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The scientific monograph presents the theoretical and practical aspects of the development of modern scientific research. General questions of economics and enterprise management, regional economics, marketing, technical sciences, technology of food and light industry, and so on are considered. The publication is intended for scientists, educators, graduate and undergraduate students, as well as a general audience.

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TECHNICAL AND TECHNOLOGICAL PREREQUISITES FOR THE INTRODUCTION OF AUTONOMOUS ENERGY SYSTEMS OF AGRO-INDUSTRIAL ENTERPRISES USING RENEWABLE ENERGY SOURCES

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Abstract. The research is devoted to solving important tasks of interdisciplinary research work on the topic: «Development of scientific and technical support for energy autonomy of the agro-industrial complex based on environmentally efficient use of agrobiomass for biofuel production», state registration number 0122U000844, implementation of which is planned for 2022–2024 at the expense of the state budget of Ukraine. The main purpose of the planned research is to increase the level of energy independence of agricultural enterprises through renewable energy sources through the use of the principles of dispersed hybrid energy supply, development of energy-efficient and environmentally friendly technologies for growing and processing agrobiomas for biofuel production, as well as modernization of means of control and monitoring of parameters of energy generating equipment. Given the complexity and interdisciplinarity of the planned research, the authors set a task, the solution will be an intermediate stage to achieve the overall goal of research. Such tasks are assessing the potential and identifying promising ways of decentralized power supply of agro-industrial producers based on the analysis of modern technical and technological solutions in the field of electrical engineering and synthesis of promising schemes of combined autonomous power supply of agricultural enterprises. Research of technical and technological prerequisites for the development of a combined system of autonomous energy supply and its components was carried out using the methods of analysis, generalization and

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systems approach. The potential benefits and effects of the proposed scheme are based on the laws of development of technical and power systems. The technical and technological aspects of the use of wind power generation in combination with solar energy conversion were evaluated. Also, the known methods of accumulating electrical energy received from autonomous electrical installations were analyzed. For efficient generation of electrical energy by modern wind turbines (vertical and ridge), wind speeds from 1.0-1.5 m/s are sufficient, and the nominal operating mode starts at 2-3 m/s, which corresponds to the meteorological indicators of the Vinnitsa region and confirms the possibility use of wind power generation. Also, a scheme was developed for a combined wind-solar autonomous power supply system for small and medium-sized agricultural enterprises and priority areas for further research were formed to improve the efficiency of such a system. At the same time, the most functionally and economically viable option is the use of energy storage systems based on flywheels with partial use of a backup lithium-ion battery pack. A flywheel scheme with a variable dynamic moment of inertia has also been developed, the use of which will improve the maneuverability of the autonomous power supply, and increase its performance.

1. Introduction

In modern realities, the agro-industrial complex of Ukraine acts as the most stable part of the national economy and is one of the main and stable in terms of revenues to the budget of intersectoral formations. However, the production and processing of agribusiness, as well as other sectors of the economy, is characterized by significant energy intensity, which according to experts [1] is much higher than in other industrialized countries and identifies Ukraine as one of the most energy inefficient countries in the world. Virtually all energy consumption in Ukraine is met by fossil fuels, most of which are imported, including from Russia, which in the current realities of aggressive actions of the eastern neighbor, threatens the energy security of the state and in particular strategically important budget-generating industry – agriculture. Responding to the challenges of today, the state authorities have developed and approved the Decree of the President of Ukraine of May 26, 2015 № 287/2015 «National Security Strategy» [2]. In accordance with paragraph 5 of section 3 of this strategy, the main threats to energy security have been identified:

– distortion of market mechanisms in the energy sector;
– insufficient level of diversification of energy sources and technologies;
– criminalization and corruption of the energy sector;
– ineffective energy efficiency and energy supply policy.

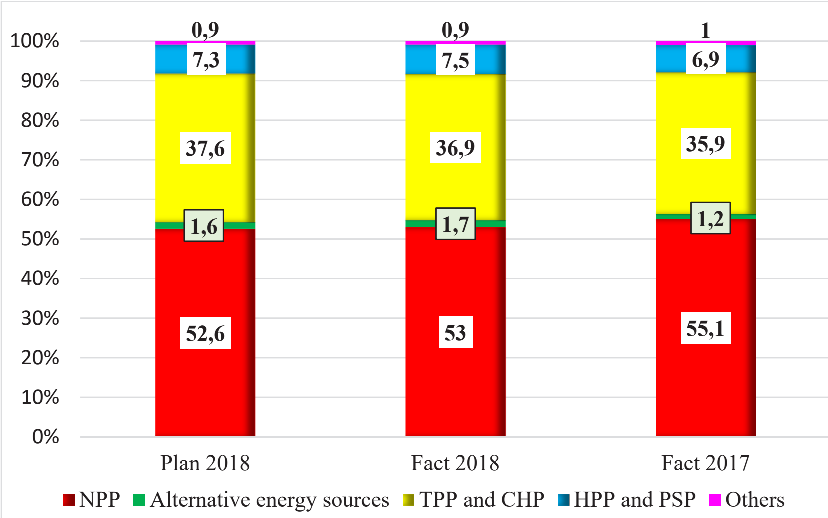
Clause 4.11 identifies priority areas for Ukraine's energy security, including diversification of energy sources and routes, overcoming dependence on energy supplies and technologies from Russia, development of renewable and nuclear energy, taking into account the priorities of environmental, nuclear and radiation safety [2]. Therefore, research aimed at developing and modernizing highly efficient autonomous energy supply systems of agro-industrial enterprises based on the use of renewable energy sources is relevant, has practical value and strategic importance in ensuring Ukraine's energy security and efficient functioning of the economic system.

2. Analysis of recent research and publications

One of the basic provisions of the European Green Course is the reduction of greenhouse gas emissions, ie the decarbonisation of the energy system. while the main emphasis is placed on increasing the share of renewable energy sources (RES) in the overall structure of energy generation. EU Member States ensure that the EU's common climate and energy goals are met through the adoption of National Energy Strategies. Thus, having ratified the Association Agreement with the EU, Ukraine must move to EU environmental standards. In accordance with this normative legal act, the order of the Cabinet of Ministers approved the Energy Strategy of Ukraine for the period up to 2035 «Security, energy efficiency, competitiveness» [3], which envisages a steady expansion of the use of all types of renewable energy with a projected increase in its share in 2025 to 12% of total primary energy supply and at least 25% – by 2035 [3, 4]. However, as can be seen from the diagrams (Figure 1), which were taken from the official website of the Ministry of Energy – only in 2018 managed to exceed the planned growth, but only by 0.1%.

As we can see from the latest charts, as of the end of September 2021 (Figure 2), the deviation from the planned level is 1.5% to the corresponding period of 2020.

However, as can be seen from Figure 3, currently in the EU, the energy sector is characterized by rapid dynamics of increasing the volume



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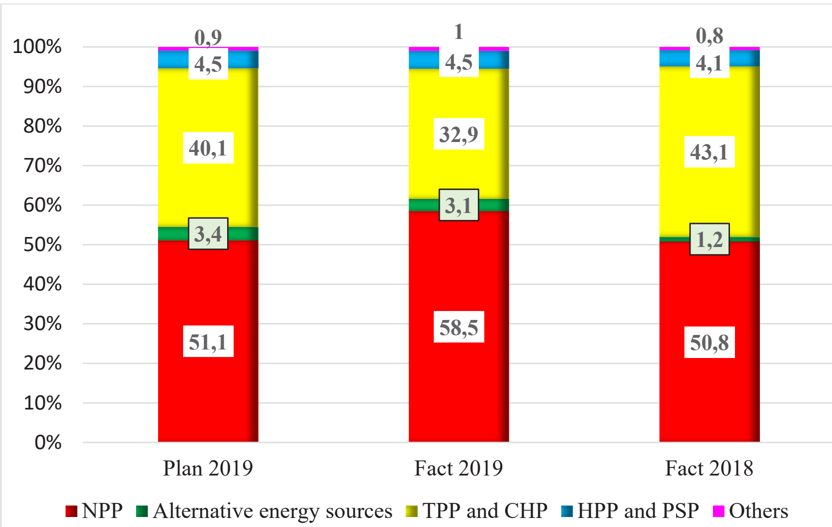

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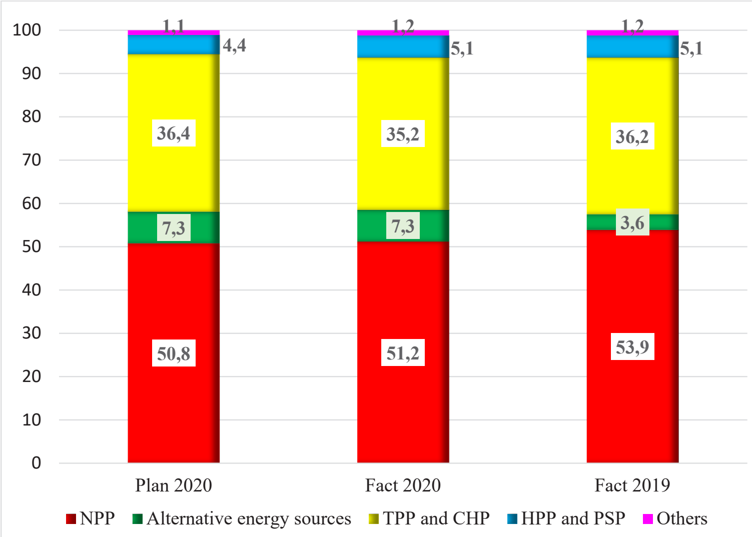
Figure 1. Structure of electricity production in Ukraine [11], %: a) in 2017–2018; b) in 2018–2019



