

Justification of Parameters of the Energy Supply System of Agricultural Enterprises with Using Wind Power Installations

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Abstract. The methodology is proposed and the simulation model of functioning of the energy supply system of agricultural enterprises using wind power installations is developed, which enables to solve the problem of justification of the parameters of the relevant system. The model of the energy supply system of an agricultural enterprise using wind power is developed, which is based on the method of stochastic simulation and provides justification of the parameters of this system by the cost criterion. On the basis of passive production experiments, the study of the natural-industrial conditions of energy supply of agricultural enterprises using the wind power installations for the conditions of Zhovkva district of Lviv region was performed. Computer experiments were carried out using the developed simulation model of functioning of the energy supply system of agricultural enterprises using wind power installations. On the example of the natural and production conditions of Zhovkva district of Lviv region, system functional indicators of the energy supply system of agricultural enterprises with the use of wind power installations are established. The tendencies of change in the cost of utilized energy for changes in parameters of the energy supply system of an agricultural enterprise using wind energy and the share of its replacement are justified.

1 Introduction

The current state of the energy market in the world, including Ukraine, is characterized by a clear tendency to increase the cost of traditional energy sources [1]. The environmental hazard of global warming also makes contribution. All this forces to search and improve alternative methods of energy conversion, including those that use wind power [2]. At the same time, the problem of energy supply of rural settlements, often remote from energy transmission lines, is equally acute. Thus, it may well be justified, at least in part, to cover the needs of agricultural producers in energy at the expense of specialized wind power installations.

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Although the construction of wind installations are currently quite advanced, their serial production in Ukraine is not well-organized. This condition is due to the lack of scientifically grounded methodology for determining the optimal parameters of the production system of such equipment, in particular the parametric number of wind machines, their release program, etc.

The use of wind energy to meet the needs of agricultural consumers is a rather actual problem, taking into account the rising fossil fuels' prices [3, 4, 18]. The peculiarity of the use of small wind installations is that individual wind power stations operate not on a network, but individually, that is, providing electricity with a limited range of consumers. That is why an adequate assessment of their effectiveness can only be carried out taking into account specific natural and production conditions [5, 16, 17].

Taking this into account, the task of justification the parameters of the energy supply system of agricultural enterprises using wind power installations has an important scientific and practical value.

The aim of the work is to justify the parameters of the energy supply system of agricultural enterprises using wind power installations for the given natural and production conditions.

2 Theoretical backgrounds

Energy supply of an agricultural enterprise using wind power installations involves the operation of a separate system with wind energy equipment, which operates effectively under certain natural and production conditions [6]. This system is complicated, and therefore its research requires the use of a statistical simulation model of processes occurring in the system. The complexity of the energy supply system of agricultural enterprises using wind power installation is confirmed by the presence of specific properties that occur in all complex systems [7], namely: uniqueness; difficult predictability; purposefulness.

The uniqueness of this system is that the use of wind power for electricity production has a number of features that are inherent in no other methods, including the occasional nature of the wind load, which is further deepened by the autonomous provision of agricultural consumers, as the technological processes of agriculture are also characterized by volatility of energy needs in time and lack of deterministic patterns of its change.

The complex predictability of the energy supply system of agricultural enterprises using wind power installations follows the same considerations as the uniqueness principle, namely the inability to unambiguously reconcile the needs of consumers of electric energy and the possibilities of using wind power potential.

The purpose of the energy supply system is to create conditions for reducing the level of unpredictability of the project.

Also, this system corresponds to three principles that underlie research, use and creation of complex systems: the principle of physicality; the principle of modeling; principle of purposefulness.

The principle of physicality lies in the fact that the designed system is characterized by physical laws, some of which are unique. These laws determine causal link, existence and functioning. The principle of modeling lies in the fact that a complex system can be represented by a finite set of models, each of which reflects a certain aspect of the system. This principle allows you to study the necessary group of properties of the system with the help of simplified narrow-oriented models. As it is known, a model, oriented to a certain group of properties of a complex system, is always simpler than the system itself. The principle of purposefulness is understood as a functional tendency aimed at the system achieving a certain state.

On the basis of system engineering for the study of such a system, it is necessary to stratify and determine the characteristics of the system's impact on objects and vice versa. After that, it is necessary to elaborate the details of the subsystems and the processes in them proceeding to a level sufficient for the description in the model [8, 9].

