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STATIC AND DYNAMIC TARIFFING ELECTRIC POWER AUTONOMOUS MICROGRID

The paper presents a static model of the price calculation for the various alternative electricity sources, and includes technical and economic performance of different energy sources for the guaranteed power. The table with calculated technical and economic indicators for various alternative energy sources is provided. The presented dynamic model which unites energy indicators of power generating systems and economic indicators of the closed macroeconomic system because price regulation on the power market of Ukraine happens in a statics. That's why not allowed to perform an assessment of dynamic change of the tariff price of the electric power in the local isolated systems. When abrupt change isolated power generating capacity of the system is changing the tariff price of electricity cannot be taken into account when using static models. An example of the isolated system consisting of the diesel generator and the consumer is reviewed. The model allows to research influence of transition processes of the generator on change of cost indicators of an economic system, and also to estimate the adequate tariff price both for the producer, and for consumers of the electric power. This model is modelled in Matlab.

1. INTRODUCTION

At development of the system of management of power supply of knots of the distributed generation the combination of the centralized and decentralized management can lead to contradictions with tasks which minimize consumption of other resources (water, gas, etc.) [5], [15]. Therefore it is necessary to choose criterion of efficiency which would be the general for various problems of management and I allowed to carry out a complex assessment of a condition of system of power supply of local ob-

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ject of Micro Grid. Such criterion is the integrated cost parameter which allows estimating the direct and mediated expenses necessary for development and consumption of electric energy, and losses from her inefficient use.

Because as criterion cost is used, it is expedient to apply the theories developed in economic branches [2], [6], [10] to realization of optimum behaviour of system. Then the problem of optimization is reduced to the joint solution of the equations describing electromagnetic processes in technical devices and the equations considering cost factors [4], [7]. As target functionality which value has to be minimized the cost of energy which pays off as amount of energy, increased by the corresponding tariff operating in this interval of time is chosen. The accounting of tariffs it is necessary as only existence multitariff systems of payment gives the chance to lower expenses by transfer of intervals of work of separate loadings of intervals of lower tariffs, and the moments of turning on of alternative generators – in intervals of higher tariffs of a network. The modern technological level allows to apply the current tariffs for the electric power of a network [1] to realization of formation of more flexible management with feedback and an assessment of a condition of the operated objects.

Optimum function of management which allows providing performance of the set useful work as loadings with minimization of expenses is result of the solution of a task. Optimum function of management represents set of values of the operating parameters in the set time intervals.

For the purpose of the accounting of cost factors (processes of consumption, production, the budgetary restrictions) by development of systems of management of power supply of knots of the distributed generation the electro technical equations are combined with the equations borrowed from the economic theory [2]–[4], [6], [7], [11]–[13]. Such combination leads to creation of electro-cost models which, except definition of currents and tension of electro technical objects of Micro Grid, the minimization of cost costs of service and use of these objects allowing solving a problem.

The model of the general equilibrium allows describing and solving a wide range of the problems arising at management of power consumption in a common market of MicroGrid.

With the development of the Smart Grid technology [16] there are widespread isolated systems, including power generation systems based on diesel generator. Regulation of electricity prices now is not dynamic, and based on the set value [16], [22]. There are many available methods for a spot forecasting, for example, presented in [23], which produces forecasts for the electricity price in the spot market, for a term of 24 hours and can be used for the spot trade optimization. Another method for a electricity price forecasting is pointed in [24], where a single-hour and 24-hour models are used to study the electricity price forecast. For a fixed hourly tariff price, availability a considerable part of transients in the base period of time causes significant deviation of actual established tariff prices, that leads either to a lack, or an excess of money in the system. The apparent actuality creating a flexible dynamic tariffication that will provide a money balance between consumer and producer of electricity.