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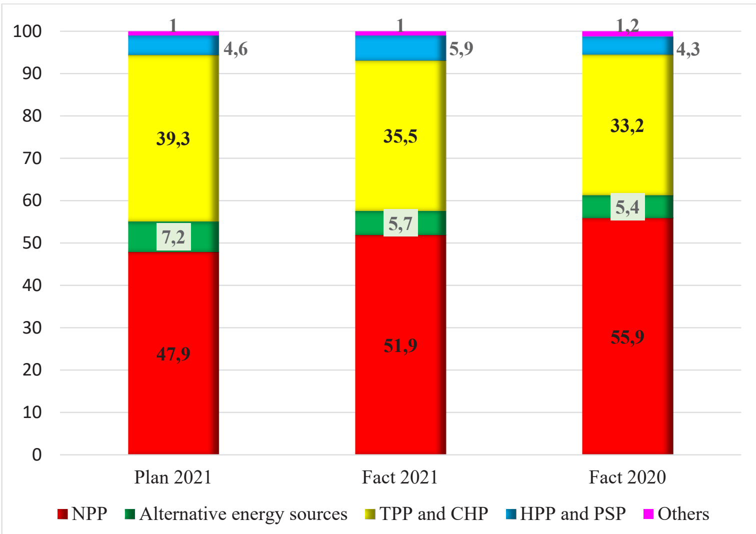

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Figure 2. Structure of electricity production in Ukraine [11], %: a) in 2019–2020; b) in 2020–2021

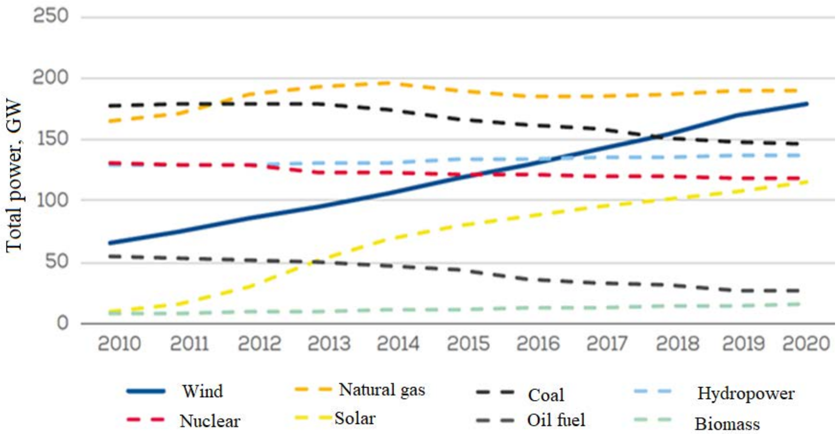


Figure 3. Total power generation in the EU 2010–2020

of alternative generation for electricity production and the gradual abandonment of fossil fuels [8].

Although Ukraine is experiencing a gradual development of RES, which is a key component of the integration of the national energy network into the EU grid, there is still a significant difference in the share of renewable energy sources in the structure of electricity generation. From 5 to 47%, which currently makes such a merger impossible. Therefore, research aimed at developing and modernizing highly efficient autonomous energy supply systems for consumers, in particular agro-industrial enterprises based on RES, are relevant, have practical value and strategic importance in ensuring energy security of Ukraine and efficient functioning of the economic system.

3. Purpose and methods of research

Thus, the purpose of the research was formulated, which is to assess the potential and identify promising ways of decentralized power supply of agro-industrial producers based on the analysis of modern technical and technological solutions in electrical engineering and synthesis of promising scheme of combined autonomous power supply of agricultural enterprises. Assessment of technical and technological capabilities and natural and climatic potential of Vinnytsia region for autonomous power supply of agricultural enterprises on the principle of conversion of renewable energy sources was carried out taking into account the experience of domestic [5; 6; 7] and foreign scientists [10; 11] working in this field. In addition, the information presented according to the results of research of leading international companies [9; 12; 13] and the Ukrainian Hydrometeorological Center [14] was used. The analysis of known technical solutions and technologies of accumulation of electric energy received from autonomous electrical installations was carried out with the use of generalization methods and system approach. Hypothetical-deductive method in the development of the scheme of the combined system of autonomous energy supply. Potential advantages and effects from the implementation of the proposed system are based on the laws of development of technical and power systems [15].

4. Technical and technological possibilities of low-capacity RES use by agricultural producers

Today, agro-industrial complexes occupy large areas, they are built closer to raw materials, so electricity is supplied from 10-0.4 kV networks, in some cases 110 kV. In order to ensure high-quality heat and electricity supply, agro-industrial enterprises are increasingly using renewable energy sources. The use of alternative energy sources not only ensures the energy independence of agricultural enterprises, but can also be an additional source of income regulated by the Law of Ukraine «On Alternative Energy Sources» (as amended by the Law of Ukraine «On Electricity Market»). stimulating the development of electricity production from alternative energy sources by setting a «green» tariff. Technical and technological aspects of efficient use of alternative energy sources are reflected in the works of many scientists [1; 5; 6; 7; 24–40], which in addition to the benefits also noted the problems that arise in the development of these types of electricity. If the growth of solar energy in energy supply systems is becoming increasingly popular [1; 8; 41–50], the potential of wind generation is unjustifiably underestimated and is explained by a number of reasons, including insignificant or insignificant nature and low wind speed in most parts of Ukraine, which creates difficulties. to forecast the production schedule, as well as the need to use expensive technical means and equipment for the accumulation of electricity generated by low-power installations. However, according to the experience of EU countries, currently the wind energy industry is the most promising and characterized by rapid dynamics of increasing generation volumes for electricity production (Figure 3) [9].

These global trends are forcing us to reconsider the claims about the inexpediency of wind energy conversion for the purposes of agriculture and contribute to the intensification of research on the development of highly efficient autonomous energy supply systems of agro-industrial enterprises based on alternative energy sources.

World experience in implementing low-power wind and solar energy technologies that can be used to increase the energy autonomy of agro-industrial enterprises shows that the main advantages of using wind turbines (WT), solar power plants (SPP) and solar collectors for water heating (WH) include:

– reduction of environmental impact on the environment compared to traditional methods of obtaining electricity, by avoiding emissions of harmful substances (sulfur dioxide, nitrogen oxides, dust, greenhouse gases), as well as almost complete absence of waste;

– stability and predictability of costs per 1 kWh of electricity, regardless of external macroeconomic factors and the geopolitical situation in the world;

– wind flow and solar energy are inexhaustible in contrast to traditional sources of electricity generation;

– full autonomy of wind turbines and solar collectors, which eliminates the need to use other energy sources to ensure their operation;

– high ergonomics due to low complexity of installation and maintenance of low power equipment, compact location of wind power plants, the possibility of installing solar panels and solar panels on surfaces not used for industrial purposes (roofs of buildings and structures, land unsuitable for commercial purposes activities, etc.) [16].

As already mentioned, in addition to the above advantages of using wind and solar energy, experts also note the disadvantages and problems that arise in the development of these types of alternative sources:

– the difficulty of forecasting the schedule of energy production, due to the complete dependence of the operation of wind and solar power plants from weather conditions, seasons and other natural factors;

– the problem of accumulation and storage of electricity generated by low-power installations, which is the need to use expensive technical means and equipment;

– high capital costs for the construction of new SPP and WT;

– low compared to traditional power plants utilization rate of installed capacity, which leads to relatively low power output;

– in the potential risk of death of birds due to their exposure to the range of rotating blades of wind turbines and high noise levels during operation [17].

It is obvious that these shortcomings lead to a significant slowdown in the diversification of heat and electricity sources in our country, in particular due to the conversion of wind and solar energy, which led to a situation where 30 years of independence Ukraine has managed to reach the share of renewable energy sources and biomass) in the overall structure of energy generation in 5.7% (Figure 1, 2) [18], while highly developed European countries produce from 15% to 52% (Figure 4) using only unstable (stochastic) renewable energy sources (sun and wind) [19].

Such rapid development of the alternative energy sector in the world and the general tendency to increase the cost of traditional fuel resources encourages us to reconsider these shortcomings, which are currently becoming obsolete in advanced technologies and innovations, which allows to partially or completely refute them. The claim of low suitability of wind and solar energy for use in agricultural production processes due to possible power failures due to weather factors that are uncontrollable and independent of human activities, becomes unfair when integrating into the energy system of several plants with different power levels. short oscillations of generation compensate each other [51–80].

At the same time, in the case of combined wind and solar installations, the electricity generation schedule is even more stable, stochasticity becomes less pronounced, and critical changes in energy generation will usually occur within an hour, which can be taken into account accumulation of electric energy.

In addition, the modern development of intelligent information systems allows meteorological modeling methods to perform meteorological forecasting with a high level of reliability.

Experts from Lazard Ltd. (USA) in 2019 a study was conducted and the indicator of the total cost of electricity was determined (LCOE – Levelized Costs of Electricity), reflecting the dynamics of the total cost over the entire life cycle, taking into account the costs of design, production needs, modernization, operation and disposal of waste elements of power plants.

