Increasing power supply efficiency of livestock complexes at small farms using renewable energy sources

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Abstract. The paper provides technical recommendations for designing power supply systems for livestock complexes of small farms based on renewable sources of electric energy. Resource analysis of solar and wind energy on the Russian Federation territory shows that the use of the hybrid solar-wind power plants is most appropriate. In the case, it is advisable to use batteries and diesel generators to ensure reliable and uninterrupted power supply. Herein is offered a version of making up a structural diagram of power supply system for a small farm with combined power supply from centralized power grids and renewable energy sources. It is shown that the use of such a system can significantly save due to the power not consumed from the grid, and also allows selling excess energy to the power system. Herein is offered a version of building up a structural diagram of an autonomous power supply system based on a hybrid solar-wind power plant and a diesel generator for those regions, where there is no distributive electrical network. A design of a vortex wind power installation has been developed for practical use as part of the considered options for power supply schemes, which allows using small winds and low-potential thermal upward flows, reducing low-frequency vibration and noise, placing it on the top of industrial buildings with ease of installation, maintenance and repair.

1. Introduction
The world food problem is recognized as the global problem of mankind. Agricultural development is key to making significant and lasting progress towards ridding millions of people out of poverty and food insecurity [1].

The main part of agricultural products is produced at large diversified agro-industrial complexes (AIC), specialized enterprises at the federal and regional levels. In market economy, the share of agricultural products produced by small farms (SFs) increases as the latter become established and developed in all regions of the Russian Federation [2], in particular the sector of production and supply of high-quality meat and dairy to consumer market.

Reliable and uninterrupted power supply to SF enterprises is an urgent task. Unlike large agro-industrial complex enterprises for cattle fattening and pig breeding, which are supplied from the centralized power system, power supply to similar SF enterprises may be hindered for the following reasons:
- SF enterprises can be created in territories remote from stationary sources of electric energy, where the wear of distributive electric networks is significant [3];
- cost of constructing power lines and connecting to electric grids may exceed the farmer's available financial resources.
In the paper [4], there was shown that at the SF enterprises, to ensure the technological process for the production of livestock products, it is most expedient to use power supply systems (PSS) using renewable sources of electric energy (RES).

As such sources there can be used: solar panels (SP), storage batteries (SB), wind power plants (wind turbines, WPP) and diesel-electric plants (DEP).

Thus, justification and development of the structure of power supply systems for SFE is an urgent scientific and technical task.

2. Research materials
The problem is formulated as follows: to develop technical recommendations on the design of power supply system for the livestock breeding complex of SFE based on renewable sources of electrical energy.

To solve this problem, it is necessary to study the following issues:
- analysis of the resources of solar and wind energy to build the SFE PSS;
- development of options for building the structures of SFE PSS;
- development of energy sources for SFE PSS.

2.1. Analysis of solar and wind energy resources
The resourcing base of solar and wind energy in the Russian Federation is as follows:
- zones of effective use of wind energy plants (WPP) are in the following regions of the Russian Federation: Arkhangelsk, Astrakhan, Volgograd, Kaliningrad, Kamchatka, Leningrad, Magadan, Murmansk, Novosibirsk, Rostov, Tyumen; Territories: Krasnodar, Perm, Primorsky, Khabarovsk; Republics: Dagestan, Kalmykia, Khakassia, Sakha (Yakutia); Autonomous districts: Nenets, Chukot, Yamalo-Nenets [5, 6];
- most promising regions in terms of the use of solar panels: Kalmykia, Stavropol krai, Rostov oblast, Krasnodar krai, Volgograd oblast, Astrakhan oblast and other regions in the Southwest, Altai, Primorye, Chita oblast, Buryatia and other regions of Western and Eastern Siberia and the Far East [6,7].
- most popular today are hybrid solar-wind plants, which are a combination of solar panels with wind generators [8, 9].

Currently, manufacturing technologies allow to create WPP with a unit capacity of 4.5-5.0 MW. By 2020, the total installed capacity of wind turbines in the world is going to be 1200 GW, and by 2040 - 3100 GW. In 2030, the annual production of photovoltaic systems should reach 140 GW. In Russia in 2020, it is planned to produce 24 billion kWh of electricity on the basis of renewable energy sources (RES). [10].

