Substantiation of Algorithms of Functioning of the Combined Power Supply System with Renewable Sources

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Abstract – Algorithms of forecast changes in the volume of electricity consumption from centralized and local sources as part of a combined power supply system are presented. The dependence of integrated accounting of hourly, daily and seasonal changes in electricity consumption on centralized and local energy supply systems has been developed.

It is proposed to use an improved method of feasibility study of investment decisions at the stages of formalization of the technical task, based on the assessment of projected allowable costs for the construction of local power supply, which will allow consumers to have a positive economic effect and reduce the number of alternative solutions.

Keywords – renewable energy, local energy supply system,power supply, mathematical model, energy efficiency

I. INTRODUCTION

In the complex of energy supply tasks, the use of renewable sources (RES) is justified in many areas of activity: energy efficiency and economy of fossil fuels [1-5], which is used for centralized energy supply; reducing the share of energy in the cost of agricultural products and the impact on the environment [6-11]. Renewable energy has its own features, for example, more appropriate use in local integrated energy supply systems [6, 12-15]. Relevant features and directions should be taken into account both in autonomous use and in the construction of combined power supply systems. A combined power supply system is a system in which the local system (LS) is connected in parallel to the centralized power supply system (SS) and AIC consumers via an automatic power switching unit (APS), as shown in fig. 1.

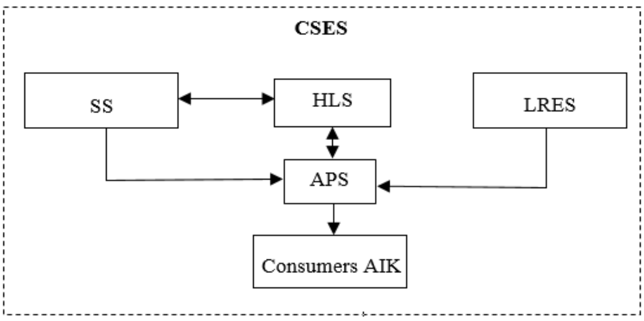

Fig. 1. Block diagram CSES

SS acts as a battery for renewable sources and at the same time as a backup source for the consumer. Such systems require additional high shunting loads (HLS) [7, 16]. But HLS today have a high cost and worsen cost-effectiveness. In the conditions of Ukraine, various options of the decision of the corresponding problem are offered.

For example, due to the possibility of dynamic management of the network configuration [8, 17]; use, for example, biogas plants as HLS [9, 18], etc. But such systems are recommended to be built with economic effect, the value of which should be anticipated in the early stages of design. Management of indicators of economic effect of such systems is entrusted to APS.

The purpose of the research -construction of algorithms for automated processing of input information to substantiate the projected economic effect of the introduction of CSES in conditions of uncertainty.

II. BASIC MATERIAL AND RESULTS

To ensure stable continuous operation of the automated power supply system, it is advisable to substantiate the mathematical model of describing the graphs of electricity consumption. The corresponding schedule will constantly grow. Assume that CSES provides active electricity to consumers whose consumption changes are characterized by equation (1).

$$W_{\kappa c(jt)} = W_0 + W_1 \frac{t_j}{T} + W_2 \sin\left(\frac{\pi t_j}{T}\right) + W_3 \sin\left(\frac{2\pi t_j}{T}\right) + \ldots + W_{n+1} \sin\left(\frac{n\pi t_j}{T}\right) \quad (1)$$

where W_0 – the initial ("reference") value of the amount of electricity consumed, *kWh*;

W_1 – the value of the ever-increasing component of the amount of electricity, *kWh*;

W_2, $W_3 \ldots W_i$ – coefficients of the variable component of the consumed volumes of electric energy, *kWh*;

t_0, t – terms, initial and final time of fixing of consumption of electric energy, *h*;

t_i – current time of day, which determines the amount of electricity consumed, $t_0 \le t_i \le t$, *h*;

T – total time of day, T =*24 h*;

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π – cyclic change constant, $\pi = 3,14$ *r.u.*

Let the consumer be able to receive energy from a centralized system or a local system at certain intervals:

- From - SS - in hours $0 \le t_1 \le 8$ and $21 \le t_2 \le 24$ days;
- From - LS - at $8 \le t \le 21$ days.

