Modernization of the energy system of an enterprise

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Abstract. Energy saving in any enterprise is an actual problem associated with the rising cost of energy. In this case, the cost of electricity is among the most expensive components. One of the most effective ways to save electricity is to use energy-saving technologies and modernize energy systems, including the use of “small” energy systems. The task was to modernize the energy system of the Cherepovets poultry farm in order to reduce energy costs. After completing the cycle of work on a comprehensive assessment of possible options, production verification and implementation, the most effective way to reduce the cost of electricity was the method of upgrading the energy system based on “small generation” means using traditional fuels. The modernization allowed the Cherepovets poultry farm to annually generate up to one-third of its own electricity through a mini-combined heat and power station (mini-CHP) and keep the cost of the kWh generated three times lower than that in the grid. It confirmed the possibility of sharing the poultry farm and grids of its 6 (10) kV transmission lines and transformer substation on the territory of the farm.

1. Introduction
The level of energy efficiency of agricultural production largely determines the cost of production. The share of energy consumption in the cost estimates of agricultural enterprises for the production of agricultural products is a significant part (from 10 to 50 %), and the implementation of energy saving measures in increasing the energy efficiency of agricultural production takes on particular importance [1].

Spending on energy, the main share of which is the payment of electricity, is in the third place in the cost of poultry products after the cost of feed and wages [2]. Until recently, the annual consumption of electricity, for example, by a poultry farm outputting 14,000–15,000 metric tons of meat per year, was 16–19 million kWh. Broiler houses had up to 70 % of the load accounted for the microclimate (brooders, ventilation, etc.), 25 % for lighting (incandescent lamps), the rest for feed distribution and other process steps. With the introduction of LED lighting and less energy-consuming ventilation systems, this ratio has changed, but the continuous increase in energy prices leaves the issue of reducing the cost of energy components among the most relevant [2-4].
2. Immediacy of the problem
Energy conservation in the poultry industry is devoted to many works of researchers. There are more widely covered solutions for energy saving in the field of lighting that give a good economic effect during implementation (Bagaev, K.I., Zhilin, A.S., Bayneva, I.I. et al.), heat savings, in particular, for reducing heat loss from structural members of buildings and ventilation air (Gubaidullin, N.M., Melnik, V.A., Gusev, V.A., Koroleva, N.A. et al.), for autonomous heating and power supply, including using “small” generations (Chilikov, A.A., Nikolaev, V.I., DolgovI.Yu.et al.). Papers on the modernization of the energy system of an enterprise based on heat-saving technologies with the use of "small" energy sources were not found.

3. Problem description
The Cherepovets poultry farm was tasked with reducing the cost of electricity. With the involvement of independent specialists, the workers of the APK-OGO JSC agroholding completed a cycle of work on a comprehensive assessment of possible options, modeling, production verification and the introduction of the most effective method of reducing electricity costs.

4. Theoretical part
To solve this problem, the possibilities were considered among others regarding the “small generation” using traditional fuels among others, i.e. production at the farm of the required annual amount of electricity at prices lower than the grid ones.

There area of "small" energy of the Russian Federation has more than 232 GW of generating capacity, of which 2/3 is heat plants and most of them run on gas. “Small” energy means local (autonomous by enterprise, locality) power systems, including those running on traditional fuels [12–15].

The economic legitimacy of small systems is based on the fact that the calorific value of 1 Nm3 of gas according to GOST 5544-2014 is 8,000 kcal, which, without taking into account the transformation efficiency, is equivalent to 8,000/860 = 9.3 kWh of electricity. Taking into account the working range of efficiency variation, the electricity generation at mini-power plants will be in the range of 2.5–3.8 kWh per 1 Nm3 of gas [17].

Modeling the use of "small" energy means acceptable for most farms, it is necessary to proceed from the following provisions:
• Most farms own only low voltage electricity.
• Level of permissible replacement of grid electricity with own generation should be such that funds from the supply of the rest of electricity would be enough to renovate the entire grid structure at the poultry plant (6 (10) / 0.4 kV substation and 6 (10) kV power transmission line), ensuring the salaries of employees and a certain level of profit [18].

