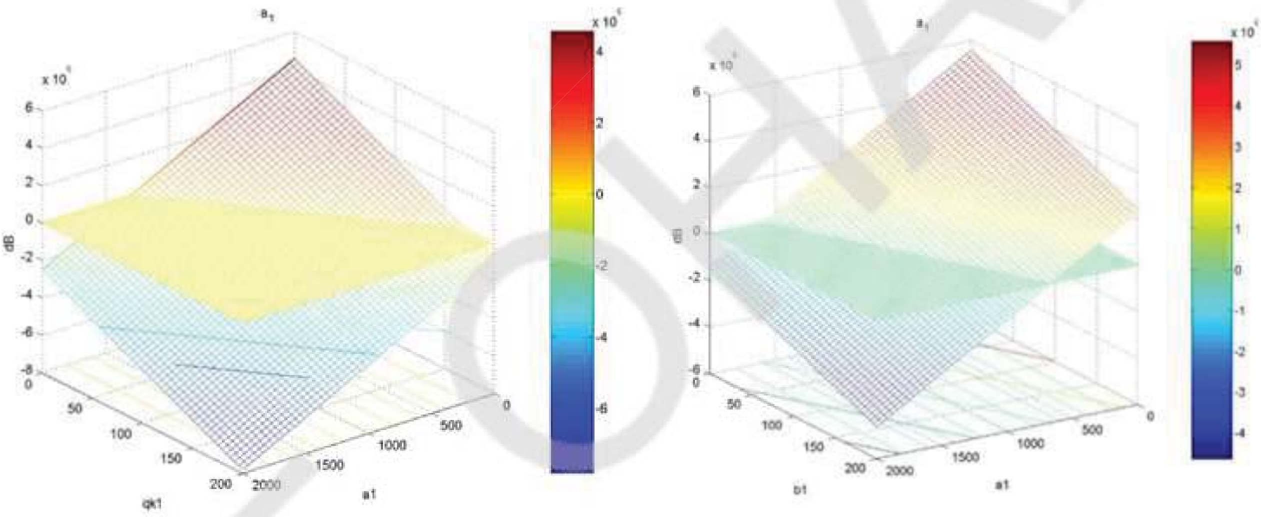

Fig. 8. Nomogram of annual cost limits (*dB*), under which the consumer will have a positive economic effect from the introduction CSES.

When designing CSES, it is advisable to consider the variants when $dB_i > 0$, which subsequently, according to (8), will allow us to obtain from its use a positive economic effect for the year *i*.

We will postpone on the nomogram the prime cost of various types of produced energy LSRES, for example $b_a = 40$ *\$/GJ*, $a_a = 800$ *\$/t*. Their intersection will be denoted by point 1 (fig. 2). The next step is to establish the permissible value of annual costs (point 2) for the implementation of CSES, which is predicted on the basis of BGP with a reactor volume of 200 m^3 (taken from the preliminary processing of computer data - the third stage of the algorithm block diagram, Fig. 7.): $dB_i \approx 16000$ *\$/year*.

Limit of admissible costs *Cv* in view of service life BGP P_o *(20 років)*:

$$C_v = dB \cdot P_o = 16000 \cdot 20 = 320000 \ \$, \quad (11)$$

Capital costs excluding the discount factor for construction BGP:

$$K_{BGR} = B_{BGR} - V_{BGR} = 500 \cdot 200 = 100000\ \$, \quad (12)$$

where B_{BGP} – Average statistical data on costs of purchase BGP [7], $B_{BGP} = 500\ \$/m^3$

In doing so, conditions for a positive economic effect are fulfilled (6):

$$dB_i\ (16000) > C_i,\ (5000),$$

where $C_i = K_{BGR} / P_o = 100000 / 20 = 5000\$$

Thus, having a positive evaluation of the use of AES and the power of devices for conversion of AES (WPP, SPP, BGP, etc.), We pass to the second stage of the solution of the problem – Organizational, technological and technical directions of solving problems on reducing the influence of internal factors on the amount of cash costs to the level of the established limit.

When performing technical solutions, we recommend, according to Fig. 1, use BGP as HSL, which will additionally provide the consumer with high-quality fertilizers and improve the state of the environment.

V. Conclusions

According to the results of scientific research, the following main results were obtained:

1. Connection of RES to UEC requires construction of additional EMF, which creates additional economic burden

2. The proposed methodology allows to substantiate economic guidelines for technological, organizational and technical measures in the construction of UEC using RES and to obtain for the consumer the projected economic effect of its implementation.

3. The principles of CSES construction for AIK consumers are developed on the basis of the analysis of existing measures on the use of RES in UES and it is proposed to use BGP as EMP, which will allow:

- maintain the reliability of the UEC;
- reduce the economic burden through the use of BGP as a highly maneuverable capacity;
- get biogas, which can be stored for a long time and cheaply;
- additionally receive high-quality ecologically clean fertilizers and restore land fertility;
- to improve the state of the environment through the processing of organic waste.

VI. LITERATURE

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