The volumes of electric energy from SS and LS are determined using a system of equations:

$$W_{SS}(t) = \begin{cases} W(t), 0 \le t < t_1 \\ W(t_1), t_1 \le t < t_2 \\ W(t) - [W(t_2) - W(t_1)], t_2 \le t < 24 \end{cases} \quad (2)$$

$$W_{LS}(t) = \begin{cases} 0, 0 \le t < t_1 \\ W(t) - W(t_1), t_1 \le t < t_2 \\ W(t_2) - W(t_1), t_2 \le t < 24, \end{cases}$$

where $W_{SS}(t)$, $W_{LS}(t)$ – respectively, the amount of energy received by the consumer from SS and LS in *t* hours, *kWh*;

$W(t_1)$, $W(t_2)$ – respectively, the amount of energy received by the consumer in hours t_1 and t_2, *kWh*.

The system equation describing the process of electricity consumption from CSES has the form:

$$W_{CSES}(t) = W_{SS}(t) + W_{LS}(t), \quad (3)$$

The coefficients of equation (1) *W2, W3,…,Wn* are determined using the program MATHCAD using the built-in function Linfit [10]. As an example in fig. 2 shows the results of calculations of coefficients (W_n) of daily schedules of electricity supply of the state enterprise of the research unit (SERU) "Gontarivka" in the spring-autumn season.

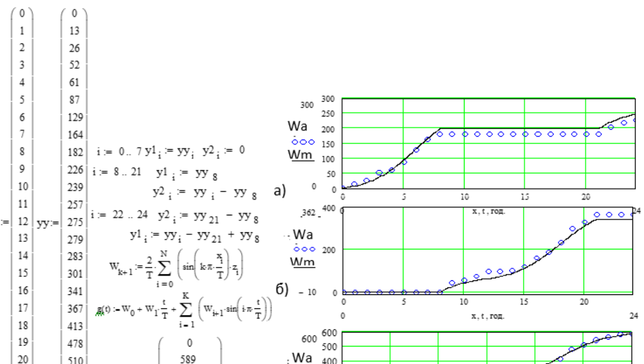

Fig.2.The coincidence of the volumes of active electric energy consumption, determined experimentally (*Wa*) and by equation (*2*) - (*Wm*), provided that consumers are fed from: a) - *SS*; b) - *LS*; c) - *CSES*.

In this case, the coefficients of equation (1) have the values:

$$W_2 = –29,152;\ W_3 = 0,564;\ W_4 = 4,566;\ W_5 = –30,498.$$

The algorithm for substantiating the projected amount of electricity consumption from CSES is solved using computer data processing. When entering input data must take into account:

$x \rightarrow t$ - time of day, $t = 0..24$ *h*;

$i \rightarrow t_1$, t_2 – hours of the day in which energy sources are used, respectively, SS and LS, *h*;

$yy \rightarrow W_{CSES}$ - total daily volumes of electricity consumed by the consumer from CSES, *kWh*;

$y1 \rightarrow W_{SS}$– hourly consumption of electricity by the consumer from the SS, *kWh*;

$y2 \rightarrow W_{LS}$ – hourly indicator of consumer consumption of electricity from LS, *kWh*.

The coefficients W_0 and W_1 have a fixed value, which corresponds to the initial and final readings of the meter during the day – 0 and 589 kWh. If we accept the constant values of the coefficients of electricity consumption from CSES, SS, LS, the solution is simplified. Table 1 shows the projected volumes of electricity consumption from SS and LS.

TABLE 1. ESTIMATED ELECTRICITY CONSUMPTION WITH SS (U1) AND LS (U2)

t, h	0	1	2	3	4	5	6	7	8	9	10	11	12
y1	0	13	26	52	61	87	129	164	182	182	182	182	182
y2	0	0	0	0	0	0	0	0	0	44	57	75	93

Continuation of table 1

t, h	13	14	15	16	17	18	19	20	21	22	23	24
y1	182	182	182	182	182	182	182	182	182	205	218	227
y2	97	101	119	159	185	231	296	328	362	362	362	362

The value of the average daily deviation of the actual data of power consumption SERU "Gontarivka" and theoretical, obtained by computer processing of dependence (1) and the system of equations (2), does not exceed 5%. The results of the calculations were obtained using the dependence (4).

$$\delta = \frac{\sqrt{\frac{1}{N}\sum_{i=0}^{N}(Wa - Wm)^2}}{\frac{1}{N}\cdot\sum_{i=0}^{N} Wa}\cdot 100, \quad (4)$$

where N – the number of meter readings per time interval, $N=24$ *r.u.*

Thus, the use of equation (1) makes it possible to:

- to characterize the patterns of electricity consumption for existing consumers who work on standard load schedules, regardless of its nature: industrial, mixed, household;
- to determine the forecast daily volumes of electricity consumption from SS and LS in the corresponding hours of the day.