To provide a quick recoupment of a mini-combined heat and power station (mini-CHP), it is necessary to install it in separate workshops (areas) with an extremely high daily demand factor for connected loads, as well as to select the generator power for the loads of a specific section (parent flock, young stock or a part of the product area). For example, 18 floor-standing broiler houses require 315 kW, etc. Under these conditions, mini-CHP is capable of producing up to 2.4-2.7 million kWh per year, providing electricity for the production of 10,000 metric tons of broiler meat, two such power plants are capable of producing up to 20,000 metric tons, etc. [19, 20, 21]

Figure 1 shows the connection diagram of a container mini-CHP at the existing6 (10) kV transformer substation to the low volt-age power line belonging to the poultry farm, with disconnecting the isolator on the low voltage busbars of the transformer sub-station.
The heat recovery units introduced at the farm showed high efficiency: the 0 ºC air flow was applied to the reheat heater at an outside air temperature of minus 15 ºC. This allowed the farm for several years to reconstruct the ventilation-heating system for heat recovery units and utilize heat in 81% of poultry houses at the poultry farm (45 buildings). The large-scale re-equipment enabled the farm to reduce the annual heat consumption by a third (79,000 Gcal instead of 119,700 Gcal) in comparison with broiler factories of comparable capacity (13,500-15,000 metric tons a year) of a similar climatic zone.

The overall heat savings allowed the poultry farm to put into operation the necessary number of mini-CHPs without obtaining permits from gas farms to increase annual gas consumption [18, 24].

This technique was tested during the inspection of a mini-CHP option at the Cherepovets poultry farm (the main collaborators were V. Minaev and V. Mokhov). The farm began to save substantial amounts of heat (and gas) through installing heat recovery units on a large number of poultry houses. One of the DKVR steam boilers (double-drum vertically-water-tube reconstructed unit) at the boiler house of the poultry farm was freed from the load. This made it possible to install a steam turbine generator (STG) having a capacity of 1.25 MW (ProletarskyZavodPJSC, St. Petersburg) in a separate room at the boiler room and eliminate all problems of limits on the amounts and connections of the mini-CHPs on the gas side (STG parameters fit well with the DKVR boiler at an output pressure up to 2.5 MPa and steam temperature up to 370 ºC, as well as at a pressure behind the turbine of 0.6-0.12 MPa) [25].

With the implemented scheme, it was necessary to solve the problem of the possibility of joint operation with the power grid, since it is impossible to transfer 1,250 kW of electricity to several sections that were remote from the boiler room more than 300 m via low voltage lines, and because the electric generators having a capacity of 1.25 MW were high voltage ones.

The long-term operation of the mini-CHP at the Cherepovets poultry farm with annual generation of up to one-third of its own electricity (up to 4 million kWh with an annual amount of electricity consumption of 12 to 13 mln kWh) has allowed the cost of kilowatt-hours to be kept at three times lower than that of the grid. It has confirmed the possibility of sharing by the power lines of the poultry farm its 6 (10) kV power transmission line and transformer substations at the premises (it is necessary to measure the "overflows" and plan the flow directions).

The mini-CHP scheme with a gas piston engine and an electric generator (according to Figure 2) and later implemented by the Sredneuralskaya poultry farm showed itself as the most efficient.
Figure 2. Mini-CHP diagram (Legend: 3 – 0.4 kV power transmission line; 4 – electricity loads (poultry buildings); mini-CHP (gas piston engine + electrical generator)).

It should be noted that foreign gas piston engines have quite high engine service hours (Wilson) equal to 170,000 to 180,000 hours of operating time (this is more than 21.1 years with 2 overhauls), at the same time, domestic gas piston engines are close to foreign ones in these indicators (Rybinsk Complex, Russian Diesel, Balakovo). Those enterprises that do not have pipeline gas can use mini-CHP running on crude oil (Konver LLC and KolomenskyZavodOJSC) [27-30]. Table 1 shows the specifications of such power plants.