The problem of the development of dynamic tarrification rose much earlier, for example in [25] presented an integration of consumer and utility, applications oriented theoretical models, for the purpose of establishing an overall systems approach to the behavior and interaction of the participants in a dynamic tariff environment. This method assumes that industrial loads which can be started or stopped without technical limitations, so the starting and stoping times are so short that they can be taken as zero. Another method presented in [26] is based on dynamic models to correctly incorporate the fundamentally dynamic nature of power system regulation and incentive the corresponding desirable actions. In [27] presented a dynamic pricing strategy for Smart Grid. The objective of this strategy is to discourage concentrated electricity usage and flatten peak load in the power system. The price is subject to multiple factors such as location, time, and usage. Current pricing strategy links the price to time and location only and ignores its usage-dependent nature. The methods considered above do not take into account the influence of transient processes when switching operating modes. It is obvious that the duration of transient processes in generator has a direct impact on the cost parameters of an isolated system, i.e. the deviation of actual tariff price of electricity from that accepted by static values set out in the existing model of hourly billing. As a part of the introduction of a flexible tariffication we need a dynamic electro-cost model that combines energy and economic indices of the closed power generating system, consisting of a generator and consumer, that allows to explore the impact of transients generator to changing value indicators of the economic system and calculate an adequate tariff price for producers and consumers.

The rest of this paper is organized as follows. Section II describes the general principles of creation of electro-cost models. Section III is devoted to the static model of the isolated electro-cost system. Section IV illustrates the dynamic model isolated electro-cost system. Section V shows the research of transition processes in system. Section VI is dedicated to conclusions of the paper.

2. GENERAL PRINCIPLES OF CREATION OF ELECTRO-COST MODELS

At creation of control algorithms of power supply of knot of the distributed generation taking into account cost factors the greatest interest is caused by the theory of the general equilibrium [6] which allows formulating conditions of the most effective management of power supply with providing the minimum cost expenses in a common market of production and consumption. From positions of the economic theory products produced and consumed in the market of the local system (Fig. 1) is electrical energy. The electric network and alternative generators, being a part of system, carry out a role of producers of production, and loading-her consumers.

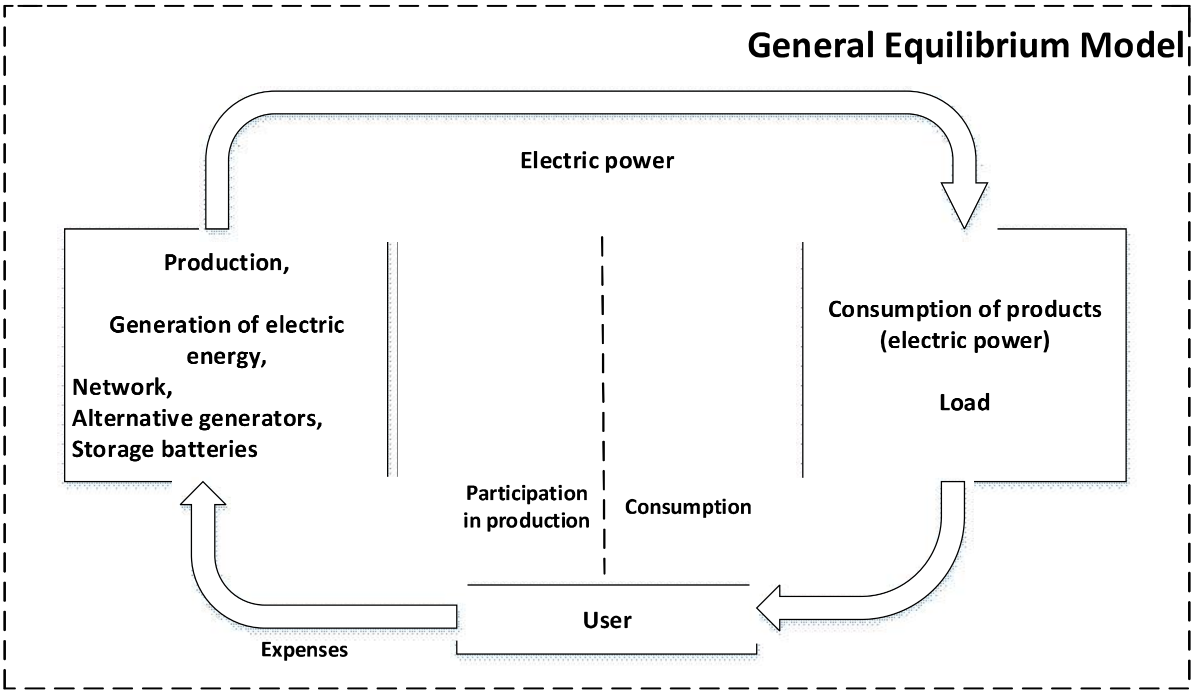

Fig. 1. The balance of production and consumption

For each electro technical device (the generator or the consumer of energy) it is necessary to solve the optimum problem in the field of minimization of expenses with ensuring efficiency of functioning. Set of separate optimizing tasks allows to formulate a problem of the general equilibrium and to define the most expedient strategy of adaptation of management both separate devices, and all system taking into account the expenses necessary for maintenance of this balance in the system providing optimum use of energy [6].