It is known [10-13] that the study of complex systems with variable natural and productive conditions in various sectors of the national economy should be carried out using their simulation modeling, which ensures obtaining accurate predicted indicators.

The efficiency of the energy supply system should be considered as a consequence of the joint action of the two subsystems of the lower level: the subsystem of the power generation system and the subsystem of energy consumption in the agricultural enterprise.

According to the chosen power supply scheme, the wind power installation generates energy accumulated in the accumulation system and is used by the consumer if the level of charge of the batteries is sufficient for "comfortable" operation. If the charge level drops to the given critical limit E_{min} , the system switches and the electricity is taken from a parallel source until the sufficient wind speed allows the batteries to be charged to a level sufficient to safely withdraw power from the accumulation system.

On the other hand, the upper limit of charging the accumulation system is also limited by the upper limit - the value E_{max} corresponds to the energy capacity of the batteries installed in the wind power installation.

Thus, the work of a wind power installation in the energy supply system of an agricultural enterprise should be considered as a change in the state of the system in time with a certain discrete interval. An example of charging-discharging schedule of the electric energy accumulation system at the wind power station is shown in Fig. 1.

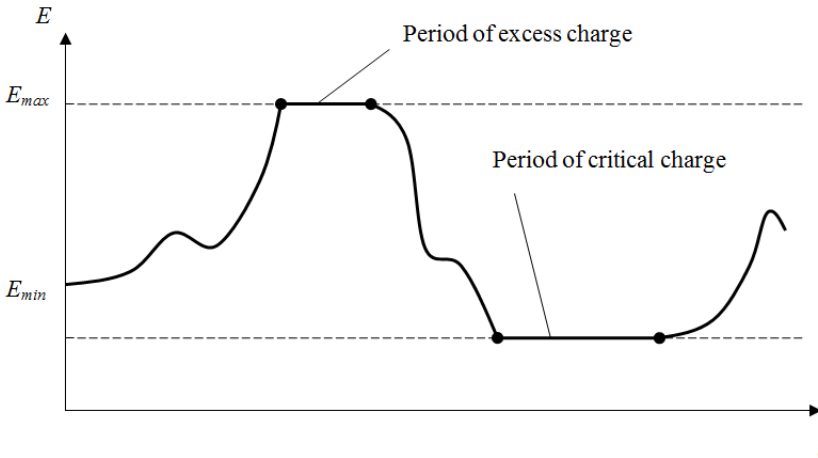


Fig. 1. An example of a graph of the charge level of the energy accumulation system of a wind power station.

As can be seen from the graph, the battery charge level is within the specified limits, with the possibility of establishing two characteristic periods - the period of excess charge, when the electricity can no longer accumulate in the system of wind power storage, and the critical charge period, when the use of energy from the wind power station is not feasible considering the damage of deep discharge to accumulating elements.

The subsystem of energy production is characterized, first of all, by the transforming function - the dependence between the wind speed and the parameters of the wind installation on the one hand, and the power output of the generator:

$$W_{\Sigma} = 0.615 \cdot 10^{-3} \cdot S_{\Sigma} \cdot v^3 \cdot \xi \cdot \eta_{BEV} \quad (1)$$

where W_{Σ} – total power produced by a complex of wind turbines, kW; S_{Σ} – total area of rotation of wind turbines installed in an agricultural enterprise, m²; V – instantaneous wind speed, m / s; ξ – coefficient of wind usage; η_{BEV} – efficiency output of wind turbine.

Wind speed is considered as a variable, non-constant value, as described by the relevant distribution law.

The amount of energy received from the wind power turbine for the elementary period of time Δt is equal to, kW/h:

$$\Delta E = W_{\Sigma} \cdot \Delta t \quad (2)$$

The subsystem of energy consumption is characterized by two main parameters - the amount of annual energy consumption in the economy P_p and unevenness of power consumption during the year.

An elemental amount of time consumed Δt energy is equal to, kW/h:

$$\Delta A = P(t) \cdot \Delta t \quad (3)$$

where $P(t)$ – instantaneous value of power consumption in an agricultural enterprise, kW.