Consequently, the simultaneous use of various types of alternative energy, for example, wind and solar, is the most effective. By complementing each other, together they guarantee the production of a sufficient amount of energy.

Solar batteries and wind turbines in terms of their environmental properties are the most preferable for use in the composition of the SFE PSS, since their negative impact on the environment is minimal [11].

Units based on diesel generators, used as backup sources, are significantly inferior to SB and wind turbines in environmental properties. Expediency of their use at the enterprises of meat and dairy production is determined on the basis of minimizing the costs for maintaining and operating these units. Obviously, their applying at the large livestock complexes is most appropriate [12].

2.2. Options for building structures of SFE PSS
In order to ensure the technological process of the SFE livestock complex, depending on the region of its location on the Russian Federation territory, it is advisable to consider options of building power supply schemes for these complexes.
For northern regions with a predominance of wind energy and snowy winters, the most appropriate is the use of wind turbines. Power sources in this case are: the district centralized power system and a group of wind generators consisting of several wind turbines connected in parallel. The SFE PSS scheme is presented in Figure 1. The system operation algorithm is as follows. At the current value of the required electric power $P_{\text{Req}}$, less than the total power generated by the wind turbine (WPP) $P_{\text{wpp}}$, receivers are provided with electricity from WPP. There is no electricity consumption from the centralized energy system, which means that there is a saving of the farmer’s money for paying for this energy. With the current value of the required electric power $P_{\text{Req}}$, greater than the total power generated by the wind turbines (WPP) $P_{\text{wpp}}$, the receivers are provided with electricity from a centralized power system and wind turbines. The described algorithm is implemented by the circuit shown in Figure 1.

![Figure 1. Structural diagram of power supply system for small farm with combined power supply from electric networks and renewable energy sources.](image)

When $P_{\text{Req}}$, less than the total power generated by wind turbines $P_{\text{wpp}}$, electric power of 0.38 kV is supplied from the output of a group of WPP 1 ... WPP N through switches S2, S1, switchboard SB1, to the receivers of the complex. The current value of the required power is monitored by the PCS power consumption sensor. In the case of a decrease in the high-speed air pressure and a decrease in the generated electric power for this reason, on the command from the control system, the switch S2 switches the outputs of the wind turbine to the R1 rectifier. From the output R1, the rectified voltage is supplied to the AI adjustable inverter, from the output of which the voltage is supplied to the MD matching device. After the conditions for parallel operation of the transformer substation of stationary network and the voltage from the wind turbine are met, the S3 switch is activated by a command from the control system. Electricity from the output of the MD through the switch S1, switchboard SB1, is supplied to the receivers of the complex. In the case, the power generated by the wind turbine group is an integral component of the overall balance of the power consumed by the receivers. As a result, the power consumption from the centralized power system through the TS decreases, which in turn increases the efficiency of the proposed power supply system.

In regions of the Russian Federation where solar energy resources are predominant, the described algorithm can be successfully implemented on the basis of solar panels. In regions of the Russian
Federation, where there are resources of energy and wind, and the sun, the combined schemes containing wind turbines and SB can be successfully used.

For the country regions with undeveloped distributive networks infrastructure of a centralized energy system, a considerable distance from them or difficulties in connecting to stationary networks, the most suitable option for power supply for the created SFE is the organization of power supply to the enterprise on the basis of autonomous power supply system (APSS SFE). To solve the problems of ensuring not only the technological process of livestock production, but also ensuring the living conditions of production personnel as part of the power supply system, it is advisable to have at disposal the wind turbines, solar batteries, batteries, and diesel-electric plants (DEP) as a backup.

The basic principle of building such an APSS SFE is the maximum possible use of wind and solar energy and the minimization of using the DEP energy. It is advisable to evaluate wind energy by the current value of electric power generated by wind turbines ($P_{\text{WPP}}$). The solar energy is the current value of the electric power generated by the SB ($P_{\text{SB}}$). The total consumed electric power at each moment of time can be estimated by the required current value ($P_{\text{Req}}$).