Electro-cost model of the general equilibrium in a common market of production and consumption of electric energy:

$$\begin{cases} \dfrac{dX(t,\Delta W,\Delta\$)}{dt} = A(t,\Delta W,\Delta\$)X(t,\Delta W,\Delta\$) + U(t,\Delta W,\Delta\$) \\ \Delta W = \sum_{f=1}^{F} W_j^f - \sum_{h=1}^{H} W_j^h \to 0, \quad j=\overline{1,n} \\ \Delta\$ = \sum_{f=1}^{F} r_i^f - \sum_{h=1}^{H} r_i^h \to 0, \quad i=\overline{1,m} \end{cases} \tag{1}$$

where H and F – number of consumers and sources in compliance; W_j^f and W_i^h – the amount of energy, makes each generator f and each consumer of h respectively consumes, ΔW – excess of the developed energy which can't be used that defines a condition $\Delta W \to 0$; r_j^f and r_i^h – volumes of expenses of *i* a look, $i = \overline{1, m},$ necessary for electricity generation by each generator *f* and for functioning of the consumer of *h*.

Under a common market of production and consumption in this context set of the devices making and consuming energy and also channels of an exchange of energy at the certain tariff rates (prices) means.

Use of the given models allows describing the technical and economic processes proceeding in separate components of electro technical object of Micro Grid, interaction between them, and also the general behaviour of object is realized for achievement of an overall objective of ensuring effective management of power supply.

3. STATIC MODEL ISOLATED ELECTRO-COST SYSTEM

For quantitative estimation and comparison of different energy sources in uninterruptible power supply system the generalized method is used for estimation of most important parameters common for considered sources [2], [7], [11].

1) **Specific equipment cost** of energy supply system:

$$B_{spec} = \frac{K_{eq}}{P_{nom}} \tag{2}$$

where K_{eq} is the cost of equipment set; P_{nom} – nominal power of the system;

2) **Lifecycle** of energy supply system that is regulated by equipment manufacturer for each concrete system separately. On the average, lifecycle of PV cells and wind generators is about 15–30 years. The lifecycle of diesel generators is limited by amount of working hours and depends on the type of equipment, working conditions and other factors;

3) **Consolidated year expenses** for the generation of 1 kW of total capacity per year:

$$Z = \frac{P_r \cdot K_c + C}{P} \tag{3}$$

where P_r is regulatory value of profitability; K_c is common investment; C – expenses for technical support service, maintenance, repair; P – total capacity of supplied object;

The general capital investments of K_c are in turn calculated as:

$$K_c = K_{eq} + K_{pr} + K_m \tag{4}$$

where K_{eq} is equipment set cost; K_{pr} is the value of designing, definition of placement location, and installation; K_m is cost of construction and installation works, installation cost.

The standard coefficient of profitability in (3) is calculated as:

$$P_r = \frac{1}{T_{ex}} \tag{5}$$

4) **Prime cost** of 1 kW*h generated by alternative sources:

$$C_{prime} = \frac{K(t) + C(t)}{W_{gen}(t)} \tag{6}$$

where $W_{gen}(t)$ is total generating power of the system for some period t; $K(t)$ – expenses for the generation for the period t.

Expenses on generation of energy during t time:

$$K(t) = \frac{K_c}{T_{ex}} \cdot t \tag{7}$$

Total generating power is calculated as follows:

$$W_{gen}(t) = \int_0^t P_{gen}(t)dt \tag{8}$$

where $P_{gen}(t)$ is the power generated for the period t.