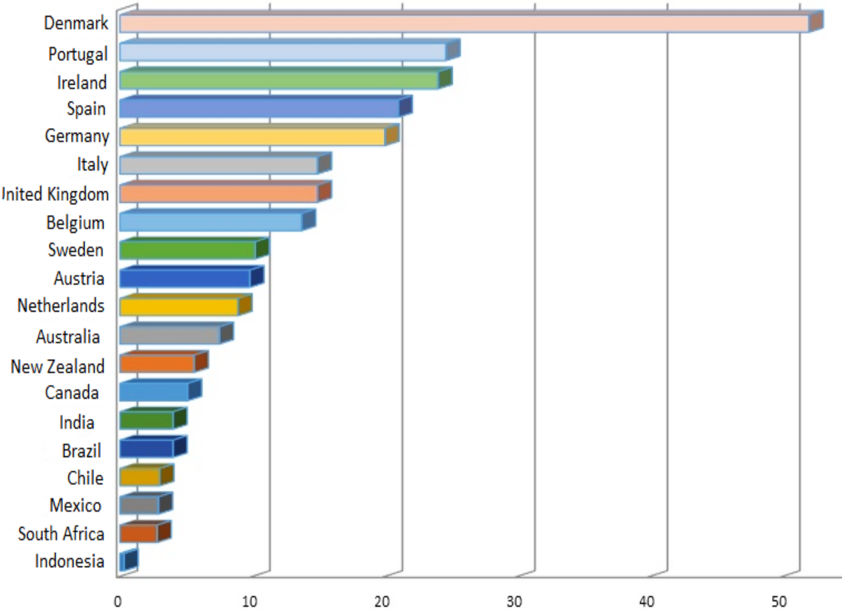


Figure 4. The share of stochastic renewable energy sources (wind and solar) in the annual production of electricity for a number of countries as of 2021 [12]

Thus, between 2016 and 2018, the profitability of wind and solar power plants (including capital investments) increased by 7.5% [19] with a slight decrease in the profitability of coal technologies and increased costs for the development of nuclear power plants [81–92].

Capital costs per kilowatt of installed capacity for SPP are in the range of 1100-1375 USD USA/kW, for WT – 1200-1650 USD. USA/kW [19]. At the same time, increasing the capacity of alternative energy on a global scale leads to increased competition in the market of wind and solar technologies, which contributes to lower prices for equipment for wind and solar energy conversion, while providing high installed capacity. Today it is technologically possible to achieve the value of the coefficient of utilization of the installed capacity of SPP – 21-30% (silicon) and 23-32% (thin film); WT – 38-55%.

Another constraint on the development of small wind and solar power to meet the needs of the agricultural sector is the assertion of low natural and climatic potential of Ukraine, especially for the operation of WT (low speed and inconsistency of wind flows) and the possibility of efficient WT only in some areas.

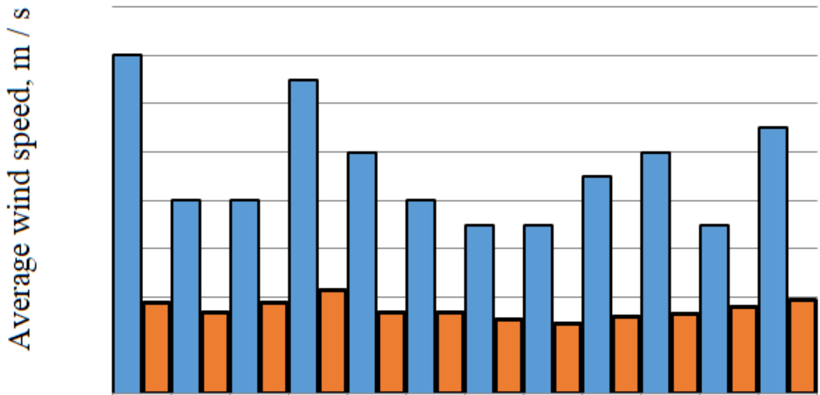
Today, domestic and foreign manufacturers offer technical solutions for wind generation that eliminate the problem of stochastic and at the same time low wind load (Figure 5) and can be used to increase energy autonomy of Ukrainian agro-industrial enterprises, regardless of regional.

The main advantages of vertical wind turbines (Figure 5 a, b) are: unpretentiousness to the wind direction, which makes them suitable for use in almost any area.

Quite interesting design solutions in terms of ergonomics and functionality are ridge horizontal wind turbines (Figure 5 b), the main advantages of which are: no need to build a mast due to the placement of turbines on the roofs of buildings and structures near solar panels; the use of the effect of raising air flows, which in the laminar mode of movement and depending on the angle of the roof allows you to get the wind speed on the ridge 2-3 times higher than the initial; perception of crosswinds and the possibility of placing the installations directly next to each other. In addition, the blades of these wind turbines (Figure 5 a, b, c) are made of fiberglass, which gives the structure when rotating good airflow and almost no noise, which solves the problem of negative impact on human and animal health. As for the danger to the life of birds, wind power plants are accidental in nature, in contrast to thermal power plants (TPP), which

a) b) c)

Figure 5. Wind turbines: a, b) – vertical; c) ridge



	1	2	3	4	5	6	7	8	9	10	11	12
Max	14	8	8	13	10	8	7	7	9	10	7	11
Averange	3,80	3,40	3,80	4,30	3,40	3,40	3,10	2,90	3,20	3,30	3,60	3,90

Figure 6. Wind speed in Vinnytsia region in the period 01.01.2021–31.12.2021

usually during the entire period of operation emit harmful substances into the environment, adversely affect all species of living organisms within radius pollution actions.

To assess the potential of wind power to feed agricultural consumers, the data of the Ukrainian Hydrometeorological Center for 2021 (on the example of Vinnytsia region) were used [13] and diagrams of average and maximum values of wind flow speed by months were constructed (Figure 6).

As can be seen from the analysis of wind activity, in the Vinnytsia region during the year there are winds suitable for the operation of wind turbines. At the same time for 10 months, except for July and August, it is possible to ensure their operation at nominal operating modes.

One of the known options for autonomous power supply of agricultural consumers using wind energy is the well-known design of an autonomous power supply system based on a wind power plant with battery and flywheel (Figure 7) [5].

According to this scheme, the torque from the shaft of the windmill 1 is fed to the rotor of the induction generator 5 with the flywheel 2 mounted on it, which allows to some extent to smooth out the changes in torque during wind gusts and load switching. Energy from the generator 5 is fed to the inverter-switch 7, then through the charger 4 accumulates in the batteries 3. If necessary, when reducing wind speed, for electricity supply to consumers 8 uses the energy stored in the batteries 3. Control operation is provided by an automated control system 6 [6].

Also known is the design of an autonomous power supply system based on a hybrid wind-solar power plant [20] (Figure 8), which is a station based on a mast wind generator with a horizontal axis 1 and a set of photovoltaic modules 2 connected to a single power system. Distribution of electricity and automation of the entire system is provided by a hybrid controller 4. Excess electricity is accumulated using the battery pack 5. Conversion of direct current into alternating current for further power supply 6 is carried out by the inverter 3.

The main advantages of such an autonomous power supply system include the mutual compensation of the deficit of electricity generation, the essence of which is a fairly high performance of photovoltaic batteries in summer and relatively low in winter. In turn, in summer, the mast wind turbine usually operates at minimum power, due to frequent windless days typical of this time of year.

The common disadvantages of the described options for autonomous energy supply (Figure 7, Figure 8) include the imperfection of the energy storage system, which is the need to use expensive batteries of large capacity. For the first case (Figure 7), such a system should provide electricity to consumers during the period of calm, while the use of the flywheel is limited by inertial characteristics and small values of maximum energy consumption.

For the second option (Figure 8) the problem of reducing the total capacity of batteries is partially solved by the already mentioned mutual compensation, but the option of energy deficit is not excluded in the absence of stable wind flow and solar radiation (calm at night). In addition, as experience [8; 10] shows for the operation of wind turbines with a horizontal axis of rotation in the nominal mode, a prerequisite is the presence of wind flow at speeds 1… 2 times higher than the average wind speed in Vinnytsia region during the year.

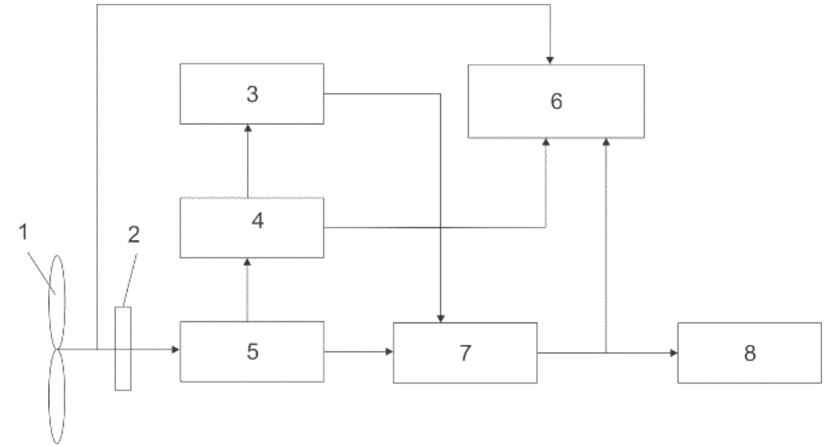


Figure 7. Scheme of an autonomous power supply system based on a wind power plant with a battery reserve

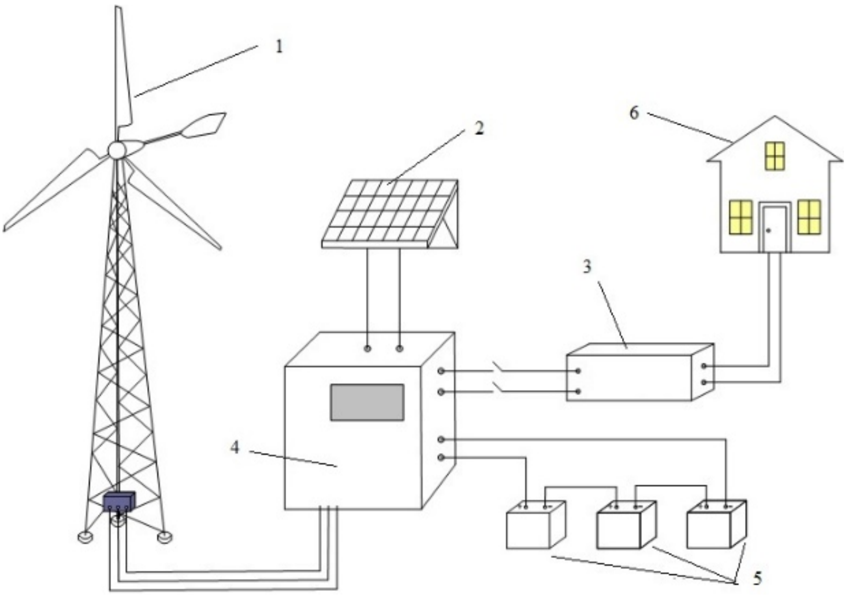


Figure 8. Scheme of wind-solar hybrid installation

It will also be advisable to use ridge wind turbines, with their placement on the roofs of industrial buildings and structures next to solar panels. The advantages of such wind turbines include [4; 8; 9]: the use of the effect of raising air flows, which in laminar mode and depending on the angle of the roof allows you to get the wind speed on the ridge 2-3 times higher than the original; perception of crosswind; almost complete silence.