The algorithm of the system is as follows. Wind turbines ($P_{\text{INS,WPP}}$) and SB ($P_{\text{INS,SB}}$) installed in the stations can be equal in power or differ in nominal values, depending on the specifics, priority of the tasks being solved by the station and the natural and climatic conditions.

When the current value of the electric power $P_{\text{WPP}}$ is greater than the current required value of $P_{\text{Req}}$, the station receivers can be provided from the wind turbine. Similarly, at the current value of the electric power of SB $P_{\text{SB}}$, all receivers can be provided from the SB. In general case, if the current values $P_{\text{WPP}}$ and $P_{\text{SB}}$ exceed the current value of the power $P_{\text{Req}}$, then the level of the generated power by each of these sources is provided by the corresponding regulators.

If the installed capacities are equal, $P_{\text{INS,WPP}} = P_{\text{INS,SB}}$, the required current value of power $P_{\text{Req}}$ is provided by their combination also by means of corresponding regulators. The current values of the generated capacities are monitored by appropriate sensors (WPP CS, DEP CS, SB CS). The required current power value is monitored by the power consumption sensor (PCS).

If the total current value of the $P_{\text{WPP}}$ and $P_{\text{SB}}$ is insufficient, the DEP start functioning to provide consumers with power. Thus, DEP as a backup source is used only if it is not possible to cover the required current power $P_{\text{Req}}$ from wind turbines and SB. The described algorithm is implemented by the circuit shown in Figure 2.

With a sufficient level of the current value of $P_{\text{WPP}}$, the alternating voltage from the wind turbine output through switch S1, the switchboard SB1 is supplied to the station receivers and rectifier R1 to recharge the battery.

With a sufficient level of the current value of $P_{\text{SB}}$, the constant voltage from the SB output is supplied to HFI, the high-frequency inverter, from the output of which the voltage is supplied through the rectifier R2, S2 switch to the LFI, low-frequency inverter, and then through the switchboard SB1 also to the station receivers. With a lack of power generated by the separate wind turbines ($P_{\text{WPP}}$) and SB ($P_{\text{SB}}$), its shortage is covered by their total generated power.

The switch S2 by signals from the control system ensures that the battery is connected to the R2 rectifier (when charging the battery from the SB) or to the R1 rectifier (when charging the battery from the wind turbine). In case of emergency, the battery itself, through the S2 switch and the switchboard SB2, provides the operation of the emergency lighting system for the SFE premises.
In the case, the total current value of the electric capacities $P_{WPP}$ and $P_{SB}$ turns out to be significantly less than the required current value of $P_{\sum Req}$, the control system through the S1 switch generates a command to disconnect all receivers from the wind turbine and the SB, starts functioning the DEP and after controlling its output parameters transfers the power of the receivers from the wind turbines and SB to the DEP through the S1 switch and SB1 switchboard. Battery charging is carried out from the DEP through S1 switch and R1 rectifier.

### 2.3. Development of energy sources for SFE power supply

Taking into account the above approaches to building SFE power supply systems, at the Don State Technical University (Rostov-on-Don) there have been developed a utility model of a vortex wind turbine [13] and invented a vortex wind turbine [14], which can be used to increase the efficiency of power supply to livestock complexes.

The proposed vortex wind turbines have the following advantages [11, 15, 16]:
- low noise and vibration (less than 35 dB), which allows you to place it on the top of industrial buildings, which makes it possible to use not only the energy of horizontal wind flows, but also the energy of upward vertical air flows during ventilation of the production building of the barn;
- no need to erect a separate high-rise structure in the form of a mast for wind turbines with a height of at least 30 to 40 meters to ensure the required wind speed;
- efficiency and ease of installation, maintenance and repair, since the installation is located on the top of a building, and not on a high-rise mast;
- possibility of using small wind and low potential thermal upward flows;
- simplification of operation technology by extending the life of bearing assemblies.