So, based on the equations given above, provided $t < T_{ex}$ cost of 1 kWh of electricity generated by power plants on the basis of alternative energy sources is calculated using the following formula:

$$C_{prime}(t) = \frac{\frac{K_c}{T_{ex}} \cdot t + C(t)}{\int_0^t P_{gen}(t)dt} \tag{9}$$

5) **Payback period** of energy supply system under the condition $P_{gen} < P_r$ can be calculated as:

$$T_{pb}(t) \frac{K_c + C(t)}{C_{network} \cdot W_{gen}(t)} \tag{10}$$

where $C_{network}$ is actual tariff for electrical energy from the power network 220 V.

6) **Profit** from system functioning – the difference between the revenue and corresponding expenses:

$$T_{pr}(t) = C_{network\_total} \cdot W_{gen}(t) - K(t) \tag{11}$$

where $C_{network\_total}$ is the tariff for electrical energy from the state power network of public use [8], [10].

For each of types of alternative power sources there would be some distinctions in efficiency assessment. In particular, such distinctions could be caused by the way of energy tracking, or other factors and indicators connected with structural features of different kinds of generating systems.

The prime cost of different AES is calculated by formulas above, and the decision about expediency of their use, sale or purchase of the electrical energy by the calculated prices is accepted.

The analysis of different pricing methods showed the effectiveness of the method of maximizing the current profit based on the demand for the calculation of electrical energy price [11], [12].

Behind this method the price pays off on the following formula [9]:

$$C_{el} = C_{prime}(t) + \frac{N_{pr} \cdot K_{inv}}{100 \cdot N} \quad (12)$$

where N_{pr} is desirable rate of return as a percentage; K_{inv} – it's the size of the invested capital; N – the planned sales volume.

4. DYNAMIC MODEL ISOLATED ELECTRO-COST SYSTEM

With development of the Micro Grid [16] technology the isolated systems which in particular are power generating systems on the basis of the diesel generator [17] were widely adopted. Usually such systems have limited power and limited loadings. Price control to the electric power happens not dynamically so far and proceeding from the established cost. At the tariff price fixed hourly, existence of a large number of transition processes in basic a period causes a considerable deviation of the actual tariff price established that leads either to a shortcoming, or to surplus of means in system. Relevance of creation of flexible dynamic tariffing is obvious that it will allow providing balance of means between the consumer and the producer of the electric power.

Within introduction of flexible tariffing creation dynamic electro – the cost model uniting power and economic indicators of node of the distributed generation, consisting of the generator and the consumer by means of which it is possible to investigate influence of transition processes of the generator on change of cost indexes of object of MicroGrid, and calculations the adequate tariff price for producers and consumers of the electric power is required.

System "the producer–the consumer of the electric power" it is schematically presented in Fig. 2 as the closed macroeconomic system [18] which combines dynamic and economic parts of the isolated system.

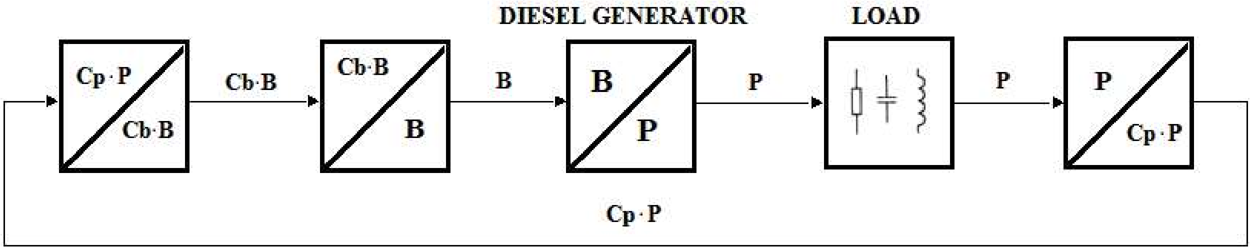

Fig. 2. System "the producer–the consumer of the electric power"

The generator provides electricity power P to consumer, and the consumer pays its cost in the amount of $C_P \cdot P$, where C_P is unit price of power. Generation system spends a certain amount of funds received for the purchase of fuel $C_B \cdot B$, where C_B is unit price of fuel, and a certain amount on their own needs. Received remaining of funds is the profit of the system. The balance of closed power generated system described by the Fisher equation [19] will look like:

$$M \cdot V = C_B \cdot B + C_P \cdot P$$

where M is money supply, which rotates once per time T_V, [uah]; $V = T/T_v$ is number of turns of the money supply M during the analysed period of time T.