Another option for autonomous electricity supply is the use of hybrid power supply systems based on wind energy and gasoline generators. The combination of a guaranteed energy source – a gasoline generator and unstable renewable wind energy allows you to build universal autonomous power supply systems that provide uninterrupted power supply to consumers [7]. This system of power supply with two energy sources allows covering (at certain intervals) the energy needs of the produced gasoline generator in case of failure or lack of wind load.

In the general case, this hybrid system (Figure 9) is a combination of different in nature energy sources on the AC bus. During periods of high wind resources, the gasoline generator is turned off.

Among the main disadvantages of this system is the need for frequent switching on and off of the gasoline generator from the AC bus with the pulsed nature of wind generation and the high cost of energy produced by it.

Also known is the design of the wind power plant of autonomous power supply, the reserve of which is the fuel power plant (Figure 10).

The wind turbine moves the rotor of the asynchronous generator. Capacitors provide perturbation of an asynchronous generator with a short-circuited rotor. Energy from the asynchronous generator through the switch and inverter is converted to the required voltage level and supplied to the

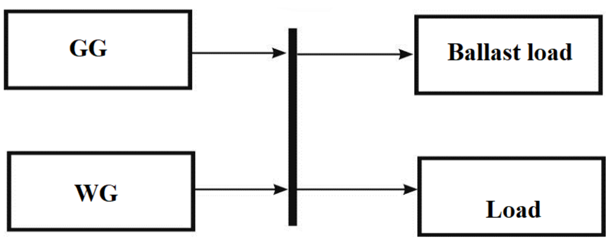


Figure 9. Hybrid system of autonomous power supply: GG – gasoline generator; WG – wind generator; BL – ballast load; L – load

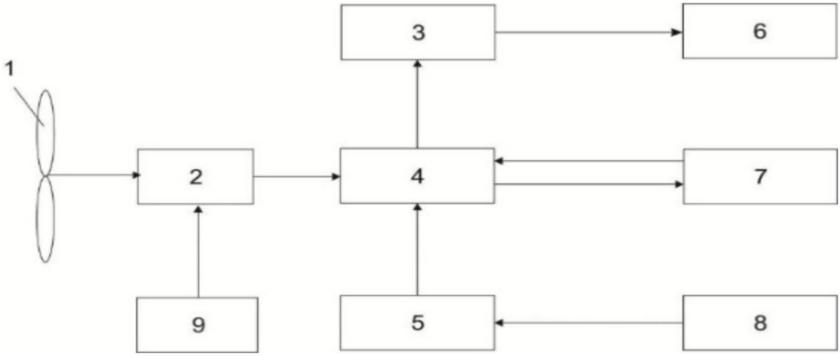


Figure 10. Scheme of an autonomous power supply system based on a wind power plant with a backup power plant: 1 – wind turbine; 2 – asynchronous generator; 3 – inverter; 4 – switch; 5 – fuel power plant; 6 – consumer of electricity; 7 – the accumulator; 8 – installation on biofuels; 9 – capacitor

consumer. Excess energy accumulates in batteries and is used in case of windless weather. A petrol-diesel electrical installation is used as a backup power supply [6]. This system is characterized by the presence of certain shortcomings inherent in the previously presented options.

Thus, despite a number of obvious advantages, the stochastic nature of alternative electricity generation often leads to a situation where the amount of energy produced far exceeds the need for food for consumers and vice versa. In addition, there are monthly, seasonal and annual fluctuations in the intensity and availability of renewable energy sources.

On the other hand, as experience shows, the need for energy may change from time to time, which does not always coincide with the frequency of renewable energy sources, creating problems of reliability of autonomous energy systems [11].

After analyzing different options for autonomous power supply, we can conclude that in order to stabilize energy production/consumption, it would be advisable to use a combined autonomous power supply system, which will include a main wind turbine module and one or more backup modules (using solar panels and generators running on traditional fuels). The maximum efficiency of such power supply can be achieved only if it includes the system of accumulation (accumulation) of energy Energy storage system (ESS).

The ESS process involves the conversion of electricity from one available source to other forms of energy and its storage, with the possibility of reverse conversion if necessary back to electricity. The form of energy conversion can be chemical, mechanical, thermal, electrochemical and electrical (Figure 11) [11].

Energy storage will be appropriate during periods of low consumer demand (night time, maintenance of basic technological electric machines, etc.) and when increasing the required level of generation (increasing wind and/or solar load). At the same time, the accumulated energy can be consumed in periods of increasing consumer demand (energy-intensive processes) and in cases of slow generation (wind load failures, reduced luminous flux, etc.) [9].

Known means and technologies of energy backup have different cost, capacity and speed (Figure 11), and their choice should be made taking into account specific requirements for production processes, characteristics of daily and annual energy consumption, composition and parameters of autonomous energy system and more.

For small and medium-sized enterprises in the agricultural sector, depending on the above factors, it will be appropriate to use in the structure of ESS super-flywheels, which are characterized by energy capacity from 1 kWh to 100 kWh, while the duration of energy storage and return is 1 min… 1 year [9]. Flywheels are characterized by high reliability, low cost, durability and are environmentally friendly means of energy storage. The main functional purpose of the flywheel is to form a reserve of kinetic energy from rotational motion with the possibility of its conversion into electrical energy for further transfer to an autonomous power system.

At the same time, the complete abandonment of batteries in the ESS may lead to a deterioration in the controllability of the autonomous power system. Therefore, as a backup means of accumulation, in addition to flywheels, it is necessary to provide for the use of a unit of lithium-ion batteries, which are characterized by a high ability to respond quickly to fluctuations in deficit / excess energy. However, in contrast to the described options, the main purpose of these batteries is to perform the functions of scheduling the autonomous system, while the main means of accumulation will be a unit of inertial mechanical drives – flywheels.

Global trends in rising prices for traditional fuel resources used to generate electricity require agricultural enterprises to take measures to diversify sources of electricity supply and increase energy autonomy.

Despite the existing general opinion on the low efficiency of wind and solar energy in the natural and climatic conditions of Ukraine, the experience of highly developed countries says otherwise:

– implementation of projects for the implementation of autonomous energy supply systems of agricultural enterprises on the basis of SPP and WT has environmental and economic advantages over traditional electricity supply;

– modern development of technologies allows the conversion of solar and wind energy into electricity in areas that were previously (20-30 years ago) considered unsuitable for this type of energy.

For the enterprises of the agro-industrial complex of Ukraine the most optimal option, along with the use of the combined energy system, is to

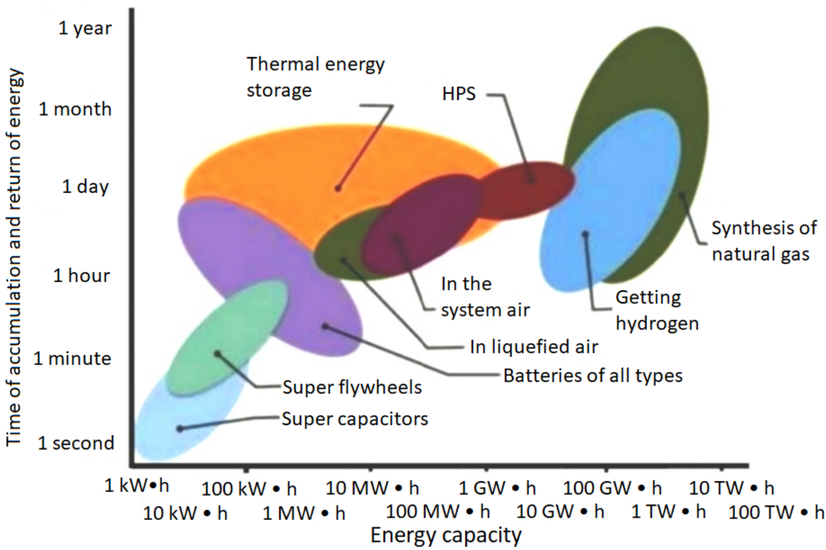


Figure 11. Characteristics of energy storage systems [9]

create a «flexible» autonomous power supply network, which depending on the energy needs of the enterprise may include: WT with vertical wind turbines, solar panels and ridge aerodynamic power generators mounted on the roofs of buildings and other structures, energy storage system based on lithium-ion batteries, control and dispatching system of the autonomous network.

Such diversification of sources of electricity contributes to reducing the level of energy dependence of the agro-industrial complex and is one of the factors increasing the competitiveness of products in domestic and foreign markets by reducing production costs.

5. Development of a hybrid system of autonomous power supply

As a result of the analysis, the authors systematized and summarized information on the advantages and disadvantages of using existing options for technical and technological support and proposed a block diagram of an autonomous hybrid power plant (Figure 12), which can be used to power small and medium agricultural enterprises.

Main Power Generation System (MPGS) includes a Wind Power Module (WP) with vertical wind turbines and Solar Power Module (SPM) with installed on the roofs of production facilities or on specially designed structures (farms) photovoltaic panels. The functional purpose of MPGS is the conversion of wind energy and solar radiation into direct current electric energy (DCE) and transmission to the switching unit of the control system.

