KAPITEL 7 / *CHAPTER 7*
ANALYSIS OF FINANCIAL AND TECHNICAL INDICATORS OF SYSTEM EFFICIENCY IN DYNAMIC MODES
АНАЛІЗ ФІНАНСОВИХ ТА ТЕХНІЧНИХ ПОКАЗНИКІВ ЕФЕКТИВНОСТІ РОБОТИ СИСТЕМИ В ДИНАМІЧНИХ РЕЖИМАХ

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Introduction

Smart Grid is considered as an electrical network or system that integrates the actions of all connected participants through the use of intelligent solutions in order to ensure a sustainable, cost-effective and secure energy supply. The concept of Smart Grid development in energy in a more global sense is not only the latest energy technologies, but also modern information and communication technologies of billing, e-commerce, modeling and data storage, virtualization, computer security, distributed computing, collection, processing and transmission real time information.

In implementing the provisions of the Smart Grid concept, it is necessary to note the outpacing growth of the role of local electricity markets for the development of local energy supply systems (Microgrid), in particular, the evolution of Microgrid as active consumers (prosumer) and virtual power plants (Virtual Power Plant, VPP). Generation (DRG) - (Distributed Energy Resources, DER) [2, 3, 4]. Retail electricity prices that change over time significantly help reduce the cost of producing or purchasing electricity in the system, meet operational capacity reserve requirements, and so on.

7.1. Systems of active management of distributed energy facilities

Depending on the type of managed network (Network Manager) it is possible to distinguish between power transmission control systems (TMS) and power distribution control systems (DMS) energy management systems (EMS) [6, 7]. Prior to the abolition of state regulation, energy management systems (EMS) were mainly used for integrated management of electricity generation and transmission. After the abolition of state regulation, the separation of these two functions led to the creation of power generation management systems (GMS) for independent management of generating capacity.

For Microgrid and VPP, the DER Management System (DERMS) optimally manages the operation of DER to provide network services, facilitates alternatives, and allows DER to participate in markets. DERMS allows you to increase situational awareness while increasing DER penetration by providing DER modeling, aggregation, and grouping. There is a problem of building new algorithms of accounting and control, when when building a control system it is necessary, along with the technical (technological) circuit, to use the economic control circuit.

The new RES support mechanism in Ukraine should take into account: the introduction of new RES support mechanisms should be carried out together with a significant increase in carbon taxes, the rates of which in Ukraine are lower than in

Europe; non-tariff methods of RES support; maximum support for RES for self-generation (consumption of energy produced by the consumer without return to the grid); creating favorable financial conditions not only for the development of distributed generation, but also for the establishment of means of energy storage and conversion by households and businesses.

7.2. Dynamic pricing in Microgrid

Reducing the price paid by consumers for electricity is invariably the first reason for the introduction of competitive electricity markets [8]. Electricity generation costs depend solely on the type of technology and fuel used to generate electricity.

Consumer behavior is related to consumption patterns, as most consumers use large electrical loads at the same time. The expected dynamic pricing program affects the behavior of consumer demand [9]. Changing consumption patterns at the macro level can affect strategic decisions, such as the construction of power plants, as well as increase the efficiency of operating costs. Consumers may be interested in dynamic pricing if they are well informed and if the schemes are designed in an easy-to-use way to allow them to save on their bills [10].

The active introduction of Microgrid in liberalized local markets has necessitated the implementation of flexible tariff policies, in particular, dynamic tariffs [1, 2]. There is a need to consider the possibility of forming these "adjustable" components on the basis of power, as well as carefully study the possibility of more dynamic formation [5, 11, 12].

The analysis showed that the technical implementation of Microgrid is quite fully developed for all levels, in particular, with time forecasting and the day ahead. However, it is important to conduct research to assess the demand-price ratio at the micro level, to determine the impact of dynamic pricing on Microgrid functions, taking into account the factors affecting electricity demand, depending on generator and load modes. It is important to optimize fuel consumption through the implementation of the dynamic pricing methodology and, as a consequence, the reduced costs for the production of 1 kWh of electricity in Microgrid.

Let $c_e(t)$ and $c_f(t)$ be the tariff for electricity and the unit cost of fuel; $P(t)$ and $B(P(t), t)$ - power consumption and current consumption of primary fuel. With the allocation of the constant components B_0 costs of Microgrid, and variable $B_N(P(t), t)$ non-fuel costs (in particular, the operation of Microgrid) and the corresponding cost indicators $c_0(P(t))$ and $c_N(P(t), t)$ we can write the value of the current cost C_F, $N_F(t)$ for power generation in the Microgrid interval [0, t)

$$C_{F,NF}(t) = \int_0^t c_0(P(t))dt + \int_0^t c_N(P(t),t)dt + \int_0^t c_f(t) \cdot B(P(t),t)dt$$

The task is to optimize the power processes in Microgrid in terms of efficient operation of both generators and loads.