To reduce the set of alternative solutions and conditions of uncertainty, it is recommended to assess the economic effect of the implementation of RES in the early stages of design. According to the calculated cost limits, the substantiation and composition of LS are carried out, capacities and types of installations are determined depending on the accepted cost limits.

According to SSTU 3886-99 "Energy saving", the criterion of the effect of energy saving measures (ESM), when considering different options, are:

$$E_t = I_t - C_t\,, \qquad (5)$$

where E_t– economic effect from the implementation of the ECM for the reporting period;

I_t– estimate of income results from ESM for the settlement period;

C_t– cost estimate for the implementation and operation of ESM for the calculation period.

The task of the first stage is to substantiate the options for the use of RES in the power supply system of agro-industrial complex consumers. Performed by determining the value of the differentiated economic indicator (DEI) from the implementation of the CSES in comparison with the existing indicators of the SS for the t-th year, taking into account [7, 19], is performed by the formula:

$$\Delta I_t = C_{ts} - C_{tc} = C_{ts} - (\Delta C_{ts} + \Delta C_{tl}), \qquad (6)$$

where ΔI_t – the value of DEI from the introduction of CSES for the t-th year, *UAH*;

C_{ts}– cash costs for the purchase of energy from the SS for the t-th year, *UAH*;

C_{tc}– cash costs for obtaining the total amount of different types of energy from CSES for the t-th year, *UAH*;

ΔC_{tl}, ΔC_{ts} – respectively, the share costs for obtaining various types of energy from the local and centralized systems as part of the CSES for the t-th year, *UAH*.

The DEI change study was carried out for conditions when LS, as a component of CSES, generates only electrical energy. In this case, the magnitude of the economic effect can change as a function of time. This is due to the fact that there is an impact of cyclical changes in daily and seasonal loads, tariffs, consumption and production of LS energy (Fig. 2). Based on the results of analysis (6), the probability of occurrence of both positive and negative DEI values was established: $\Delta I < 0$, $\Delta I = 0$, $\Delta I > 0$. The positive value of DEI ($\Delta I > 0$) can be equated to the cost boundaries for the implementation of the local power supply system, which will make it possible to predict the magnitude of the economic effect, namely:

$$0 < \Delta C < \Delta I. \qquad (7)$$

Studies to substantiate ΔC will be carried out according to the actual data of daily electrical loads of SERU "Gontarivka" consumers in the spring.

Estimation of the limit of costs ΔC from the use of KSES in SERU "Gontarivka" is carried out taking into account the system of equations (2):

$$\Delta C_\tau = \Delta y \cdot (\beta_\tau - \alpha_\tau) = \left[\begin{cases} 0, 0 \le t < t_1 \\ W(t) - W(t_1), t_1 \le t < t_2 \\ W(t_2) - W(t_1), t_2 \le t < 24 \end{cases} \right] \cdot (\beta_\tau - \alpha_\tau), \qquad (8)$$

where Δy–volumes of electricity consumption from LS, *kWh*;

β_τ–tariff for electricity from SS at time τ, *UAH/kWh*;

α_τ–notional cost of electricity produced LS, *UAH/kWh*.

To study ΔC in dynamics, depending on the time of day, a program was developed [11, 20], the algorithms of which are presented in fig. 3.

