Wind power plants functioning model in the power supply system

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Abstract. The system of complex energy supply of various objects is considered, existing problems in the field of wind power engineering are identified, those that leave complex energy supply using renewable energy sources are analyzed, and the quality of supplied energy is assessed by the efficiency factor. The structural model of wind power plant (HPU) functioning as a subsystem in the autonomous power supply system was considered separately. Methodological bases of designing in the form of structural scheme of methodology of development and creation of rotor HPU have been developed. All stages of designing and development of a wind power plant are analyzed.

Based on the general provisions of the existing power supply system, various energy production facilities, including different renewable energy sources (RES), can act as a converter of primary energy into electrical and (or) thermal energy. It has been established that the use of RES as possible alternative energy sources, both separately and (or) together with traditional ones, gives both economic and environmental effects [1-2, 7-8]. At the same time, issues of joint work are important, i.e. their interaction both with the general network and with various possible energy sources, including the energy received from wind power plants (WPP).

Therefore, considering WPP as a source of energy for various energy systems, opens up wide possibilities for its application in many sectors of the national economy, including agriculture for autonomous power supply.

Based on the analysis of existing research and development in the field of wind energy [3-7] we can conclude that there exist some methodological, technological and financial problems, on which the efficiency of using wind power plants in the power supply system depends.

Methodological problems include issues related to the need to use the theoretical and experimental foundations of research, as well as the development of a scientifically based methodology for creating WPP. The subjects of theoretical research are the obtained analytical dependencies in the course of research, describing the processes of WPP elements interaction with wind flows, taking into account the aerodynamic forces and moments acting on the rotors of various wind wheels. The main tools for such studies of various objects are mathematical methods of analysis, including static and dynamic methods for describing what happens during WPP work. When conducting experimental studies, it is necessary to take into account the specific features of WPP, namely, because of its high cost it is not always possible to conduct laboratory and industrial experiments. In such cases, it is advisable to use other research methods, for example, computer design, the use of physical models, etc. Namely, taking into account all of the above features is the basis for the development of scientific and methodological
foundations for the creation of WPP. Therefore, for a reliable power supply, including autonomous, for example, for agricultural facilities, it is necessary to design and create WPP, based on the developed scientific approaches.

Technological problems include the issues of energy efficiency of the functioning of both the WPP itself and the general power supply network. In addition, it is important to develop methods for choosing the structure of power supply, taking into account wind energy.

Financial problems include issues of competitiveness of wind energy, namely, low prices for electricity from traditional electricity supply.

Based on the foregoing, we note that the existing energy supply facilities using RES are distinguished by a great variety, which are based on traditional and renewable energy sources. They can be considered as a complex power supply system, Figure 1.

In an integrated power supply system, the determining factors are both the input flows of incoming energy resources and the output flows of useful energy from the source used.

![Figure 1. Integrated power supply system for various objects HS, ES – traditional electrical and heat supply systems; DPP, LPP – diesel power plant and local power plant; RES – renewable energy source; WPP – wind power plant.](image)

According to the energy balance, it is known that the required energy $Q_H$ includes:

$$Q_H = \sum_{i=1}^{n} Q_{EC_i} + \sum_{j=1}^{m} Q_{TC_j} + \sum_{k=1}^{s} Q_{BHE_k},$$

(1)

where $\sum_{i=1}^{n} Q_{EC_i} = Q_E$ – total consumed electricity from ESS or LPP;

$\sum_{j=1}^{m} Q_{TC_j} = Q_T$ – consumed total heat energy from HSS or TGP;

$\sum_{k=1}^{s} Q_{BHE_k} = Q_B$ – total consumed energy from RES or WPP.

To the total required electrical ($Q_E$) and (or) thermal energy ($Q_T$) useful energy can be added from one or more renewable sources:

$$Q_H = Q_T + Q_B.$$ 

(2)
Then, the efficiency of the consumer’s power supply will be determined by a rational combination and use of not only traditional sources \( Q_T \), but also resources RES \( Q_D \). In this case, the received useful energy from RES \( Q_D \), is an integral part of the required energy, which can replace a certain share of the traditionally used energy resource. In this case, the total energy from a traditional source depends on the efficiency of the use of wind, solar and other types of energy. It is important, at the same time, to know the share of replaced energy from each WPP for the calculated period (season, year):

\[
 f_B = \frac{Q_B}{Q_H} .
\]  

(3)

Taking into account the classification of existing RES by types of energy used, the component \( Q_B \) can be written as:

\[
 Q_B = Q_M + Q_C + Q_X ,
\]  

(4)

where \( Q_M = \sum_{p=1}^{P} Q_{B p} \) – total mechanical energy from wind and water;

\( Q_C = \sum_{l=1}^{L} Q_{C l} \) – total heat and radiant energy from the sun and earth;

\( Q_X = \sum_{r=1}^{R} Q_{X r} \) – total chemical energy contained in biomass.