Then for the cost of electricity consumed CE (t) and the cost of fuel consumption CF (t) in the interval [0, t) we can write:

$$C_E(t) = \int_0^t c_e(t) \cdot P(t)dt;$$

$$C_F(t) = \int_0^t c_f(t) \cdot B(P(t),t)dt;$$

We describe the features of the individual elements of Microgrid in terms of determining the optimal and suboptimal modes of their operation. In the future, we use the Frieze power and the Q_{OB} exchange power as a criterion for the optimality of processes in Microgrid [13].

In order to reduce losses by analyzing the possibilities of power supply control, the method of estimating suboptimal levels based on the Frieze power index Q_{f} [13] is usually used, which is defined as the quadratic discrepancy between full S and active P power: $Q_{\phi} = \sqrt{S^2 - P^2}$.

Frieze's power allows to identify groups of consumers with the greatest impact on the overall unevenness of the system and to analyze possible options for corrective action. Losses in Microgrid transmission and distribution lines are neglected.

To implement dynamic tariffing by state, namely to record changes in the amount of energy received in dynamic mode according to relations (3), (4), the generalized algorithm of Smart-counter contains the following steps [12, 14]:

1. Installation of initial standards.
2. Introduction of the i-th mode. Control of W and B values and ΔW and ΔB increments.
3. Switch to the new mode $i = i + 1$.
4. Calculation of the instantaneous cost of fuel $B_{\text{i}}(P)$ and electricity $W_{\text{i}}(P)$.
5. Determination of increases in the cost of fuel $\Delta B_{\text{i}}(P)$ and electricity $\Delta \text{W}_{\text{i}}\ P)$.
6. Verification of the condition: whether the value is in the i-th zone of tariff constancy, ie verification of the conditions: $\Delta B_{\text{i}}(P) > \varepsilon_{\text{B}}(P)$ and electricity $\Delta \text{W}_{\text{i}}(P) > \varepsilon_{\text{W}}(P)$, $\varepsilon_{\text{B}}(P) > 0$ and $\varepsilon_{\text{W}}(P) > 0$.
7. Transition to the installation of a new electricity tariff $W_{\text{i}}\,(T)$.
8. Control of levels of generation and consumption of the electric power according to the i-tariff.
9. Formation of the current report of spreadsheets and graphs on instantaneous and integrated values of tariffs, generation and consumption of electricity.
10. Transition, if necessary, to the 2nd stage; otherwise to step 11.
11. Removal of information about instantaneous and integral characteristics at specific times.
12. Completion of the algorithm.

7.3. Algorithm for calculating the price of primary fuel depending on the uneven consumption of active power.

To estimate the cost of primary fuel in Microgrid dynamic mode, we present an algorithm for calculating the price of primary fuel depending on the uneven consumption of active power over a period of time T^* (duration from minutes, hours, several hours to days, etc.). Let's mark it as some technological period of T_T. To simplify the calculations, we assume that fuel costs depending on the level of active power consumption are known, and the cost of primary fuel does not change over time and is sustainable [14].

To estimate the cost of primary fuel in Microgrid dynamic mode, it is necessary to analyze the graphs of generation and consumption of electricity, in particular, graphs of electrical loads. Different types of generation and consumption of electricity reflect the functions *P (t)*, *Q (t)* or *I (t)*, which are integral characteristics of the change in load on the selected interval (minutes, hours, days). Depending on the methods and accuracy of measurement (approximation), the load graph can be considered as a continuous or stepped curve [15].Наведемо кроки алгоритму оцінки фінансових та технічних показників ефективності роботи Microgrid в динамічних режимах розрахунку вартості первинного палива.

Step 1. Determination of the functional dependence of the active power *P (t)* on the interval T^*. As an example in Fig. 1 shows a graph of changes in active power *P (t)* with the selection of the controlled time interval T^*.