Full control of the autonomous power supply system takes place using the Control System (CS), which includes Switching unit, Monitoring unit, Dispatching unit and an Inverter unit.

Switching unit – designed to control and distribute the flow of electricity coming from various elements of a hybrid power plant.

Monitoring unit – performs the functions of monitoring, control and registration of parameters of all elements in real time.

The main structural elements of the proposed scheme and the relationships between them are shown in Figure 12.

Dispatching unit – is responsible for processing the information received from the monitoring unit, its analysis and formation of commands for operational management of the state of structural elements.

Inverter unit – designed to convert DC to AC.

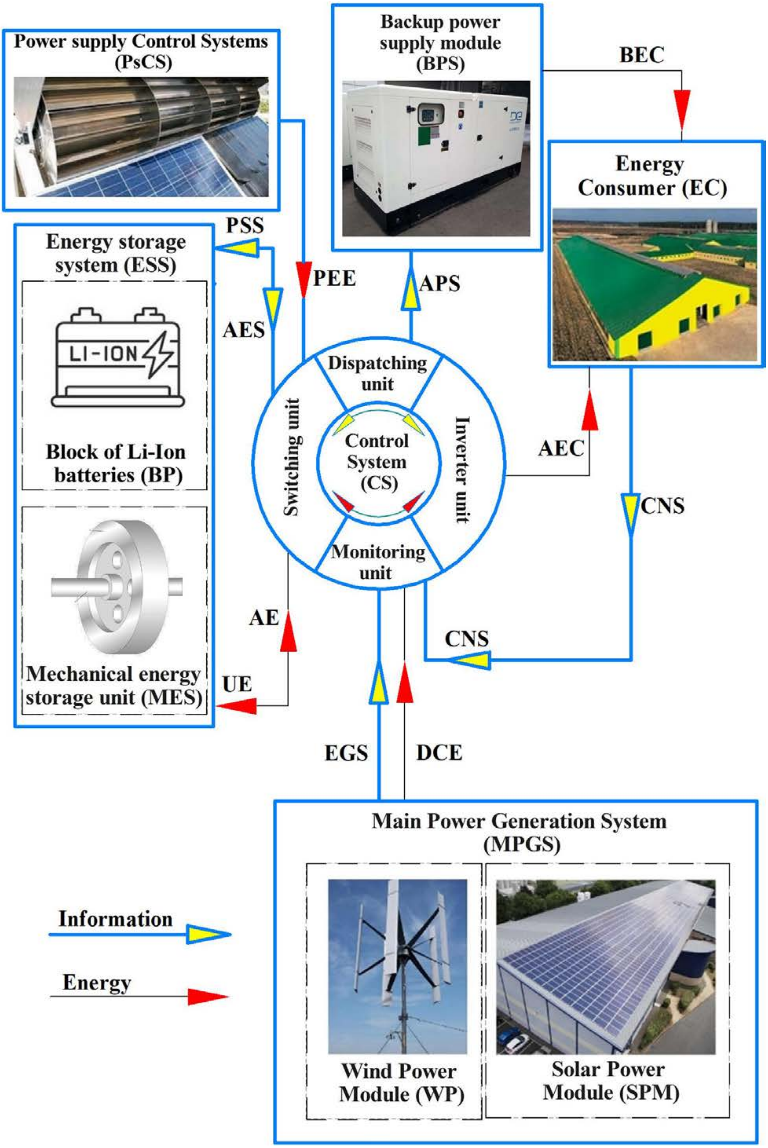


Figure 12. Hybrid system of autonomous power supply

Energy storage system (ESS) is designed to accumulate unused energy (UE) and return (AE) it when receiving a signal of power shortage (PSS), which occurs in cases where the capacity of MPGS less than the actual needs of EC, determined by the monitoring unit CS by comparing information flows of need (CNS) and generation (EGS). Information on the amount of reserve ESS (AES) in real time comes to the CS. Operation ESS is provided by the block of Mechanical energy storage unit (MES), equipped with flywheels with various inertial characteristics and the block of lithium-ion batteries (BP).

Backup power supply module (BPS) is used when receiving the information signal about the need for backup power (APS) from the Dispatching unit CS. The formation of such a team of SU occurs when the total current from the MPGS is less than required to power the EC, provided almost the maximum use of ESS reserves. It is proposed to consider as such a state the case when the kinetic energy is completely converted into electrical form (stopped the flywheels of the unit MES) and after treatment with the Inverter unit CS, in the form of alternating electric current (AEC) was used to power EC, with total lithium charge -ion batteries decreased to 10% of the total capacity of the battery pack BP. Since the BPS is a diesel generator set (one or more), the supply of backup electric current (BEC) to power the EC occurs without its conversion by the inverter unit CS.

Power supply Control Systems (PsCS) is a fully autonomous power generation unit based on horizontal wind turbines mounted on the ridges of the roofs of the company's premises above the photovoltaic panels of the Module SPM. The purpose of (PsCS) is to provide power to electrical equipment (PEE) included in all these systems, modules and units of the most autonomous hybrid power plant, which achieves complete energy independence of the enterprise from the centralized power supply system.

Thus, this system can be used for the needs of agricultural enterprises, but a necessary condition for its practical implementation is a more detailed analysis and justification of the parameters of the subsystems of the macro-level scheme, in particular by solving the problem of stochastic nature of RES by introducing efficient.

6. Improving the efficiency of energy storage systems in the field of wind energy

Currently, the wind energy industry is the most growing and promising for «clean» electricity and its use in industry and other fields.

Wind turbine (wind turbine) – a device for converting kinetic energy of wind into electricity, consisting of a wind turbine, electric generator and ancillary equipment.

Due to the simplicity of construction, high reliability and high speed of accumulation/return of energy, flywheels successfully compete with other technologies in the field of energy storage, especially in wind generation. As you know, one of the most important parameters of the flywheel is its moment of inertia, which is characterized by a quadratic dependence on its radius, and the increase in this indicator has a directly proportional effect on the energy capacity of the system during kinetic energy accumulation.

Flywheels with the main attributes of high energy efficiency, as well as high power and energy density compete with other storage technologies in the field of energy storage. The main purpose of the flywheel will be to increase the inertia of the power system.

A flywheel is a massive rotating part with a large moment of inertia in the form of a disk or wheel, which is mounted on the drive shaft of the machine to reduce the unevenness of its rotation at steady motion. The flywheel accumulates (accumulates) kinetic energy during acceleration and gives it away when slowing down.

Simplicity of a design, reliability of the mechanism and optimum speed of accumulation and return of energy (Figure 13) are the main reasons of prevailing use of flywheels in wind generators.

Since the wind has a pulsed nature, changes a large number of times in a short period of time, the failure of the wind load in the wind turbine should be replaced by a high-speed device, such as a flywheel.

The energy (J) stored on the flywheel depends on its angular velocity, mass and geometric dimensions and is determined by the formula [21; 22]:

$$E = \frac{J}{2}\omega_м^2, \tag{1}$$

where $\omega_м$ – angular velocity of the flywheel, rad/s; J – moment of inertia of the flywheel, kg·m^2. In the General case, the moment of inertia of the flywheel with a steel rim is determined by the formula [21; 22]:

$$J = \frac{mr_м^2}{2}, \qquad (2)$$

where m – flywheel mass, kg; $r_м$ – flywheel radius, m.

As can be seen from (1) and (2), the moment of inertia and, as a consequence, the kinetic energy that can be accumulated on the flywheel is characterized by a quadratic dependence on its radius and angular velocity. Mass has a directly proportional effect on energy performance. As you know, the angular velocity $\omega_м$ which can be developed by a flywheel is limited by requirements of durability of a design, the maximum wind speed and nominal value of quantity of turns of a rotor of the asynchronous generator, and weight m – metal consumption, one of the ways to increase energy consumption E there is an increase in the radius of the flywheel $r_м$. It is worth noting that $r_м$ also has some limitations: requirements for overall dimensions, the difficulty of balancing at large parameter values $r_м$, complexity of manufacture and operation. In addition, a significant increase in the moment of inertia of the flywheel complicates its acceleration and stop, which is unacceptable when using the latter as a mechanical accumulator of kinetic energy of the wind power system of autonomous power supply with pulsed wind load. Thus, at high inertia values, a situation may arise where the flywheel causes the wind turbine to brake and the asynchronous generator to operate in sub-nominal modes, as a result of which the wind farm efficiency will be reduced.

With excessive wind load, low values of the moment of inertia can lead to a situation where the energy consumption of the flywheel is less than the excess generated by the wind turbine, and the generator operates in overload mode, ie above the nominal value.

Given the above, one of the promising options for stabilizing the wind power system of autonomous power supply is the use of a mechanical flywheel battery, the design of which allows stepless change of radius $r_м$ in real time, ie provides the ability to adaptively control the value of the moment of inertia J, and as a consequence, energy consumption E.

On the basis of VNAU laboratories, a flywheel design with four inertial elements was proposed, which are located opposite to each other and equidistant from the axis of rotation (Figure 13) [23]. In this case, the moment of inertia of this mechanical battery is determined by the dependence [21]:

$$J_M = \sum_{i=1}^{n} m_i \cdot e_i^2, \quad (3)$$

where m_i – mass of the i-th element, kg; e_i – distance from the center of mass of the i-th element to the axis of rotation, m.

Then the energy consumption of this flywheel can be defined as:

$$E_M = \frac{4m_E \cdot e_E^2 \cdot \omega_M^2}{2} \Rightarrow 2m_E \cdot e_E^2 \cdot \omega_M^2, \quad (4)$$

where m_E – mass of one inertial element, kg; e_E – distance from the center of mass of the element to the axis of rotation, m.