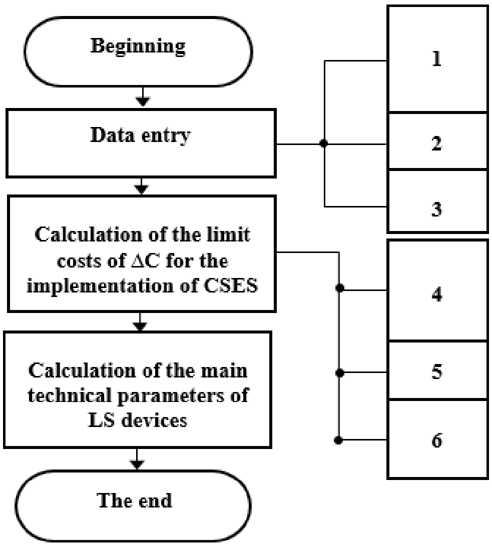

Fig. 3. Block diagram of the algorithm for determining ΔC and the main technical parameters of the devices of the local power supply system, where the input components of the program include:

1 –Introduction into the program of equation (1) and its coefficients characterizing the volumes of electricity generation from LS;

2 – Introduction to the program of equation (7), which characterizes the changes ΔC;

3 – Assignment of values β, α; t_i, K_Z, $W_{(1-i)}$;

4 –Determination of zones of efficiency of RES use depending on time t and tariff coefficient K_Z;

5–Determining the cost limit ΔC;

6 –Determining the cost limit ΔC taking into account the operating time during the day t and the zone change of the tariff β.

The implementation of software calculations is performed in the package of mathematical programs MATLAB.

At three-zone change of tariffs for the electric power of CA in fig. 4 presents the zones for which the more promising daily changes of ΔC are determined.

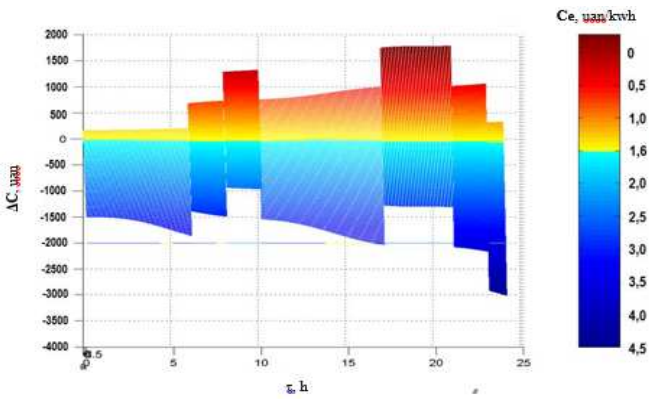

Fig. 4.Nomogram of changes in the cost limit Δ*C* and the cost of electricity produced *Ce* by time of day

Based on the results of the analysis of the obtained nomogram, we will conduct a study of the change in the cost limit ΔC and the cost of electricity Ce produced by the LS during the day. The lowest cost of generated energy is observed from 8.00 to 10.00 and from 17.00 to 21.00 with the maximum value of the admissible costs ΔC for the project implementation. A positive economic effect can also be achieved when LS are operated from 6.00 to 23.00 hours. In this case, the average value of ΔC for the j-th season is:

$$\Delta C_j = \frac{\sum_{t_п}^{t_к} \Delta C_t}{N_j \cdot t_j}, \quad (9)$$

where: $\sum_{t_п}^{t_к} \Delta C_t$ –the sum of hourly values of ΔC during the *n-th* number of days of the *j-th* season, *UAH·h;*

$t_п$, $t_к$ – respectively, the initial and final operating time of the consumer from LS for the day of the *j-th* season, *h*;

t_j –time of work of the consumer for the period of day from LS for the *j-th* season, *h*;

N_j – number of days in the *j -th* season, *r.u.*

Determining the allowable projected annual costs for the implementation and operation of LS in the early stages of design will allow to focus from an economic point of view on the choice of renewable energy devices, the implementation of which will provide the consumer with a positive economic effect.

III. CONCLUSIONS

1. The total discrepancy of the dependence, which interprets the amount of electricity consumption by different groups of AIS consumers, does not exceed 5%, which allows us to recommend it to:

- forecasting electricity consumption according to current, standard and theoretical load schedules, regardless of their nature of change;
- determination of daily volumes of energy consumption from SS and LS as a part of CSES irrespective of terms of use of RES;
- determination of capacity of power plants of local systems, automation devices, etc.

2. It has been established that the proposed approach to a comprehensive substantiation of RES use cases, based on original technical and economic indicators, an algorithm, methodology and software for their calculation, makes it possible to reduce many variant solutions and determine the positive and negative aspects of CSES operation already at the first stages of the technical and economic assessment efficiency of CSES implementation and RES use by AIS consumers.

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