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EFFECTIVE CONTROL OF INDEPENDENT WIND TURBINE BY USING A HYDRAULIC SYSTEM

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ЕФЕКТИВНЕ КЕРУВАННЯ АВТОНОМНОЮ ВЕУ ЗА ДОПОМОГОЮ ГІДРОСИСТЕМИ

Proposed to use a range of wind velocity, instead of determination range of a working-time intervals duration, of wind-energy generator (WEG), for pre-prognosis of energy value, which generated by WEG. We offer a criteria of WEG energy efficiency, that allows to choose a rational value of nominal power and working range of wind stream speed, and considers the energy consumer type (type of load), connected to WEG. Considered an opportunity to increase the energy efficiency of WEG by using a hydraulic transmission, in a power dispense system. It will allow to expand a range of working wind velocities and will let to use a several consuming loads, from different functional groups, in a one system.
Keywords: *wind generator, energy efficiency, hydraulic drive*

Introduction

A problem of energy economy and rational using of it makes actual conceptions of designing a systems and devices that use a renewable energy sources. Active development of technical approaches, those let to use rationally a wind energy, had allowed to provide designing and creating a new types of combined wind generators, that use different alternative and traditional energy sources [1]. To this type relate different kinds of autonomic wind generators, devices, which consuming thermal energy (hydrothermal power plants) etc. In articles [2], [3] represented some principle decisions for such systems. The efficiency of using of them significantly depends on an energy cadaster (wind, streams) of areas, where they installed. Practical solving of energy saving problems showed, that the most effective are aggregated systems, performed by a “devise synthesis”, used several kinds of energy (for example, energy of wind and energy of waves and so on). As module of this system may be used a complex of wind energetic and hydro energetic constituents.

During designing combined systems, the most important questions are problems of reliability for extreme using, and problems of rational control with orientation for a maximum energy supplying of consuming objects, connected to them. The description of calculation methods for energy generators with a row of main parameters established in articles [1, 3].

A very difficult problem is to build a rational structure and organization of an effective "control" of such, multi-component energy system. A number of new technical solutions have been formed to develop devices, which use the energy of the air flow – wind energy generators (WEG). In the problem of control and increasing the efficiency of the wind turbine, main problem is the volatility of wind flow, limiting the energy efficiency of traditional solutions by the value of 20 ... 25%, and 10 ... 15% in areas with low average annual values of speed (3 ... 5 m/sec). This is, primarily, due to the fact, that energy production of wind turbines is generated in periods when the air flow power is equal or exceeds the nominal power of the wind turbine.

Creating combined power plants partly helped to solve this problem by combining uncontrollable, bad controllable and controllable energy sources into the overall system (wind turbine, water turbine, devices using the energy of the tides, solar-stations and diesel generators). Wherein, this separation of consumers included in the overall circuit, the group of prioritized energy consumption, makes it possible to quickly redistribute the excess energy and thus improve the degree of the incoming stream energy using.

Given the stochastic nature of the velocity distribution of the air flow (AF) in time, the using of small wind velocities leads to a further reduction of the energy efficiency of wind turbines. This leads to limited development of small and medium wind energetic (air flow speed less than 8 m/sec). At the same time in Ukraine a large number of regions with sufficient wind energy potential, characterized by average annual speeds (4 ... 6) m/sec.

To determine the reasons for the low efficiency of wind turbines and the ways of its improvement, have been made some investigations of power conversion circuit of the AF into the input power, applied to the consumer [4]. The analysis showed that the greatest losses based on a mismatch of the values of the instantaneous power of the AF and the connected power consumer system (Fig. 1). Matching characteristics of all links in the chain, based on the estimating of energy, that produced and the effective time of the wind turbine, is a perspective scientific direction.