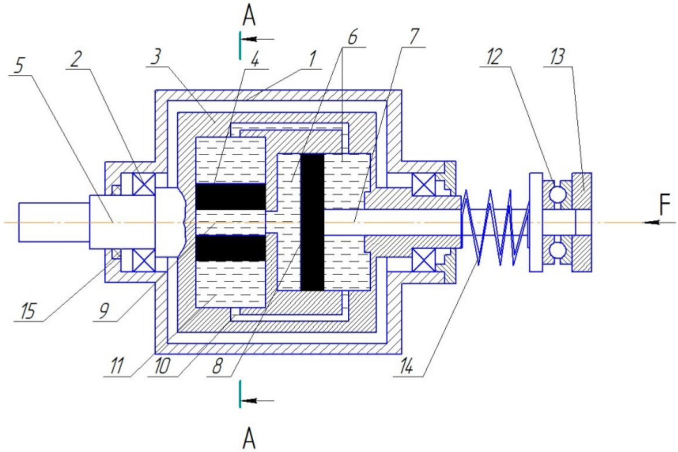
Flywheel «VDMI» contains a housing 1 mounted on supports 2, the base 3 in the axisymmetric cavities of which are placed pistons-weights 4 with the possibility of radial movement mounted on the shaft 5, the cylinder 6 is divided into right and left parts mounted on a rod 7 piston 8.

Left part 6 is connected to the cavity 9, and the right part, in turn, is connected by channels 10 to the cavities 11, located respectively below and above the pistons-weights 4. At the end of the rod 7 is a thrust bearing 12 with a pressure device 13 and a spring 14. Sealing supports 2 are provided with seals 15. Hydraulic cylinder 6, cavity 9, 11 and channels 10 are filled with working fluid.

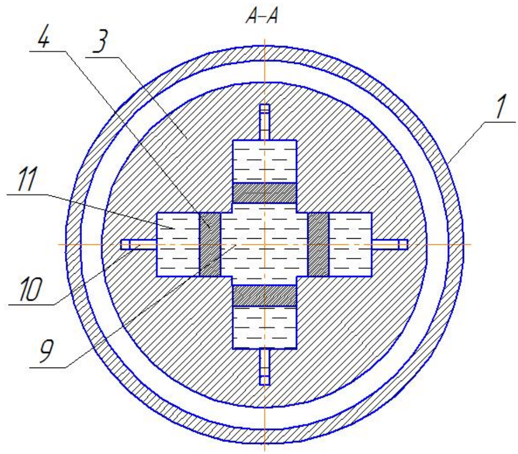
It is known that the dynamic moment of inertia of the flywheel depends on the position of the distribution of its mass relative to the axis of rotation. The change in the mass distribution of the flywheel is due to the radial movement of the pistons-weights 4 from the axis of rotation to the periphery, or vice versa, from the periphery to the axis of rotation, due to compressed fluid supplied from the cylinder 6 by the piston 8.

Thus, when the pistons-weights 4 are near the axis of rotation, then the dynamic moment of inertia of the flywheel is the smallest, and when the pistons-weights 4 are on the periphery, then the dynamic moment of inertia of the flywheel is greatest.

When a force F is applied to the pressure device 13, the spring 14 is compressed and the rod 7 with the piston 8 is moved to the left, which causes compression and supply of working fluid from the left part of the working chamber of the hydraulic cylinder 6 into the cavity 9. At the same time it displaces the working fluid from the cavities 11 and feeds it through the channels 10 in the right part of the working chamber of the hydraulic cylinder 7. When removing the force F of the pressure device 13 under the



a



b

Figure 13. Flywheel «VDMI»: a) Schematic diagram; b) section for AA: 1 – body; 2 – supports; 3 – base; 4 – inertial elements; 5 – drive shaft; 6 – hydraulic cylinder; 7 – stock; 8 – the piston; 9, 11 – cavity; 10 – channels; 12 – thrust bearing; 13 – pressure device; 14 – spring; 15 – seals

action of the spring 14, the rod 7 volumes of working fluid and movement of inertial elements from the periphery to the axis of rotation [23].

When starting the wind turbine, the flywheel must be set to the minimum value of the moment of inertia (e_E = min). When there is an excess of wind load, a force F is applied to the pressure device, increasing the moment of inertia to the value when the number of revolutions of the wind turbine will be equal to the nominal number of revolutions of the generator ($n_{ВД} = n_Г$). In the event of a failure of the wind load, the kinetic energy reserve of the flywheel, for some time, will ensure the operation of the asynchronous generator in nominal mode. To eliminate the braking effect with a partial reduction in wind force, you need to remove the force F from the pressure device, until the generator reaches the rated mode.

This design reduces the inertia of the control system of the dynamic moment of inertia of the flywheel.

7. Conclusions

1. As a result of the research, one of the possible ways to ensure energy security of a strategically important sector of Ukraine's economy – agro-industrial complex, which is to diversify sources of electricity by reducing the share of the centralized network and the introduction of renewable energy technologies until full transition agricultural enterprises on an autonomous power supply model.

2. Based on the assessment of natural and climatic potential of Vinnytsia region, it was found that the current level of technical support makes it possible to implement such a model for small and medium agribusiness, and the rapid pace of further development of alternative energy technologies can predict the basis for large-scale autonomy of the industry in the near future.

3. Proposed and presented in the form of a block diagram of a macro-level hybrid autonomous power plant is a complex technological system with deep interaction of elements, taking into account the practical experience of international energy companies and theoretical and methodological developments of domestic and foreign scientists in electrical engineering. Its main advantages include:

– more stable generation of electricity and its supply to consumers compared to traditional electrical installations used by agricultural producers through the use of two independent modules WP and SPM;

– low cost of maintaining excess electricity, provided high functional and operational performance of the energy storage system, which is achieved when included in its composition, in addition to batteries, flywheels;

– minimizing the risks of power outages in the event of emergencies or maintenance of elements of the main energy generation system by using a backup power supply module based on a diesel generator set;

– autonomous power supply of the power plant equipment due to the installation of a complex of horizontal ridge wind turbines on the roofs of the premises;

– high maneuverability of the autonomous power supply system and its rapid reorientation to the required real-time modes, provided by the control system based on the real needs for consumer power and the potential of all other elements of the hybrid autonomous power plant.

4. A constructive solution for the flywheel is one of the promising options for stabilizing the wind power system of autonomous power supply, and its use allows stepless change of radius rm in real time, ie provides adaptive control of the moment of inertia J and, consequently, energy intensity E system accumulation.

References:

1. Yasnolob I.O., Chaika T.O., Gorb O.O., Radionova Ya.V. (2019) Conceptual principles of effective functioning of energy-independent rural areas. *Economics of agro-industrial complex,* no. 3, pp. 115–122. DOI: https://doi.org/10.32317/2221-1055.201903115

2. Decree of the President of Ukraine «National Security Strategy of Ukraine» of 26.05.2015 no. 287/2015.

3. Order of the Cabinet of Ministers of Ukraine «On approval of the strategy for the development of exports of agriculture, food and processing industry of Ukraine until 2026» from 01.07.2019 no. 588-r. Available at: https://zakon.rada.gov.ua/laws/show/588-2019-%D1%80

4. Kaletnik H.M. (2019) Prospects for increasing the energy autonomy of agricultural enterprises in the framework of the energy strategy of Ukraine. *Bulletin of Agrarian Science of the Black Sea Coast,* 4(104), pp. 90–98. DOI: https://doi.org/10.31521/2313-092X/2019-4(104)-10

5. Shot A. (2011) World trends and prospects for the development of non-traditional and renewable energy sources in Ukraine. *Scientific notes of Lviv University of Business and Law,* 6, pp. 220–226.

6. Klimko V.I. (2016) Wind solar power supply systems for low-power consumers: author’s ref. dis ... cand. tech. Sciences: 05.09.03 / Nat. Lviv University Polytechnic. Lviv, 20 p.

7. Shchur I.Z., Klimko V.I. (2014) Method of calculation of power supply indicators of a separate object from a hybrid wind-solar system. *Problems of energy saving in electrical systems. Science, education and practice,* 1, 2, pp. 83–85.

8. Chen H., Cong T. N., Yang, W., Tan C., Li Y., Ding Y. (2009) Progress in electrical energy storage system: *A critical review. Progress in Natural Science*, vol. 19, 3, pp. 291–312. DOI: https://doi.org/10.1016/j.pnsc.2008.07.014

9. Amiryar M.E., Pullen K.R. (2017) A Review of Flywheel Energy Storage System Technologies and Their Applications. Applied Sciences, vol. 7, 3, pp. 286–299. DOI: https://doi.org/10.3390/app7030286

10. Wind Europe. European Statistics – Statistics. Wind energy in Europe in 2018 – Trends and statistics. windeurope.org. Available at: https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf

11. The International Energy Agency. Key World Energy Statistics. www.iea.org. Available at: https://www.iea.org/statistics/kwes/

12. Lazard. Levelized Cost of Energy and Levelized Cost of Storage 2018. www.lazard.com. Available at: https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018

13. Ukrainian Hydrometeorological Center. meteo.gov.ua. Available at: https://meteo.gov.ua//ua/33345/climate/climate_stations/

14. Gunko I.V., Galushchak O.O., Kravets S.M. (2019) Analysis of technological systems. Substantiation of engineering decisions: textbook. way. Vinnytsia: VNAU, 216 p.

15. Savchenko E. (2012) Application of solar energy in agriculture of Ukraine: opportunities and problems. *Agrarian economy*, vol. 5, no. 1–2, pp. 128–135.

16. Povkhanych A.Yu. (2017) Wind energy as a key element of energy strategy. *Scientific Bulletin of Uzhhorod National University. Series: International Economic Relations and the World Economy*, no. 13, 2, pp. 81–86.

17. Rykovanova I.S. (2017) Wind power generation: world experience and prospects of development in Ukraine. *Bulletin of the National University «Lviv Polytechnic». Series: Logistics,* no. 863, pp. 159–167.