The design of a useful model of a vortex wind turbine is shown in Figure 3 [13]. A device for converting kinetic wind energy into mechanical energy contains a bell 5, made in the form of a truncated cone or cylinder, turning into a truncated cone, and a rotor located in it along its vertical axis, made in the form of a shaft 2 with blades 7 fixed to it by means of connecting disks 6 with a partial protrusion 8 of them from the lower part of the bell 5. In addition, the specified bell 5 is installed on the supports 9 with thrust bearings 16, at least three according to the stability conditions, at the level of the upper cut 4 of the bell 5 in the horizontal plane, a power crosspiece 3 rigidly connected to the bell 5 is installed, in the center of which there is a bearing assembly 1, in which the rotor shaft 2 is mounted rotatably, at the level of the lower part of the supports 9 of the bell 5 in the
horizontal plane, there is a power crosspiece 13 rigidly connected to the supports 9 by means of installed structural elements 14, in the center of which is the bearing assembly 15, in which the rotor shaft 2 is mounted for rotation. The height of the supports 9 of the bell 5 is determined by the possibility of air passage. The EMF generator 10 with the inductor 11 and the armature 12 is mounted on the power crosspiece 13 at the level of the lower part of the supports 9 of the bell 5 in the horizontal plane, the rotor of the EMF generator 10 is rigidly connected to the shaft 2 of the rotor, and the overall dimensions of the EMF generator 10 are determined by the possibility of obtaining the maximum possible EMF and limited by supports 9 of the bell. The bell 5 has a lower cut 17.

![Draft utility model of vortex wind power plant](image)

**Figure 3.** Draft utility model of vortex wind power plant.

2.4. *Work of utility model of vortex wind power plant*

When the blades 7 of the rotor are blown by the wind, the rotor shaft 2 starts to rotate, creating a difference in the velocity of the air layers in the space between the lower 17 and the upper 4 sections of the bell 5, resulting in a stable vortex air flow, which provides the conversion of wind energy into mechanical energy rotation of the wind wheel containing the disk 6 and the blade 7, and the shaft 2 of the rotor. The rotor shaft 2 through a bearing assembly 15 is connected to the power cross 13 at the level of the lower part of the supports 9 of the socket 5. Due to this, vibrations in the vertical plane are reduced due to the exclusion of reactions from the side of the supports 9 to the socket 5 in the vertical plane.

Reducing vibrations and reducing vibrations of the shaft 2 in the horizontal plane is provided by the bearing assembly 1 connecting the rotor shaft 2 with the power crosspiece 3, which is rigidly connected to the bell 5 at the level of the upper cut 4 of the bell.

The spatial arrangement of the EMF generator 10 on the power crosspiece 13 reduces the height of the center of mass of all rotating elements and the whole device design, which increases its stability, and, consequently, the reactions in the bearing assemblies are reduced at the level of the upper and lower sections of the bells, the bearing assembly’s life is extended, contributing to the simplification of operating technology.
Thus, the proposed vortex wind turbine allows to use small winds and low-potential thermal upward flows, reduce low-frequency vibration and increase stability [13].

Design of the vortex wind turbine invention is shown in Figure 4 [14]. A wind power plant containing a bell 5 made in the form of a truncated cone or cylinder turning into a truncated cone, and a rotor located in it along its vertical axis, made in the form of a shaft 2 with a conical screw blade 3 fixed to it, and below it on the shaft 2 blades 7 are fixed by means of connecting disks 6 with a partial protrusion 8 of them from the lower part of the bell 5. The bell 5 is mounted on at least three supports 9 with thrust bearings 14, according to stability conditions, at the level of the upper cut 16 of the bell 5 in a horizontal plane there is a power crosspiece 4 fixedly rigidly connected to the bell 5, in the center of which there is a bearing assembly 1, in which the rotor shaft 2 is mounted rotatably, at the level of the lower part of the supports 9 of the bell 5 in a horizontal plane, there is rigidly connected to the supports 9 by means of power elements of design 12, a power crosspiece 11, in the center of which a bearing assembly 13 is located, in which the rotor shaft 2 is mounted rotatably. The EMF generator 10 is mounted on the power crosspiece 11 at the level of the lower part of the supports 9 of the bell 5 in a horizontal plane, the rotor of the EMF generator 10 is rigidly connected to the rotor shaft 2, and the overall dimensions of the rotor of the EMF generator 10 are determined by the possibility of obtaining the maximum possible EMF and are limited by supports 9 of the bell 5. The bell 5 has a lower cut 15.