Reconciliation of the schedules of income and consumption of energy is dependent on:

$$E = \min \left\{ \max \left[E + \Delta E - \frac{\Delta A}{\eta_{inv} \cdot \eta_{AB}}; E_{min} \right]; E_{AB} \right\} \quad (4)$$

where η_{inv} , η_{AB} efficiency output respectively of inverter and rechargeable batteries; E_{min} , E_{AB} – respectively, the minimum allowable depth of discharge of accumulative batteries, in which there are no irreversible changes in the chemical structure of the accumulation elements, and their energy capacity, kW/h.

The amount of energy consumed by the consumer for an elementary time interval is equal to (kW/h):

$$\Delta E_y = \min \left\{ \Delta A; \max \left[(E - E_{min}) \cdot \eta_{inv} \cdot \eta_{AB}; 0 \right] \right\} \quad (5)$$

The amount of utilized energy determines the positive effect of using a wind station for the energy supply of an agricultural enterprise. The use of formulas (1-5) allows us to construct an energy supply model for an agricultural enterprise using the stochastic simulation approach.

3 Research results and discussion

In order to study the influence of changing natural and production conditions on the parameters of the energy supply system of agricultural enterprises using wind power installations, an imitation supply model and computer program were developed. The simulation modeling of energy supply of agricultural enterprises using wind power installations was carried out. This simulation was carried out in accordance with pre-substantiated characteristics of natural and production conditions. For the research the natural and production conditions of Zhovkva district of the Lviv region have been adopted.

The research of the needs of agricultural enterprises in electricity was carried out according to a well-known method [14] based on a passive experiment. Data were collected on the use of energy by agricultural enterprises in Zhovkva District of Lviv region. At the same time, the amount of electricity consumed was recorded during each month of the year 2015-2018, for which a representative sample was formed. For each farm the average values of annual electricity consumption are determined:

$$P^p = \frac{1}{3} \sum_{r=2015}^{2018} \sum_{m=1}^{12} P_{r,m}^m \tag{6}$$

where $P_{r,m}^m$ – the amount of electricity consumed by agricultural enterprises during m-month, r-year, kW.h/year.

Distribution of values P_p for Zhovkva District is described by an exponential distribution law with mathematical expectations $P_p^{cp}=25698$ kW.h/year and mean-square deviation $\omega_{P_p}=23333$ kW.h/year. The empirical frequency and the theoretical distribution curve are shown in Fig. 2

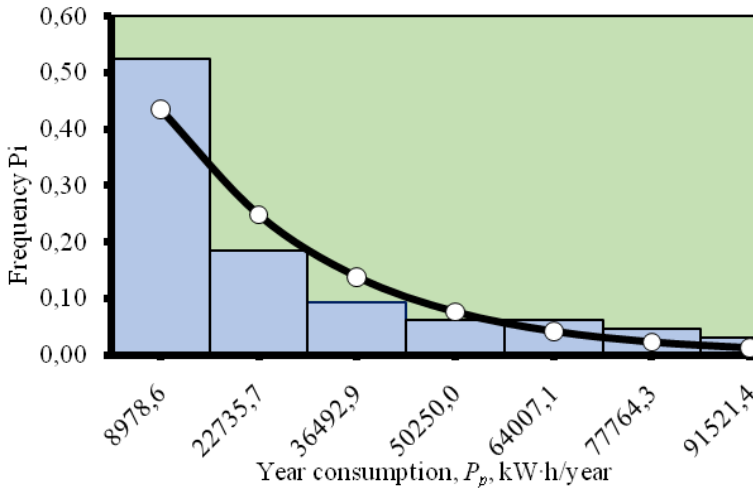


Fig. 2. Distribution of average annual electric energy consumption in agricultural enterprises of Zhovkva district of Lviv region.

During the study of seasonal fluctuations, a hypothesis was adopted that the energy consumption of the selected objects has a similar character. The data was normalized:

$$P_j^* = \frac{P_{m,j}^m \cdot 365}{P_j^p \cdot N_d} \tag{7}$$

where j – number of agricultural enterprise; N_d – amount of days in relevant month.

It is known that the needs of the consumer in power depend on the period of the year. By dividing all data for the months, we received twelve samples, each of which is described by the logarithmic normal distribution law with density:

$$f(p^*) = \frac{1}{\sqrt{2\pi} p^* \sigma_m} \exp\left[-(\ln p^* - \ln p_0^*) / 2\sigma_m^2\right] \tag{8}$$

where σ_{ln} – parameter of shape; $ln p_0^*$ – parameter of measure.