Note that if we evaluate the quality of the supplied energy by the coefficient of efficiency, then renewable sources of mechanical energy are of sufficient quality and can be used for energy production. At the same time, the share of energy replaced by it depends on the conditions of energy supply to consumers from RES, including WPP.

As for WPP, we will consider its structural model of functioning as a subsystem in an autonomous power supply system SS WPP, figure 2.

**Figure 2.** Structural model of the WPP subsystem functioning in the autonomous power supply system

\[
 f_B = \frac{Q_B}{Q_H} .
\]
The input data of the WPP subsystem are aerological and energy indicators of wind, combined into the wind energy inventory of the region. Among them, we single out unmanaged $F_c(t)$ and managed $F_c(t)$ data (indicators). The uncontrollable indicators include, for example, the average annual wind speed, the annual course of the wind, the frequency repeatability, the type and parameters of the wind speed distribution function. As for the controlled parameters, this is the current average speed ($t$) and density $\rho(t)$ or specific power and specific energy of air flow. Exclude them, the defining indicators of WPP functioning are its design parameters $K_{wwp}$ and operation modes $R_{wwp}$. Expected energy generated from WPP $Q_{wwp}(t)$ in the form of determined model, but in reality is of random nature, can be supplied to the consumer directly or used for mechanical drive of technological machines and equipment $Q_{wwp}(t)$. The same deliveries can be carried out for energy $Q_{wwp}(t)$ and heat systems through which the consumer receives. In some cases, the energy consumption from WPP is effective when combined $Q_{res}(t)$ with different settings $RES$, for example in combination with solar collectors.

The question of choosing a WPP model as an object of research depends on many factors, among which we single out: is the model widespread; Does the model incorporate advanced wind power technologies, such as hollow fiberglass blades or permanent magnet synchronous generators, etc. Separately, we note that WPP with a vertical rotor position can be used in the option of direct connection, for example, a generator or mechanisms of various devices to a wind turbine.

Considering that the performance of the wind turbine $P_{wwp}=f(u)$ depends on the speed of the wind flow ($u$), and also known air density ($\rho$) and the radius of the wind wheel ($R$), then its efficiency can be determined using the coefficient of wind energy use [6]:

$$C_p = \frac{2 \cdot P_{\text{B}} \cdot \eta_{\text{B}} \cdot \rho \cdot \pi \cdot R^2 \cdot v^3}{\rho \cdot \pi \cdot R^2 \cdot \nu^3 \cdot \eta_{\text{B}}},$$

(5)

This WPP model uses a direct connection of a generator or mechanism of various devices to the wind turbine. Then the total efficiency of the wind turbine will be determined by the efficiency of the electric generator $\eta_e$, or the mechanism used $\eta_m$.

The final criterion for assessing the functioning of the WPP subsystem and choosing a rational combination of traditional and renewable energy resources is the minimum cost of energy required:

$$3 = \sum_{i=1}^{n} \left( C_{B_i} \cdot Q_{B_i} \right) + \left( C_e \cdot Q_e + C_T \cdot Q_T \right) \cdot \left( 1 - f_B \right),$$

(6)

where $C_B, C_T, C_{B_i}$ – unit costs, respectively, for the receipt of electrical, (or) heat and renewable energy, including from WPP.

For efficient energy supply to consumers, it is advisable to use any WPPs that are developed and created taking into account the above provisions.

The object of research is a vertical-axial rotary wind power plant for a number of significant factors: the independence of WPP from the direction of the wind flow; minimum starting speed of electricity generation; the ability to regulate the speed and mechanical drive of various machines and equipment; simplicity of design; convenience of service and repair; lack of noise and vibration; low cost of electricity received. However, for efficient energy supply of various objects from WPP, advanced technical means and technologies created based on scientific approaches should be used. Therefore, the methodological foundations for the design and development of a rotary WPP are considered, the structure of which, taking into account the provisions of the systems approach, is shown in Figure (3).

Theoretical and experimental (laboratory) studies are fundamental to the design of WPP.

Theoretical studies (TS block) are based on the study of the influence and analysis of the processes of interaction of working bodies (blades, rotor, concentrator) with the airflow. Based on the results of the calculations, the aerodynamic forces acting on the working blades and the arising moments on the wind turbine rotor are determined.
Experimental studies on the basis of manufactured WPPs are expensive, therefore laboratory studies are planned in the work (LS block)

Figure 3. Block diagram of the methodology for the development and creation of a rotary WPP

With the help of computer modeling and design, as well as a comprehensive analysis of the results obtained, it becomes possible to create physical models of the rotor and concentrator. To evaluate and compare physical models with real objects, for example, the similarity theory can be used.

At the final stage of practical implementation (PI block), a comparison of the calculated and laboratory data is carried out with a check of the conditions for satisfactory results according to the specified criteria. Constructive, technological and energy parameters must meet all the requirements for them, and all evaluation criteria must comply with the current GOST and SNiP for WPP. Additionally, with the help of new developments, opportunities are envisaged to expand the limits of efficient use of wind energy and increase the sustainability of WPP.

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