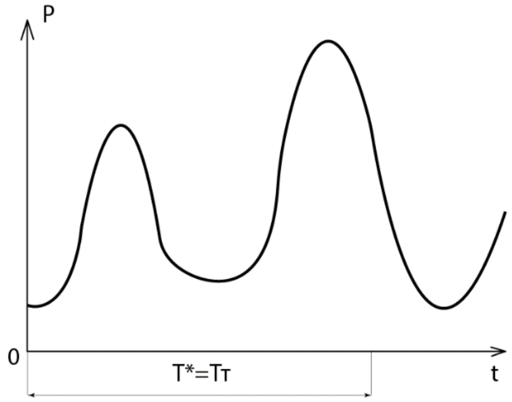

Figure 1 - Graph of active pulling *P(t)*

Step 2. We assume that as a result of approximation of the function *P(t)* by piecewise constant functions at individual intervals, we constructed a step graph of the dependence of the active power *P(t),* shown in figure 2.

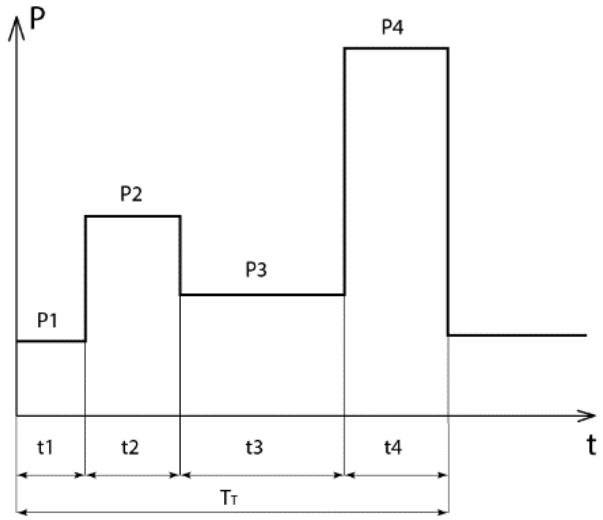

Figure 2 - Approximations of the graph of the abundance of active pressure *P(t)*

Step 3. Forming a graph of the dependence of primary fuel consumption *B(P)*. In the general case, the graph can be constructed by using normative (average) values or experimentally. If the dependence graph was previously unknown, then the graph *B(P)* is constructed by the root-mean-square approximation method, we find parameters not of a linear function but of a quadratic one, when the approximating function is a quadratic dependence: $y = ax^2 + bx + c$ [16].

Step 4. Linearization of the graph of the dependence of primary fuel consumption *B(P)* and determination of the cut-off points at which there is a transition from one approximating linear function to another (figure 3). At these points, the nature of the costs will change according to the slope coefficients of linear approximations a_1, a_2, a_3, ie the slope coefficients of linear approximations characterize the slope of the lines *B(P)*. Note that there are a significant number of methods for approximating nonlinear functions [17]. In this case, we use the piecewise linear method of approximation of a nonlinear function.

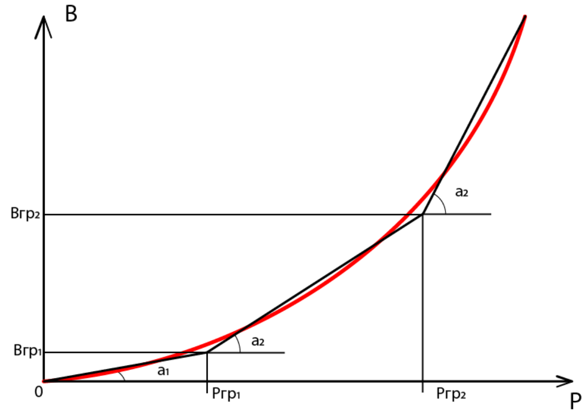

Figure 3 - Approximate graph of the dependence of primary fuel consumption on changes in active power consumption *B(P)*

We reduce the nonlinear function to several (in this case up to three) intervals with linear dependences (figure 3), each of which corresponds to its coefficient a_1, a_2, a_3 and the value of the power limit (characteristic breakpoints): P_{gr1}, P_{gr2}, P_{gr3}.

Step 5. Determining the number of the interval Δt_i, which belongs to the set of values of active power P_i, which consumes the equivalent load.