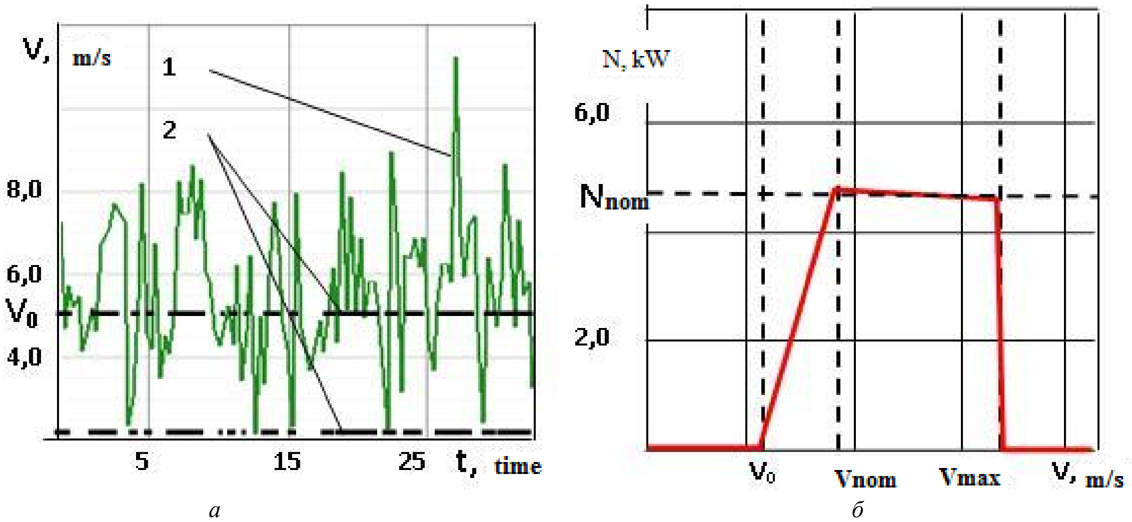


Fig. 1. Conversion of energy stream: a - characteristics of air flow, received by wind impeller; b - characteristics of energy consumer

Predicting annual energy generating

As far as the velocity distribution of AF during the year is very oscillating function (Fig. 2.a), for predicting annual energy, produced by a wind turbine and the time of its active work, has been proposed the using of probability calculation of nominal wind velocity hit into defined time intervals. Such calculation is possible in a case, when range of durations of speed intervals of air flow is replaced on a defining range of wind speeds by converting the velocity distribution function by the Lebesgue integral [5]:

$$T = \sum_{V_0}^{V_{\max}} \Delta t(V_i) = K_V \cdot \int_{V_0}^{V_{\max}} t'(V)dV ,$$

where $V_0, V_{\max}$ – initial and maximum wind velocities in a considered interval, T – time interval of speeds defining in a range from V_0 up to V_{max} , $t'(V) = a_0 + a_1 \cdot V + a_2 \cdot V^2 + a_3 \cdot V^3 + a_4 \cdot V^4$ - polynomial function, defined of the AF speed distribution for particular area (Fig. 2b), K_V - coefficient, which compensates approximation errors and considers duration of working speeds range during the year.

Prediction of annual accessible energy for a considered range of working wind speeds is performed on speed distribution of wind, in areas, where generator installation is planned.

The value of generated energy for a working speeds range (V_0, $V_{\max}$) defined by the next equation:

$$W = N_0 \cdot \int_{V_0}^{V_{\max}} t'(V)dV, \qquad (1)$$

where $N_0 = K_N \cdot V_0^3$ - nominal power, which matches the initial velocity V_0, K_N - coefficient, that considers the impeller parameters.

The value of generated energy will depend not only of impeller characteristics, it depends on the initial value of speed V_0. Firstly, initial velocity determines a value of nominal power N_0. Secondly, the initial velocity at a fixed value of maximum speed determines the time of active operation of wind turbines within a year (power generating duration). Thus, the best result of the solution (1) are such values V_0 and V_{max},, which will provide the maximum amount of energy.

With that said, for systems with one constant power consumer, the amount of energy is determined by the multiplication of power and time of active work on a time interval of one year, and the solution of the energy efficiency of wind turbines is reduced to finding the nominal value of the power that matches to the energy maximum:

$$K_{SW} = \max_{Vi = V_0}^{Vi = V_{\max}} [T(V_i, V_{\max}) \cdot N(V_i)] .$$

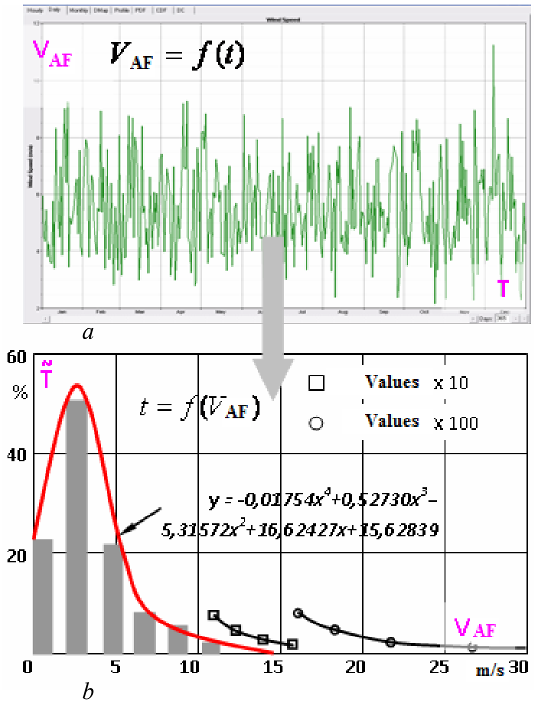


Fig. 2. Changing the range of function for the speed repetition of an air flow

The results of the comparative calculation and comparison of the proposed approach with practical data showed that the choice of the optimal value of the nominal wind speed allows to obtain 1.56 MW-hour more energy per year, based on the 4.5 kW wind turbines at an average air speed 5.2 m/sec.

At the same time it remains unused 40 ... 60% of the received energy by the wind turbine.

As the next stage, for improving the efficiency of the wind turbine, may be the using of a system with a variable (step) power characteristic. This embodiment contains a several kinds of loads in the system, which can function as a single connection mode and a parallel mode. The amount of energy, that generated by wind turbines per year is the sum of energy for each unit (the consumer) separately, taking into account the working range of speeds and time of power supply for every consumer, throughout the year:

$$W_{V_1 \div V_{\max}} = N_{V_1} \cdot K_V \int_{V_1}^{V_2} t'(V)dV + \ldots + N_{V_i} \cdot K_V \int_{V_i}^{V_{\max}} t'(V)dV \,,$$

where $N_{V_1} \ldots N_{V_i}$ - nominal values of power of every energy generating device in wind turbine unit.

Consumers in the system may have difference not only in the value of the nominal power, but also in characteristics (constant level of power, linear or other characteristic). During creating stand-alone power systems, based on wind turbine power generators, time index should be included into energy efficiency criteria. Depending on the functionality of systems, it is proposed to take into consideration the importance of the ratio of the amount of energy and the period of active work with the help of the relative operating time and the parameter **s**:

$$K_W = \max_{V_i=V_0}^{V_i=V_{\max}} \left[W(V_i, V_{\max}) \cdot \tilde{T}^{s_j}(V_0, V_i, V_{\max}) \right],$$

where s_j - coefficient of "j-s" consumers group, $\tilde{T}^{S_j}(V_0,V_i,V_{\max}) = T(V_i,V_{\max}) \big/ T(V_0,V_{\max})$ - ratio of energizing time of "j-s" consumers group by the time of the WEG "active" work.

Given the changing range $[0\ldots1]$ of the parameter **s**, depending on the functional groups of consumers (Table. 1), the energy criterion will determine the optimum values of the nominal wind speed that will provide the maximum amount of energy.

Table 1

An example of dividing on functional consumers groups

Functional group	S parameter value	Criterion of energy efficiency, K_S
continuous consumption of constant power (sensors, equipment, reserve systems)	$S_1 = 1$	$K_{S1} = \max_{V_i=V_0}^{V_i=V_{\max}} [W(V_i,V_{\max}) \times \times \tilde{T}(V_0,V_i,V_{\max})]$
consumption of certain power, according to defined time (devices of periodic action)	$S_2 = \dfrac{V_{month}^{\max} - V_{month}^{\min}}{V_{year}}$	$K_{S2} = \max_{V_i=V_0}^{V_i=V_{\max}} [W(V_i,V_{\max}) \times \times \tilde{T}^{S2}(V_0,V_i,V_{\max})]$
unregulated consumption by the power and time (households and other)	$S_3 = 0{,}5 S_2$	$K_{S3} = \max_{V_i=V_0}^{V_i=V_{\max}} [W(V_i,V_{\max}) \times \times \tilde{T}^{S3}(V_0,V_i,V_{\max})]$
consumption as the generating, accumulation (water heating, heat accumulators)	$S_4 = 0$	$K_{S4} = \max_{V_i=V_0}^{V_i=V_{\max}} [W(V_i,V_{\max})]$

The calculations, performed by the example of system with three consumers of fourth functional group ($S_4 = 0$, Table 1) showed that the use of the nominal speed, obtained during the optimization, may increase the annual volume of energy by 40% as compared with single-level systems, where the rated speed is selected by the average annual value with a correction factor of 1.2 - 1.3.