The characteristics of the wind potential are described by the distribution of the velocity and direction of the winds. It is commonly accepted to use the Weibull distribution [15] to study the time-varying wind flow. The research was conducted on the basis of a passive experiment based on the data of the Yavoriv Agrometeorological Station (in connection with the proximity of its territorial location to the Zhovkva district) over a five-year period. For each month, charts of the specified characteristics were constructed. In Fig. 3 an example of the wind speed distribution in December is given.

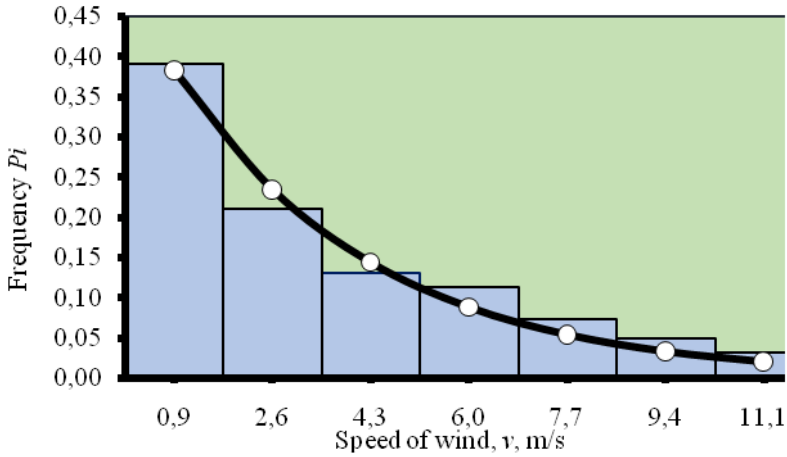


Fig. 3. Characteristics of the wind potential for Zhovkva district conditions for December.

We have carried out the simulation modeling of the energy supply system of the average agricultural enterprise ($P_p=25000\text{kW}\cdot\text{h}/\text{year}$) using wind power installations for natural and production conditions in Zhovkva district, Lviv region. This made it possible to get the predicted values, which are presented in the table 1.

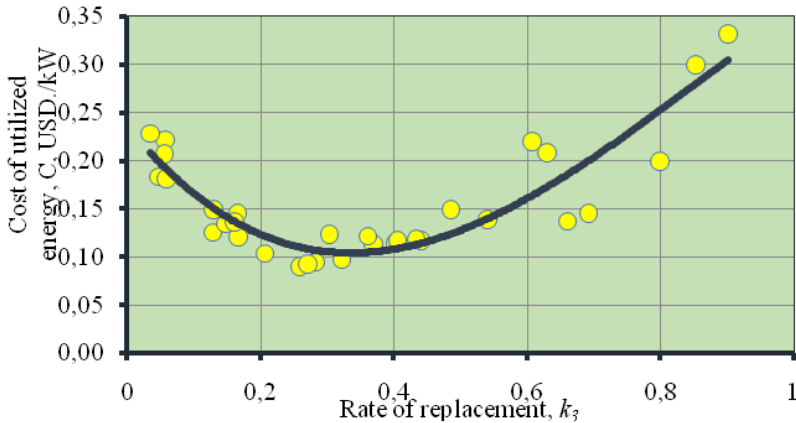


Fig. 4. Dependence of the cost of utilized energy (C) on the replacement factor (k_3) by the energy of the wind.

Table 1. Results of the justification of energy supply indicators of agricultural enterprises with annual consumption $P_p=25000\text{kW}\cdot\text{h}/\text{year}$.