According to the results of step 2, we have as the initial set of values of P_i depending on time *t*. The power of P_i has a constant value at a certain time interval Δt_i. therefore it is necessary to determine which i-in the interval of fig. 4 belongs to the set of power values P_i:

$$P_{gr(i-1)} \le P_i \le P_{gr(i)}. \qquad (8)$$

Step 6. Calculation of fuel consumption at *n* intervals (in this case, these intervals are denoted by I, II and III) in accordance with the function shown in figure 4 (by the value of $P_{гр,i}$, a_i, $i = 1, 2, 3$):

$$B_{\text{Ii}} = P_{\text{Ii}} \cdot \alpha_1;$$

$$B_{\text{IIi}} = B_1 + P_{\text{IIi}} \cdot \alpha_2;$$

$$B_{\text{IIIi}} = B_2 + P_{\text{IIIi}} \cdot \alpha_3. \qquad (9)$$

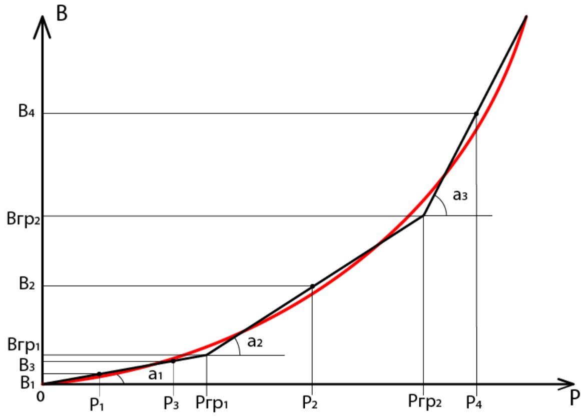

Figure 3 - Graph of the dependence of primary fuel consumption *B(P)* with indication of limit and current values

Step 7. Calculate the price of primary fuel at each interval. To do this, first calculate the total amount of primary fuel, using the value of primary fuel consumption for a certain period of time according to the formula:

$$W_B = \sum B_i \cdot \Delta t_i . \qquad (10)$$

Then calculate the cost of C_B primary fuel by the formula:

$$C_B = c_B \cdot W_B . \qquad (11)$$

The cost of primary fuel c_B can be of different nature, for example, both linear and nonlinear. Next, we form a graph of the dependence of the cost of primary fuel on capacity (figure 5).

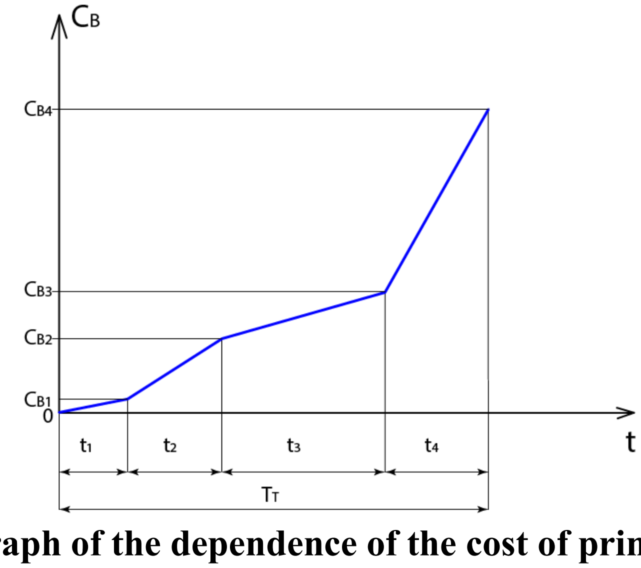

Figure 5 - Graph of the dependence of the cost of primary fuel $C_B(t)$

Step 8. Calculation of the optimal value of active power P_{OPT}, which corresponds to the uniform consumption of electricity and is characterized by minimal use of primary fuel. Steady consumption leads to a reduction in electricity losses and, consequently, to a reduction in fuel consumption. Let the value of P_{OPT} belong to the 1st interval (figure 9). According to the type of active power function shown on figure 2, we find the most rational variant of active power consumption for constant volumes of energy transfer W in the interval $T^* = T_T$. This will be when the active power consumption in the T_T interval is constant.

To transmit the same amount of electricity with uniform consumption, power is determined by the following formula.

$$P_{\text{OPT}} = \frac{\sum P_i \cdot \Delta t_i}{\sum \Delta t_i}. \qquad (12)$$

The calculated capacity will be considered the baseline, in relation to which we will assess the impact of uneven consumption on the total cost of primary fuel use.

Step 9. Calculate the optimal value of primary fuel consumption. To do this, we use the obtained value of the optimal active power P_{OPT}, calculated by formula (10). Determine the costs using the formula:

$$W_{\Sigma OPT} = P_{OPT} \cdot \alpha_1 \sum \Delta t. \qquad (13)$$

In this case, the amount of primary fuel consumption will depend on the observation interval T^* and the accuracy of the approximation of the above functional relationships. The greater the number of Δt_i intervals, the more accurately the optimal value of the active power of the P_{OPT} will be determined, which improves the reliability of the obtained analysis results.