The hydraulic drive application in the adaptive systems of power take-off in the wind turbines

Investigations have shown that increasing the energy efficiency of wind power plant capacity, by adapting energy consumers to the characteristics of the air flow is possible due to the use of hydraulic drive in the power take-off system of wind turbines. Hydraulic systems with discrete control of flow and pressure allow to separate the excess power and use it to energize additional energy consumers. Hydraulic drives may change the ratio of the angular velocity and pressure in one unit at constant power, which is a prerequisite for a more complete selection of energy. Thus, the hydraulic system is capable of performing the current (change settings) and long term (for the structure and the number of channels of power) coordination of wind turbine characteristics with the characteristics of the air flow by the criterion of the maximum amount of energy.

For example, as power take-off system that's providing parallel and / or serial operation of 3 energy consuming devices, and 7 power levels, the hydraulic circuit has been developed for this case (Fig. 3).

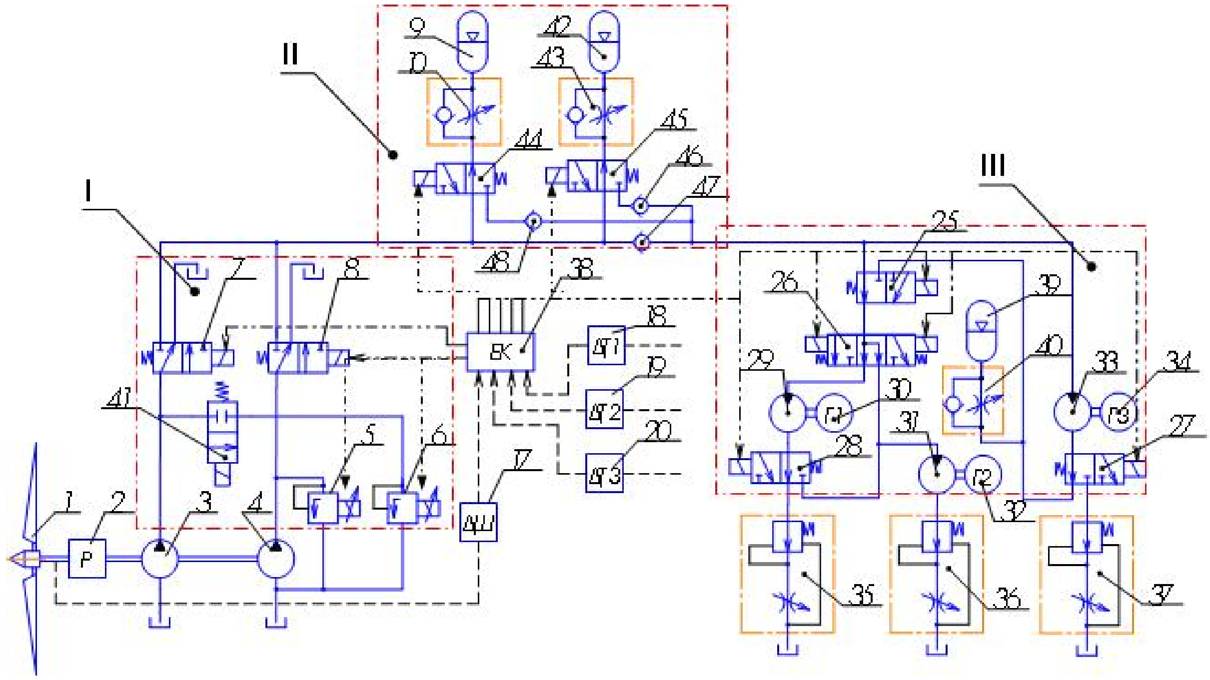


Fig. 3. The principle circuit of the adaptive hydraulic power take-off system for the WEG with step 7-level characteristic 1 – wind turbine, 3, 4 – pumps, 5, 6 – proportional valves of pressure modes adjusting, I – loading block, II – block of stabilizing and accumulation, III – control block of flow trajectory, 17 – 20 – parameter sensors, 35 – 37 – flow regulators, 38 – controller, 29 – 34 – hydraulic motors with attached generators

The energy of an air flow, received by a wind impeller 1, transmits to the hydraulic system in the form of one (4) or two (3 and 4) power channels by a pair of pumps 3 and 4. The valves 5 and 6 set pressure, which together with the set flow rate (35, 36, 37) defines a hydraulic power, supplied to the energy generating devices (32, 34, 36) in each channel. The control system via the control valves (25, 26, 27, 28 and 29) makes these channels active or conducts energy flow past them. Thus, we solve the problem of partial adaptation of level of total (all channels) connected power to the output current power value on the shaft of the wind turbine.