Table 1. Specifications of container-mounted mini-CHP running on gas and crude oil.

| Parameters                          | Power plant model | EGP 100K | EGP 200K | EGP 315K |
|-------------------------------------|-------------------|----------|----------|----------|
| Rated electric power (kW)           |                   | 100      | 200      | 315      |
| Rated voltage (kV)                  |                   | 0.4/0.22 | 0.4/0.22 | 0.4/0.22 |
| Frequency (Hz)                       |                   | 50       | 50       | 50       |
| Heat recovery unit power            |                   | 150      | 250      | 460      |
| including that for exhaust gas      |                   |          |          |          |
| recovery (kW)                       |                   |          |          |          |
| Fuel consumption                    |                   | 35 Nm³/h | 5.5 L/h  | 70 Nm³/h | 8.0 L/h  | 110 Nm³/h |
| Overall dimensions                  |                   | 4.2 x 2.4 x | 5.0 x 2.4 x | 5.8 x 3.0 x | 5.8 x 3.0 x |
| (LxWxH)(m)                          |                   | 2.6      | 2.6      | 2.6      |

*Note: EGN runs on crude oil (backup is furnace oil and diesel fuel), the rest ones use pipeline gas as the base fuel.

Table 2 shows the cost efficiency of the EGP operation.

Table 2. Cost efficiency of the EGP operation.

| Parameters                          | Power plant model | EGP100K  | EGP200K  | EGP315K  |
|-------------------------------------|-------------------|----------|----------|----------|
| Cost of EGP in basic configuration, |                   | 2,554.18 | 3,776.82 | 5,309.19 |
| ‘000 rubles                         |                   |          |          |          |
| General CAPEX with local grids     |                   | 3,509.26 | 4,731.90 | 6,264.27 |
| General expenditures for EGP        |                   | 1,370.68 | 2,056.51 | 2,863.52 |
| operation, ‘000 rubles              |                   |          |          |          |
| Annual own electricity generation,  |                   | 670,140  | 1,340,280| 2,110,000|
| kWh                                 |                   |          |          |          |
| Cost of annual own electricity      |                   | 2,345.49 | 4,690.98 | 7,388.29 |
| generation amount, ‘000 rubles      |                   |          |          |          |
| Prime cost of own electricity       |                   | 2.046    | 1.534    | 1.357    |
| rubles/kWh                          |                   |          |          |          |
| Payback time, years                 |                   | 3.65     | 1.80     | 1.38     |
5. Conclusion
At the Cherepovets poultry farm, a comprehensive assessment of possible options, production verification and the introduction of the most effective method of reducing electricity costs, namely, the so-called “small generation” using traditional types of fuel, i.e. production at the factory of the required annual amount of electricity at prices lower than the grid prices were performed.

The simulation showed that in order to provide the shortest payback time, the mini-CHPs should be installed into separate sections with an extremely high daily demand factor for connected loads and the generator power should be selected for the loads of a specific area. Under these conditions, a mini-CHP is capable of producing up to 2.4 to 2.7 mln kWh per year.

To commission a mini-CHP, it is necessary to connect it to the pipeline gas with the performance of design and installation work. According to the 315 kWmini-CHP connected power, the gas demand will be 110 m3/h, which can be obtained by reducing the gas consumption when installing heat recovery units. This method allows the poultry factory to put into operation the necessary number of mini-CHPs without obtaining permits to increase the annual gas consumption.

The Cherepovets poultry plant began to save substantial amounts of heat (and gas) by installing heat recovery units at a large number of poultry houses, so that one of the DKVR steam boilers was without any load. This made it possible to install a 1.25 MW steam turbine generator in a separate room at the boiler house and eliminate the problems of limits to the mini-CHP gas amount and connection.

A poultry farm that has no pipeline gas mini-CHP can be used that run on crude oil (Konver LLC and Kolomensky Zavod OJSC) can be used. The modernization allowed the Cherepovets poultry farm to produce annually, by means of a mini-CHPs, up to one third of its own electricity, to keep the cost price of the generated kWh three times lower than the grid cost price. It confirmed the possibility of sharing the poultry farm and grids of its 6 (10) kV transmission lines and transformer substation on the territory of the farm.

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