Step 10. Using the optimum value of primary fuel consumption found above (11), the optimal value of the price of primary fuel is calculated according to the formula:

$$C_{\Sigma\text{POT}} = c_B \cdot W_{\Sigma\text{POT}}. \qquad (14)$$

Depending on the nature of the change in the tariff of primary fuel, the optimal value of the price of primary fuel will change. With a more dynamic change in the tariff, the number of intervals to be considered will increase and, as a result, the volume of settlements will increase. To increase the accuracy of the calculation, it is advisable to take into account all aspects (factors of influence) of changes in the tariff of primary fuel.

Step 11. Assess how different the current value of the price of primary fuel $C = C_{\text{POT}}$ from the optimal value C_{OPT}. We can offer a relative value as the difference between the current value of the price of primary fuel and the optimal value obtained in the previous step (12), divided by the optimal value of the price of primary fuel by the formula:

$$\delta C = \frac{C_{\text{POT}} - C_{\text{OPT}}}{C_{\text{OPT}}};$$

$$\delta C = \frac{C_{\text{POT}}}{C_{\text{OPT}}} - 1. \qquad (15)$$

To illustrate the effect of the non-uniformity of the graph *P(t)* on the value of the current C_{POT} and the optimal C_{OPT} value of the primary fuel price for specific values of the approximating functions of the generation and consumption of electricity shown in figure 2, use the following active power values: $P_1 = 1$ kW, $P_2 = 3$ kW, $P_3 = 2$ kW, $P_4 = 6$ kW. The time intervals for the values of $P_1, \ldots, P_4$ are respectively $t_1 = 1$ h, $t_2 = 2$ h, $t_3 = 4$ h, $t_4 = 2$ h. Assume that the tariff for primary fuel is c_B = $ 27,72 / liter.

To estimate the difference between the current and optimal values of the price of primary fuel, we find by formula (11) the value of the current price of primary fuel C_{POT} = \$ 267,14 and by formula (14) the optimal value of the price of primary fuel C_{POT} = \$ 196,13. Then according to (15) the value of δC is equal to:

$$\delta C = \frac{267,14 - 196,13}{196,13} = 0,36.$$

To analyze the impact of uneven consumption of active power *P(t)* on the price of primary fuel, reduce the active power P_4 by 4 times, P_4 (1) = 0,25 P_4 (figure 5). Using the algorithm, we find new values of the current C_{POT} = \$ 198,94 and the optimal C_{OPT} = \$ 178,26 value of the price of primary fuel and evaluate their ratio. For this case:

$$\delta C = \frac{198,94 - 178,26}{178,26} = 0,12.$$

With decreasing power P_4 4 times, P_4 (2) = 0,25 P_4 and, accordingly, increasing the interval t_4 also 4 times, so t_4 (2) = 4 t_4 (figure 5). Performing all the steps of the algorithm, we list the value of the current C_{POT} = 244,4 \$ and the optimal C_{OPT} = 191,3 \$ value of the price of primary fuel and have the following ratio:

$$\delta C = \frac{244,4 - 191,3}{191,3} = 0,277.$$

Therefore, with a more uniform value of power consumption *P(t)*, the current price of primary fuel will approach the optimal value. This is due to the fact that when the unevenness of consumption is reduced, fuel consumption decreases, and therefore the total price of fuel decreases accordingly.

Conclusions

1. It is shown that the advantages of dynamic charging are most fully manifested at the local level, and modern interaction of participants in the market of ancillary services involves increasing the role of dispersed generation aggregators and dispersed consumption aggregators. development of business models with a combination of physical, communication, information and business levels.

2. Developed algorithm for calculating the price of primary fuel depending on the uneven consumption of active power over a period of time allows you to use dynamic charging when changing modes of Microgrid generators, while providing an adequate price for consumers and producers of both primary fuel and electricity supplied and consumed. Using the Frieze power modification, the developed algorithm provides for the calculation of the optimal value of active power, which corresponds to a uniform power consumption and is characterized by minimal use of primary fuel.

3. The need to combine technical and economic (financial, price) indicators in business models and technical means at the Microgrid level is substantiated, which will significantly improve the process of managing electricity demand in the local electricity market. The proposed algorithm allows us to study the impact of a fairly rapid change in the level of generator power and power consumption on changes in the cost of the system, the introduction of demand side management mechanisms and measures to improve energy efficiency.