Depending on his needs, consumer can increase or decrease the amount of electricity, characterized by level of power, so for some tariff interval Δt change of generated power will be happened, with the balance equation takes the form:

$$M \cdot V = C_B \cdot B + (C_P + \Delta C_P) \cdot (P + \Delta P)$$

Having presented changes in tariff price as: $\Delta C_P = \dfrac{M \cdot V - C_B \cdot B}{P \cdot \Delta t} - \dfrac{C_P \cdot \left(1 + \dfrac{\Delta P}{P}\right)}{\Delta t}$

and considering that $\Delta C_P = \dfrac{dC_P}{dt} \cdot \Delta t$ an equation received:

$$\frac{dC_P}{dt} = \frac{M \cdot V - C_B \cdot B}{P \cdot \Delta t} - \frac{C_P \cdot \left(1 + \dfrac{\Delta}{P}\right)}{\Delta t} \tag{13}$$

that describes the dynamic change of the C_P depending on capacity, that provides a per-second tariffication when $\Delta t = 1$ s. Component ΔP will not be used in this study, but it is necessary for the modelling in future tests.

Equation of the capacity expansion for diesel generator is presented in the following form:

$$\frac{dP}{dt} = -\frac{P}{\tau} + \frac{\eta_B}{\tau} \cdot \gamma \cdot B \qquad (14)$$

where η_B is efficiency of the generator, γ is conversion factor of fuel produced in power, τ is the time constant for the generator.

The construction of equations (13) and (14) gives a result of a dynamic system which is:

$$\begin{cases} \dfrac{dC_P}{dt} = \dfrac{M \cdot V - C_B \cdot B}{P} - C_P \cdot \left(1 + \dfrac{\Delta P}{P}\right), \\ \dfrac{dP}{dt} = -\dfrac{P}{\tau} + \dfrac{\eta_B}{\tau} \cdot \gamma \cdot B, \end{cases} \qquad (15)$$

where $C_B \cdot B = \beta \cdot C_P \cdot P$, $\dfrac{1}{\beta}$ – rate of profit of the economic system.

To reflect the changes in the output of the power generated in the resulting electro-cost model used value ΔB, despite the fact that M and V are close to constant. This assumption is based on the following facts. Money supply M is removed and returned to the system about once per quarter, respectively, studied in a small time interval, number of turns V will change insignificantly. The system (15) will look like:

$$\begin{cases} \dfrac{dC_P}{dt} = \dfrac{M \cdot V}{P} - C_P \cdot \left(1 + \beta + \dfrac{\Delta P}{P}\right) - \dfrac{\Delta B \cdot C_B}{B}, \\ \dfrac{dP}{dt} = -\dfrac{P}{\tau} + \dfrac{\eta_B \cdot \gamma \cdot (\beta \cdot C_P \cdot P)}{\tau \cdot C_B} + \dfrac{\eta_B \cdot \gamma \cdot \Delta B}{\tau}. \end{cases} \qquad (16)$$

Thus, received the system that combines electrical and economic parameters of isolated power generating systems with diesel generator, allows calculating dynamic change of the tariff price when changing level of generated power, or vice versa [20], [21].

5. RESEARCH OF TRANSITION PROCESSES IN SYSTEM

Dynamic simulation of transient processes in the system when there is a change and relative to the known initial values, with the parameters listed in Table 1, shows the macroeconomic balance of the system, because, while production power of generator is reducing, unit price of power will grow accordingly. In the absence of restrictions of increases and, after the transient process, corresponding values will be at levels optimal for the condition of the balance in Fisher equation. Simulation results are shown in Fig. 3.