Adaptation to short-term ripple input power is performed using an uncontrollable (39, 40) hydraulic accumulation device. In the case of a longer dropping or increasing of the power of the wind turbine in operation algorithm includes control unit of hydraulic accumulation devices (9, 10, 42 ... 48). This unit allows alternately charging two accumulators, with excess power in the hydraulic line, and connecting them to consumers in the case of current power input deficiency.

Adaptive control algorithm for a power take-off system

A flexible hydraulic control algorithm for the power take-off system can not only arrange switching between energy devices of different power, but also to provide their work together, depending on changes in airflow.

In systems with multiple users it's necessary to control consistent changes (increase or decrease) of the power level of the wind flow {N0, N1, N2, ..., Nk}. Accordingly, the system has multiple generating devices, the data for the adaptation obtained by the test values for both power levels, and for individual devices.

The general case of N-level system appears to multi-link graph (Fig. 4) [6]. Each part of the graph describes a single mode of constant rated power. Starting from the second mode in the sequence of commands is included the adjusting parameter, to configure the system - nominal flow rate and pressure characteristics, provided by proportional valve.

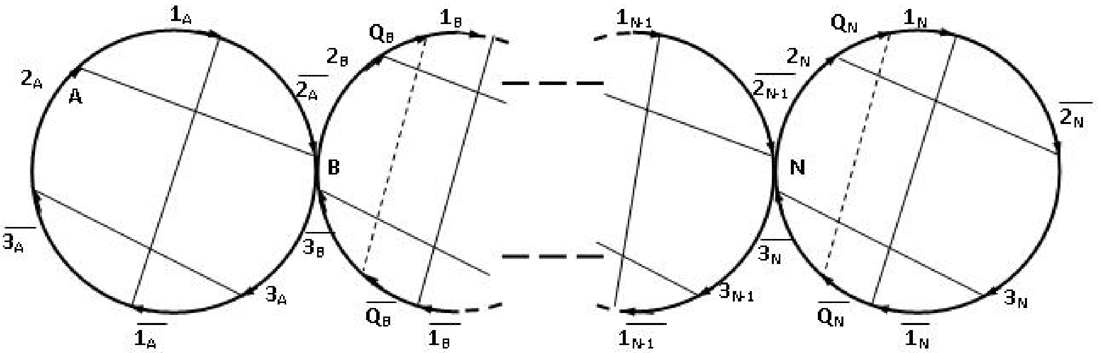


Fig. 4. Functional graph of adaptive N-level power take-off system: A, B, … , N – power levels, $1_К$ –connection of К-s level, $2_К$ – control of conditions of level increasing, $3_К$ – control of conditions of level reducing, $Q_К$ – switching of pressure and flow (К-1)-s and К-s levels

The using of cause-consequence model allows to get a common type of control commands for N-levels system: enabling /disabling of power levels (1K), of control devices of increasing (2K) and reducing (3K) of power, and of parameters switching (QK):

$$
\begin{aligned}
&Y_{1A} \Leftarrow X_{2A};\quad Y_{\overline{1A}} \Leftarrow X_{3A},\, Y_{1K} \Leftarrow X_{2K} \cdot X_{QK};\quad Y_{\overline{1K}} \Leftarrow X_{3K}\ ,\\
&Y_{2K} \Leftarrow X_{\overline{3K}} \cdot X_{\overline{1K}};\quad Y_{\overline{2K}} \Leftarrow X_{1K}\ ,\ Y_{3K} \Leftarrow X_{\overline{3K+1}} \cdot X_{\overline{2K}} \cdot X_{1K};\quad Y_{\overline{3K}} \Leftarrow X_{\overline{1K}}\ ,\\
&Y_{QK} \Leftarrow X_{2K};\quad Y_{\overline{QK}} \Leftarrow X_{\overline{1K}} \cdot X_{3K}\ .
\end{aligned}
\qquad (2)
$$

In the last range of power, the switching of hydraulic system parameters supplemented with a connection of the flow restrictor.