Figure 4. Design of vortex wind power plant.
Work of vortex wind power plant. When protrusion of the blades of the rotor blades 7 is blown by the wind, the rotor shaft 2 starts to rotate, creating a difference in the velocity of the air layers in the space between the lower 15 and the upper 16 sections of the bell 5 due to the formation of a vortex flow according to D. Bernoulli equation, resulting in a stable vortex air flow, which provides converting wind energy into mechanical energy of rotation of a wind wheel containing discs 6 and blades 7 and rotor shaft 2.

The air flow arising in the bell 5 begins to act on the conical screw blade 3. The result of this effect is the force that acts on the conical screw blade 3 from the side of the air flow flowing through it. The power developed by this force is proportional to the product of the momentum of the mass passing through the conical screw blade 3 per unit time of the air by the speed difference before and after it. Under the action of this force, an additional torque arises, created by a conical helical blade 3, providing an increase in the efficiency of using wind energy.

Thus, fastening on the shaft 2 of the wind power plant of the conical helical blade 3 with a variable radius decreasing in the direction from the lower 15 to the upper 16 cut of the bell 5 allows to obtain an increase in power on the shaft 2 due to the power generated by the conical helical blade 3, which arises due to the use of the vortex flow energy in the bell 5, and on this basis, with the same value of the air flow power as in the prototype, increase the efficiency in the proposed wind power plant [14].

2.5 Practical use of vortex wind turbines in SFE power supply systems

The use of the proposed devices as energy sources for consumers of the complex is illustrated in Figure 5, where Figure 5a shows the main view of the barn in plan with wind turbines placed on its roof, and Figure 5b shows a side view of the structure. Figure 5 shows positions: 1- wind turbine; 2 - roof of barn; 3 - barn housing; 4 - ascending air flows from the barn; 5 barn doors. As a structure for the barn, a frameless arch construction was chosen, which is proposed to be used for family mini farms for 24 and 50 cows [17]. With overall dimensions of one of the options for such a structure of $26300 \times 9650 \times 6300$, up to 7 or 8 vortex wind turbines with a capacity of 3 to 5 kW can be placed on its upper part.

![Figure 5. Placement of vortex wind turbines on the top of barn: a) main view; b) side view.](image)

Horizontal air flows at a height of 6 meters from the earth's surface provide a steady force impact on the rotor wheel of a wind turbine, and ascending flows from the internal cavity of the barn increase the force effect on the rotor wheel of a wind turbine. As a result, the mechanical power supplied to the rotor shaft of the wind turbine increases, and, consequently, the generated electric power of the wind turbine.

3. Conclusions

1. Resources analysis of solar and wind energy in the Russian Federation territory shows the most appropriate is the use of hybrid solar-wind power plants for power supply to SF enterprises. At the
same time, usage of rechargeable batteries and diesel generators ensures reliable and uninterrupted power supply.

2. The use of wind power plants and solar panels as part of the SFE power supply systems, which receive electricity in parallel and from a centralized network, can significantly save due to energy not consumed from the network.

3. The use of wind and solar energy in the Russian Federation as part of electric energy sources with a stable nature makes it possible to sell surplus energy to the power system.

4. An option has been developed to build an autonomous power supply system for the SFE on the basis of a hybrid solar-wind power plant and a diesel generator for power supply to the SFE in regions where is no distributive electric network.

5. A design of a vortex wind turbine is proposed for use as part of the SFE power supply system, which allows using small winds and low-potential thermal ascending flows, reducing low-frequency vibration and noise, placing it on the tops of industrial buildings with ease of installation, maintenance and repair.

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