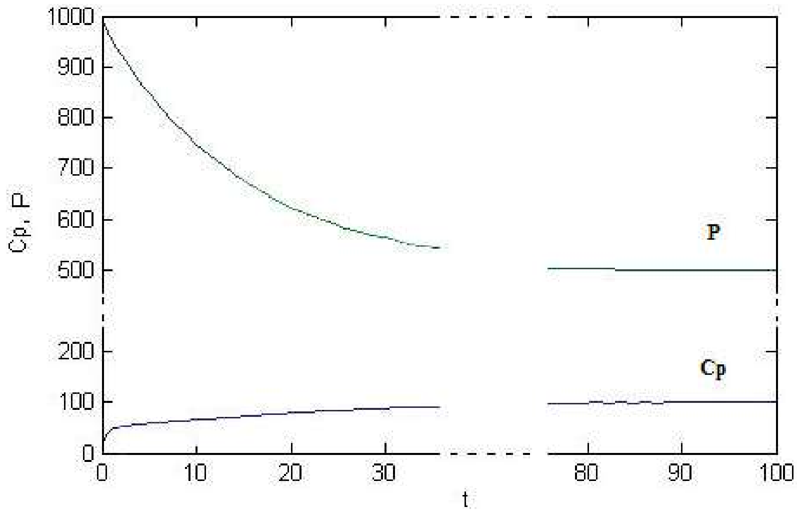

Fig. 3. Modeling of transition processes

Table 1. Parameters of dynamic model

Parameters	τ	η_B	γ	C_B	M	V	ΔB_P	β	ΔP	P_0	C_{P0}
Value	15	0.5	1 W/L	50 UAH/L	100000 UAH	1	0 L	1	0 W	1000 W	10 UAH/W

In the period of time $t = 0$ there is a decrease in the made power by 500 Wt, at the same time the tariff price increases according to a balance condition.

The resulting system allows calculating the dynamic defaults P and C_P after transient processes completed, when $\frac{dC_P}{dt}$ and $\frac{dP}{dt}$ are equal to zero.

From the first equation of (16), calculated relative C_P received:

$$C_P = \frac{M \cdot V - \Delta B \cdot C_B}{P + \beta \cdot P + \Delta P}. \tag{17}$$

From the second equation of (16), taking into account the expression for C_P obtained in (17), derived the following equation:

$$P^2 \cdot (-C_B - C_B \cdot \beta)$$
$$+ P \cdot (-\Delta P \cdot C_B + \eta_B \cdot \gamma \cdot \beta \cdot M \cdot V - \eta_B \cdot \gamma \cdot \beta \cdot \Delta B \cdot C_B)$$
$$+ \eta_B \cdot \gamma \cdot \Delta B = 0. \tag{18}$$

To solve a quadratic equation is performed substitution:

$$a = (-C_B - C_B \cdot \beta),$$

$$b = (-\Delta P \cdot C_B + \eta_B \cdot \gamma \cdot \beta \cdot M \cdot V - \eta_B \cdot \gamma \cdot \beta \cdot \Delta B \cdot C_B),$$

$$c = \eta_B \cdot \gamma \cdot \Delta B,$$

$$\sqrt{D} = \sqrt{b^2 - 4 \cdot a \cdot c}.$$

Since the money supply *M* is usually much higher than the value of other components of the equation (18), multiplier *b* will be positive. Accordingly, just one of the roots of the equation (18) will be positive: $P = (-b + \sqrt{D})/(2 \cdot a)$.

Substituting the resulting value P in the equation (17) and solving it, we will found expression of the tariff price: $C_P = (M \cdot V - \Delta B \cdot C_B)/(P + \beta \cdot P + \Delta P)$. With further research should be considered as a dynamic system parameters change and new static power value *P* and tariff price C_P, calculated in the steady state, after the transition.

6. CONCLUSIONS

It is offered static model of calculation of the price for various alternative sources. The developed algorithm of calculation of static price of electricity from alternative sources of the electric power for the consumer will allow the consumer to make reasoned decision on buy/sale the electric power. It is presented electro-cost model of the isolated power generating system allowing counting both dynamic change of the generated power, and dynamic change of the tariff price of the electric power taking into account static sizes of these parameters after completion of transition processes. Provided in paragraph IV dynamic model of isolated electro-cost system allows investigating changes in tariff price when the generator is switches to a new power regime. Using of the proposed electro-cost model of an isolated power generating system allows calculating the dynamic change of generating power and the dynamic change of the electricity tariff price, taking into account the static values of these parameters after the transition.

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