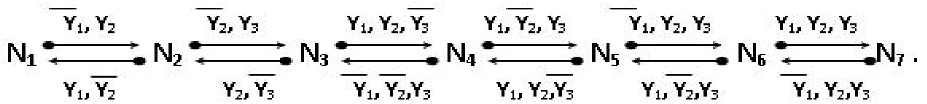
In accordance to (2) and sequence of enabling the modes of different rated power, the commands are formed for a enabling/disabling the energy generating devices, wherein the command for a device is a logical sum of commands for modes, where this device is active:

$$
Y_{i\Gamma\mathrm{Y}} \Leftarrow \bigcup_{j=1,N} Y_{1j} : i \in \{Z_j\} \vee Y_{\overline{1j}} : i \in \{Z_j\}\ . \qquad (3)
$$

For system, with 7 levels of power and with three devices, when ($N_{3г} < N_{1г}+N_{2г}$), for consistent modes changing

$$
N_{1г} \rightarrow N_{2г} \rightarrow N_{3г} \rightarrow N_{1г}+N_{2г} \rightarrow N_{1г}+N_{3г} \rightarrow N_{3г}+N_{2г} \rightarrow N_{1г}+N_{2г}+N_{3г}
$$

as result, we will get the next:



In accordance to (2) and (3) and the sequence of connection units, make a control algorithm for the direction control valves and the memory elements with a time delay (timer), sufficient to control the power level and provide energy storage. The commands of enabling – disabling of the memory elements take into account the fact that the current level of power and energy reserve, due to a pressure-relay switch, is performed by the accumulating scheme, that is, when the next level is reached, all the signals of the achievement of previous levels are saved. The transition to a higher power level can be done only when a signal from the corresponding timer is available. This timers are activated only when the pressure value in the system is enough to jump to the next level of power {T (p1), T (p2), T (p1+2)}. The pressure drop below a defined level in the range of T(pi) will disable the timer, and makes impossible the transition to a higher power level.

The proposed algorithm has been tested on the experimental model of the hydraulic system with 2 channels of energy consuming, with a range of pressure changes 2.0 ... 8.0 MPa and flow rate 3.2 ... 12.3 dm^3/min. By increasing or decreasing the hydraulic flow power supplying, automatically, upon reaching a predetermined level, connects or disconnects the 1-st, 2-nd or two hydraulic motors contemporaneously.

Conclusions

Considered approach of WEG energy efficiency increasing by the way of adaptation the value of connected power to the speed (or power) of air flow showed, that reserves of unused energy amount is (30 … 80)% and more.

This approach oriented only for dividing of energy flow – flexible algorithm of several consumers connection to the one uncontrollable energy source, it can be an air flow, water stream, heat stream of Sun energy.

Combining in the system multiple energy sources of different physical nature, with different and non-coincident in time periods of increasing and decreasing power, opens the possibility of adapting the input energy to the power consumption.

Application of the criterion, based on the passing of the time range to the range as a function of the total input power, can be used when searching for rational values of the nominal power of consumers and control algorithms of their energy supply, systems with a branched structure of energy flows aimed at achieving the maximum energy amount consumed from several sources.

Анотація. *Запропоновано для попереднього прогнозування об'єму видобуваємої ВЕУ енергії провести заміну області визначення тривалості інтервалів роботи ВЕУ на область визначення швидкостей вітру. Запропоновано критерій енергетичної ефективності ВЕУ, що дозволяє обирати раціональні значення номінальної потужності та робочий діапазон швидкостей повітряного потоку з урахуванням типу користувача, що його підключено до ВЕУ. Розглянута можливість підвищення енергетичної ефективності ВЕУ за рахунок використання гідроприводу в системі відбору та перерозподілу потужності. Це дозволить розширити діапазон робочих швидкостей вітру та використовувати в одній системі декілька користувачів із різних функціональних груп..*
Ключові слова: *вітроустановка, енергетична ефективність, гідропривод*

Аннотация. *Предложено для предварительного прогнозирования объема вырабатываемой ВЭУ энергии провести замену области определения длительности интервалов работы ВЭУ на область определения скоростей ветра. Предложен критерий энергоэффективности ВЭУ, позволяющий выбрать рациональные значения номинальной мощности и рабочий диапазон скоростей воздушного потока с учетом типа потребителя, подключенного к ВЭУ. Рассмотрена возможность повышения энергетической эффективности ВЭУ за счет использования гидропривода в системе отбора и перераспределения мощности. Это позволит расширить диапазон рабочих скоростей ветра и использовать в одной системе несколько потребителей из разных функциональных групп.*
Ключевые слова: *ветроустановка, энергетическая эффективность, гидропривод*

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