18. Ministry of Energy and Coal Energy. Statistical information. Available at: http://mpe.kmu.gov.ua/minugol/control/uk/publish/archive?cat_id=35081&page=3

19. The International Energy Agency. Key World Energy Statistics. Available at: https://www.iea.org/statistics/kwes/

20. Atmosphere website. Schemes of organization of wind power plants. www.atmosfera.ua. Available at: https://www.atmosfera.ua/uk/vitryani-elektro-stancii/sxemi-organizacii-vitryanix-elektrostancij/

21. Solona O.V., Virnyk M.M. (2012) Theory of mechanisms and machines. Course design. Tutorial. Vinnytsia, 224 p.

22. Kaletnik G.M., Bulgakov V.M., Chernysh O.M., Kravchenko I.E., Solona O.V., Tsurkan O.V. (2011) Technical mechanics: Textbook. Kyiv: Hi-Tech Press, 340 p.

23. Patent no. 124327 of Ukraine, IPC F16F 15/30 (2006.01). Flywheel «VDMI». Yanovich VP, Kupchuk IM; owner Wynn. nat. agrarian. University no. u201707514; stated 17.07.2017; publ. April 10, 2018, Bull. no. 7.

24. Telekalo N., Melnyk M. (2020) Agroecological substantiation of medicago sativa cultivation technology. *Agronomy Research*, vol. 18(4), pp. 2613–2626.
25. Palamarchuk V., Krychkovskyi V., Honcharuk I., Telekalo N. (2021) The Modeling of the Production Process of High-Starch Corn Hybrids of Different Maturity Groups. *European Journal of Sustainable Development*, vol. 10, no. 1, pp. 584–598.
26. Palamarchuk V., Telekalo N. (2018) The effect of seed size and seeding depth on the components of maize yield structure. *Bulgarian Journal of Agricultural Science*, vol. 24, no. 5, pp. 785–792.
27. Palamarchuk V., Honcharuk I., Honcharuk T., Telekalo N. (2018) Effect of the elements of corn cultivation technology on bioethanol production under conditions of the right-bank forest-steppe of Ukraine. *Ukrainian Journal of Ecology*, vol. 8, no. 3, pp. 42–50.
28. Mazur V., Didur I., Pantsyreva G., Telekalo N. (2018) Energy-economic efficiency of growth of grain-crop cultures in conditions of right-bank forest-steppe zone of Ukraine. *Ukrainian Journal of Ecology*, vol. 8, no. 4, pp. 26–33.
29. Telekalo N., Mordvaniuk M., Shafer H., Matsera O. (2019) Agroecological methods of improving the productivity of niche leguminous crops. *Ukrainian Journal of Ecology*, vol. 9, no. 1, pp. 169–175.
30. Mazur V., Didur I., Myalkovsky R., Pantsyreva H., Telekalo N., Tkach O. (2020) The productivity of intensive pea varieties depending on the seeds treatment and foliar fertilizing under conditions of right-bank forest-steppe Ukraine. *Ukrainian Journal of Ecology*, vol. 10, no. 1, pp. 101–105.
31. Didur I., Bakhmat M., Chynchyk O., Pantsyreva H., Telekalo N., Tkachuk O. (2020) Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. *Ukrainian Journal of Ecology*, vol. 10, no. 5, pp. 54–60.
32. Yanovych V., Honcharuk T., Honcharuk I., Kovalova K. (2018) Engineering management of vibrating machines for targeted mechanical activation of premix components, *Inmateh–Agricultural Engineering*, 54, 1, pp. 25–32.
33. Kaletnik H.M., Kulik M.F., Glushko J.T. (Ed.). (2006) *Energy-saving feed technologies – the basis of animal husbandry competitiveness: monograph*, Vinnytsia: Thesis, p. 340.
34. Mushtruk M., Gudzenko M., Palamarchuk I., Vasyliv V., Slobodyanyuk N., Kuts A.., Nychyk O., Salavor O., Bober A. (2020) Mathematical modeling of the oil extrusion process with pre-grinding of raw materials in a twin-screw extruder, *Potravinarstvo Slovak Journal of Food Sciences,* 14, pp. 937–944.
35. Solona O., Kupchuk I. (2020) Dynamic synchronization of vibration exciters of the three-mass vibration mill. *Przeglad Elektrotechniczny*, vol. 96, no. 3, pp. 161–165.
36. Yanovych V., Honcharuk T., Honcharuk I., Kovalova K. (2017) Design of the system to control a vibratory machine for mixing loose materials. *Eastern-European Journal of Enterprise Technologies*, 6, pp. 4–13.
37. Bulgakov V., Pascuzzi S., Ivanovs S., Kaletnik G., Yanovych V. (2018) Angular oscillation model top redict the performance of a vibratory ball mill for the fine grinding of grain. *Biosystems engineering*, 171, pp. 155–164.

38. Sergeev S.N. (2008) *Tsentrobezhno-rotornye yzmelchytely furazhnoho zerna* [Centrifugal rotary grinders for feed grain] (*Extended abstract of Doctor's technical thesis*), Chelyabinsk, p. 42.

39. Abramov A.A. (2006) *Obosnovanye parametrov y rezhymov raboty yzmelchytelia zerna skalyvaiushcheho typa* [Substantiation of parameters and modes of operation of a chopping type grain grinder], (*Extended abstract of Candidate's technical thesis*), Rostov-on-Don, p. 20.

40. Palamarchuk I.P., Yanovych V.P., Kupchuk I.M., Solomko I.V. (2013) Development of constructive-technological scheme of the vibrating rotor crusher, *Vibrations in engineering and technologies,* 69, 1, pp. 125–129.

41. Yanovych V., Kupchuk I. (2017) Determination of rational operating parameters for a vibrating dysk-type grinder used in ethanol industry. *Inmateh – Agricultural Engineering*, 52, no. 2, 143–148.

42. Honcharuk I., Kupchuk I., Solona O., Tokarchuk O., Telekalo N. (2021) Experimental research of oscillation parameters of vibrating-rotor crusher, *Przeglad Elektrotechniczny*, 97, 3. 97–100.

43. Kupchuk I.M., Solona O.V., Derevenko I.A., Tverdokhlib I.V. (2018) Verification of the mathematical model of the energy consumption drive for vibrating disc crusher, *Inmateh – Agricultural Engineering*, 55, no. 2, 111–118.

44. Yanovych V., Tsurkan O., Polevoda Yu. (2019) Development of the vibrocentric machine for the production of a basic mixture of homeopathic preparations. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, 81, 2, pp. 13–26.

45. Tishchenko L., Kharchenko S., Kharchenko F., Bredykhin V., Tsurkan O. (2016) Identification of a mixture of grain particle velocity through the holes of the vibrating sieves grain separators. *Eastern-European Journal of Enterprise Technologies*, 80, 2(7), pp. 63–69.

46. Hrushetskyi S., Yaropud V., Kupchuk I., Semenyshena R. (2021) The heap parts movement on the shareboard surface of the potato harvesting machine. Bulletin of the Transilvania University of Braşov. *Series II: Forestry, Wood Industry, Agricultural Food Engineering*, vol. 14(63), no. 1, pp. 127–140.

47. Borysiuk D., Spirin A., Kupchuk I., Tverdokhlib I., Zelinskyi V., Smyrnov Ye., Ognevyy V. (2021) The methodology of determining the place of installation of accelerometers during vibrodiagnostic of controlled axes of wheeled tractors. *Przegląd Elektrotechniczny*, vol. 97, no. 10, pp. 44–48.

48. Adamchuk V., Bulgakov V., Ivanovs S., Holovach I., Ihnatiev Ye. (May 2021) Theoretical study of pneumatic separation of grain mixtures in vortex flow, *Engineering for Rural Development*. Jelgava, 657–664.

49. Solona O., Derevenko I., Kupchuk I. (2019) Determination of plasticity for pre-deformed billet. *Solid State Phenomena*, vol. 291, pp. 110–120.

50. Telekalo N.V., Melnyk M.V. (2020) Feed productivity of medicago sativa depending on the elements of growing technology. *Colloquium-journal,* no. 13(65), pp. 18–20.

51. Didur I., Pantsyreva H., Telekalo N. (2020) Agroecological rationale of technological methods of growing legumes. *The scientific heritage,* 52, pp. 3–14.

52. Telekalo N.V., Melnik M.V. (2020) Improving agroecological methods of growing alfalfa. *Agriculture and Forestry,* 16, pp. 73–88.

53. Telekalo N.V., Melnik M.V. (2020) Fodder productivity of alfalfa sowing depending on agroecological methods of cultivation. *Agroecological journal,* 2, pp. 76–83.

54. Telekalo N.V., Melnik M.V. (2020) Seed productivity of alfalfa sown depending on the elements of cultivation technology. *Scientific reports of NULES of Ukraine,* 3(85).

55. Polishchuk I.S., Telekalo N.V. (2018) Formation of productivity of spring barley depending on the influence of foliar fertilization in the right-bank forest-steppe conditions. *Agriculture and forestry,* 8, pp. 35–44.

56. Telekalo N.V. (2018) Agroecological methods of cultivation (pisum sativum) in the forest-steppe conditions of the right bank. *Agriculture and forestry*, 9, pp. 79–88.

57. Telekalo N.V. (2019) The influence of a set of technological techniques on the cultivation of peas. *Agriculture and forestry,* 13, pp. 84–93.

58. Telekalo N.V. (2019) The effectiveness of bacterial preparations in the cultivation of peas. *Agriculture and forestry*, 14, pp. 127–140.

59. Telekalo N.V., Melnik M.V. (2019) Ways to increase the productivity of alfalfa for sowing seeds. *Agriculture and forestry,* 15, pp. 56–63.