The area of wind-receiving machine S , m^2	Capacity of the battery E_{AB} , $\text{kW}\cdot\text{h}$	Rate of replacement, k_3	Cost of utilized energy, C , USD/kW
8	30	0.058	0,222
8	50	0.057	0,208
8	10	0.048	0,183
8	5	0.035	0,229
8	20	0.059	0,182
22.9	20	0.129	0,126
22.9	40	0.167	0,122
22.9	60	0.166	0,146
22.9	30	0.149	0,135
22.9	50	0.162	0,137
50,2	30	0,259	0,090
50,2	50	0,283	0,095
50,2	70	0,322	0,097
50,2	10	0,13	0,150
50,2	20	0,207	0,104
50,2	40	0,271	0,093
78,5	70	0,402	0,115
78,5	100	0,441	0,118
78,5	50	0,37	0,114
78,5	30	0,304	0,124
86,5	40	0,361	0,122
86,5	60	0,406	0,117
86,5	80	0,434	0,119
86,5	200	0,54	0,139
86,5	500	0,607	0,220
86,5	1000	0,63	0,209
157	50	0,486	0,149
157	150	0,66	0,137
157	200	0,692	0,146
157	500	0,799	0,199
157	1000	0,852	0,300
157	2000	0,901	0,332

The obtained correlation dependence (Fig. 4) shows that the cost of utilized energy depends on the coefficient of its replacement (k_3). The obtained correlation dependence (Fig. 4) shows that the cost of utilized energy depends on the coefficient of its replacement:

$$C = -0,6074 \cdot k_3^3 + 1,5807 \cdot k_3^2 - 0,8558 \cdot k_3 + 0,236, r = 0,9 \quad (9)$$

The results of simulation modeling of energy supply of agricultural enterprises with annual consumption $P_p=25000\text{kW}\cdot\text{h}/\text{year}$ (table. 1) and the dependence of the cost of utilized energy (C) on the replacement factor (k_3) with wind energy (Fig. 4) indicate that the minimum cost of utilized energy falls within the option of using a wind power installation which has the area of the wind-receiving unit $S=50,2\text{m}^2$, the capacity of the battery $E_{AB}=30\text{kW}\cdot\text{h}$ and the rate of replacement is $k_3=0,259$.

Consequently, based on the results obtained, it can be said that for efficient energy supply of agricultural enterprises with annual consumption of $P_p=25000\text{kW}\cdot\text{h}/\text{year}$ with the use of wind energy should be based on a system consisting of both wind power installations and accumulative batteries that will replace 26% of electricity from wind power. This will allow you to get the minimum cost of utilized energy ($C_{min}=0,09$ USD/kW). The performed research will be useful for managers who perform planning and design in energy supply systems of agricultural enterprises using wind power. The regularities of changing the cost indicators of the functioning of energy supply systems of agricultural enterprises using wind power in different configurations are justified and will accelerate the implementation of the decision-making process and improve its quality.

Conclusion

To solve the problem of justification of parameters of the energy supply system of agricultural enterprises using wind power installations for given natural and production conditions, a method is proposed and an simulation model of the functioning of the corresponding system is developed. They provide a systematic study of the energy supply of agricultural enterprises using wind power installations due to the consideration of variable natural and production conditions for the given technical characteristics of equipment. The proposed approach allows us to construct an energy supply model for an agricultural enterprise using the stochastic simulation approach and the cost criterion.

On the basis of passive production experiments, the study of natural-industrial conditions of energy supply of agricultural enterprises for the use of wind power installations was performed. It is established that for the conditions of the Zhovkva district of Lviv region, the distribution of annual electricity consumption is described by an exponential distribution law with mathematical expectations $P_p^{cp}=25698$ kW.h/year and average square deviation $\omega_{Pp}=23333\text{kW}\cdot\text{h}/\text{year}$ and coefficient of variation $\eta=0,98$. It is established that for a given region, wind speed is variable. In December, it ranges from 0 to 12,3 m/s and is described by an exponential distribution law with mathematical expectations $v_{12}=3.5$ m/s and average square deviation $\omega_{12}=2,93$ m/s and coefficient of variation $\eta=0,83$.

Simulation modeling of the energy supply system of agricultural enterprises with annual consumption of $P_p=25000\text{kW}\cdot\text{h}/\text{year}$ for the use of wind power installations for the natural conditions of the Zhovkva district of Lviv region makes it possible to determine the system functional indicators of these systems that underlie the forecasting of the cost of utilized energy in the above systems. It has been established that for the efficient energy supply of agricultural enterprises with annual consumption of $P_p=25000\text{kW}\cdot\text{h}/\text{year}$ with using wind power, wind power systems should be formed, consisting of both wind power turbines and accumulative batteries, which will replace 26% of wind energy. This will allow to get the minimum cost of utilized energy ($C_{min}=0,09$ USD/kW).

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