60. Kuznietsova I., Bandura V., Paziuk V., Tokarchuk O., Kupchuk I. (2020) Application of the differential scanning calorimetry method in the study of the tomato fruits drying process. *Agraarteadus*, vol. 31, no. 2, pp. 173–180.

61. Solona O., Kovbasa V., Kupchuk I. (2020) Analytical study of soil strain rate with a ploughshare for uncovering slit. *Agraarteadus*, vol. 31, no. 2, pp. 212–218.

62. Honcharuk I., Kupchuk I., Solona O., Tokarchuk O., Telekalo N. (2021) Experimental research of oscillation parameters of vibrating-rotor crusher. *Przeglad Elektrotechniczny*, vol. 97, no. 3, pp. 97–100.

63. Gunko I., Hraniak V., Yaropud V., Kupchuk I., Rutkevych V. (2021) Optical sensor of harmful air impurity concentration. *Przegląd Elektrotechniczny,* vol. 97, no. 7, pp. 76–79. DOI: https://doi.org/10.15199/48.2021.07.15

64. Kovbasa V., Solona O., Deikun V., Kupchuk I. (2021) Functions derivation of stresses in the soil and resistance forces to the motion of a plough share for cavity creation. *UPB Scientific Bulletin, Series D: Mechanical Engineering,* 83(3), pp. 305–318.

65. Yaropud V., Hunko I., Aliiev E., Kupchuk I. (2021) Justification of the mechatronic system for pigsty microclimate maintenance. *Agraarteadus*, vol. 32, no. 2, p. 7. (in press)

66. Mazur V., Tkachuk O., Pantsyreva H., Kupchuk I., Mordvaniuk M., Chynchyk O. (2021) Ecological suitability peas (Pisum Sativum) varieties to climate change in Ukraine. *Agraarteadus*, vol. 32, no. 2, p.8. (in press)

67. Solona O.V., Kupchuk I.M., Yanovich V.P., Polevoda Yu.A. Controlled vibratory drive: US Pat. no. 131864 Ukraine: IPC B06B 1/16 (2006.01), no. u201804718; stated 04/27/2018 Publ. 11.02.2019, bldg. no. 3/2019.

68. Kupchuk I.M (2017) Compromise optimization of regime parameters of grain raw materials grinding process in ethyl alcohol production. *Vibration in engineering and technology,* no. 4(87), pp. 91–100.

69. Kupchuk I.M. (2018) Investigation of the process of grinding grain with a disk impact element. *Technical service of agro-industrial, forest and transport complexes,* no. 11, pp. 41–48.

70. Kupchuk I.M., Branitsky Yu.Yu. (2018) Development of a software algorithm for calculating the kinematic parameters of the working bodies of the fan-calibration machine. *Engineering, energy, transport of agro-industrial complex,* no. 2(97), pp. 80–87.

71. Kupchuk I.M. (2018) Prospects for the development of constructive schemes of vibration drives of transport and technological machines of agro-industrial complex. *Vibration in engineering and technology,* no. 3(90), pp. 44–52.

72. Yanovych V., Kupchuk. I. (2017) Development of movement mathematical model for executive bodies of gyroscope-type mill. *SWorld journal: Technical sciences*, issue 13, pp. 174–184.

73. Komakha V., Burlaka S., Kupchuk I., Yatskovska R. (2018) Analysis of technologies of sowing and sowing. *Agriculture and forestry,* no. 11, pp. 123–121.

74. Mazur V.A., Polishchuk I.S., Telekalo N.V., Mordvanyuk M.O. (2020) Plant growing. Part I: textbook. Vinnytsia: Druk Publishing House Publishing House, 352 p.

75. Mazur V.A., Polishchuk I.S., Telekalo N.V., Mordvanyuk M.O. (2020) Plant growing. Part II: a textbook. Vinnytsia: Druk Publishing House Publishing House, 284 p.

76. Mazur V.A., Goncharuk I.V., Pantsireva G.V., Telekalo N.V. (2020) Agroecological substantiation of technological methods of growing legumes: monograph. Vinnytsia: Works, 192 p.

77. Tkachuk O., Telekalo N. (2020) Agroecological potential of legumes in conditions of intensive agriculture of Ukraine collective monograph. Latvia, Riga: Baltija Publishing, pp. 91–104.

78. Mazur V.A., Goncharuk I.V., Didur I.M., Pantsireva G.V., Telekalo N.V., Kupchuk I.M. (2021) Innovative aspects of technologies for growing, storage and processing of legumes: a monograph. Vinnytsia: Nilan-LTD, 180 p.

79. Palamarchuk V.D., Telekalo N.V. (2021) Prospects for growing corn for grain to produce bioethanol. *Agriculture and forestry,* no. 2(21), pp. 47–61.

80. Vidmysh A.A., Wozniak O.M., Kupchuk I.M., Boyko D.L. (2020) Investigation of median filtering of one-dimensional signals. *Vibration in engineering and technology,* no. 1(96), pp. 88–102.

81. Yaroshenko L.V., Zamriy M.A., Kupchuk I.M. (2020) Development of design and research of technological parameters of machines for vibration centrifugal-planetary processing. *Vibration in engineering and technology*, no. 2(97), pp. 41–50.

82. Granyak V.F., Kupchuk I.M., Gontar V.G. (2020) Method and means of direct automated measuring control of insulation of windings of electric machines. *Engineering, energy, transport of agro-industrial complex,* no. 2(109), pp. 129–137.

83. Kupchuk I.M., Vovk V.Yu., Datsyuk D.A. (2020) Estimation of economic efficiency of technical modernization of preparatory stage of technological process of ethanol production. *Bulletin of Khmelnytsky National University. Series: Technical Sciences*, no. 2(283), pp. 36–46.

84. Kupchuk I.M., Yaropud V.M., Telekalo N.V., Granyak V.F. (2020) Prospects and prerequisites for the introduction of autonomous power supply systems of agro-industrial enterprises. *Engineering, energy, transport of agro-industrial complex,* no. 3(110), pp. 51–63.

85. Tokarchuk O.A., Kupchuk I.M. (2020) Investigation of the influence of the design and dimensions of the intake and calibration surface of chipless taps on the process of extruding threads. *Vibration in engineering and technology,* no. 3(98), pp. 76–84.

86. Pryshlyak V.M., Kupchuk I.M., Didyk A.M., Kupchuk V.M. (2020) State and prospects of application of remote administration programs in the educational process of engineering students. *Bulletin of Khmelnytsky National University. Series: Technical Sciences,* no. 4(287), pp. 57–63.

87. Kupchuk I.M., Tokarchuk O.A., Gontar V.G., Didyk A.M. (2020) Analysis of the power balance of the technological system of grinding of vegetable agricultural waste. *Engineering, energy, transport of agro-industrial complex,* no. 4(111), pp. 122–128.

88. Mazur V.A., Didur I.M., Pantsyreva H.V., Telecalo N.V. (2018) Energy-economic efficiency of growth of grain-crop cultures in the conditions of right-bank Forest-Steppe zone of Ukraine. *Ukrainian Journal of Ecology*, vol. 8, no. 4, pp. 26–33.

89. Mazur V.A., Mazur K.V., Pantsyreva H.V., Alekseev O.O. (2018) Ecological and economic evaluation of varietal resources *Lupinus albus* L. *Ukrainian Journal of Ecology,* vol. 8, pp. 148–153. (in Ukrainian)

90. Mazur V.A., Pantsyreva H.V., Mazur K.V. and Didur I.M. (2019) Influence of the assimilation apparatus and productivity of white lupine plants. *Agronomy Research,* 17, 206–219.

91. Mazur, V.A., Pantsyreva, H.V., Mazur, K.V., & Monarkh, V.V. (2019) Ecological and biological evaluation of varietal resources Paeonia L. in Ukraine. *Acta Biologica Sibirica*, 5(1), 141–146. DOI: https://doi.org/10.14258/abs.v5.i1.5350

92. Pantsyreva, H.V. Morphological and ecological-biological evaluation of the decorative species of the genus *Lupinus* L. *Ukrainian Journal of Ecology*, 9(3), 74–77. 21997. DOI: https://doi.org/10.15421/2019_711

93. Didur, I.M., Prokopchuk, V.M., Pantsyreva H.V. (2019) Investigation of biomorphological and decorative characteristics of ornamental species of the genus Lupinus L. *Ukrainian Journal of Ecology*, 9(3), 287–290. DOI: https://doi.org/10.15421/2019_743

94. Monarkh Veronika Valentynivna, Pantsyreva Hanna Vitaliivna (2019) Stages of the Environmental Risk Assessment. *Ukrainian Journal of Ecology*, 9(4), 484–492. DOI: https://doi.org/10.15421/2019_779

95. Mazur, V. A., Myalkovsky, R.O., Mazur, K. V., Pantsyreva, H. V., Alekseev, O.O. (2019) Influence of the Photosynthetic Productivity and Seed Productivity of White Lupine Plants. *Ukrainian Journal of Ecology*, 9(4), 665–670. DOI: https://doi.org/10.15421/2019_807

96. Mazur, V., Didur, I., Myalkovsky, R., Pantsyreva, H., Telekalo, N., Tkach, O. (2020) The Productivity of intensive pea varieties depending on the

seeds treatment and foliar fertilizing under conditions of right-bank forest-steppe Ukraine. *Ukrainian Journal of Ecology*, 10(1), 101–105.

97. Pantsyreva, H.V., Myalkovsky, R.O., Yasinetska, I.A., Prokopchuk V.M. (2020) Productivity and economical appraisal of growing raspberry according to substrate for mulching under the conditions of podilia area in Ukraine. *Ukrainian Journal of Ecology*, 10(1), 210–214.

98. Mazur, V.A., Branitskyi, Y.Y., Pantsyreva, H.V. (2020) Bioenergy and economic efficiency technological methods growing of switchgrass. *Ukrainian Journal of Ecology*, 10(2), 8–15.