Improving the energy system of a poultry enterprise

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Abstract. Energy saving at any enterprise is an urgent problem associated with high expenses for energy carriers and a constant increase in their cost. The aim of the study is to modernize the energy system of one of the poultry factories in the Vologda Oblast in Russia in order to reduce electricity costs. Modeling methods for a comprehensive assessment of possible options were used as well as an experiment that showed that the most effective way to reduce electricity costs was to upgrade the energy system based on "small generation" using traditional fuels. The modernization allowed the poultry farm to produce up to a third of its own electricity with the help of mini-CHPs annually, and to keep the cost of the generated kW⋅h three times lower than the network. The experience of modernization of the energy system of a poultry farm in Russia has confirmed the possibility of joint use of PTL-6(10) and a steam turbine generator at the enterprise. The paper will be useful to researchers and energy specialists who are looking for ways to save energy on a poultry farms.

1. Introduction

The level of energy efficiency of agricultural production largely determines the prime cost of production. Given the rate of growth in energy carriers costs, the implementation of energy-saving measures to improve the energy efficiency of agricultural production is of particular importance, especially in competition with foreign enterprises, where there is a higher level of technology and labor productivity.

After the cost of feed and salaries, the third place in the prime cost of poultry products is spent on energy supply, the bulk of which is paid for the electricity [1, 2]. The annual electricity consumption, for example, by a poultry farm for 14-15 thousand tons of meat per year, until recently, was 16-19 million kWh. In broiler houses, up to 70% of the load was due to the microclimate (brooders, ventilation, etc.), 25% to lighting (incandescent lamps), the rest to feed distribution and other technological operations. With the introduction of LED lighting, ventilation systems based on the principles of rarefaction with less energy-intensive axial fans (type VO-12), this ratio has changed, but the continuous increase in energy prices leaves the issue of reducing energy costs among the most relevant [3, 4].

Russia is the highest latitude country with a developed poultry industry, energy consumption in regions where less energy is spent on heating during the hot periods of the year has increased costs for
significantly greater air exchange in poultry houses, the use of energy-intensive adiabatic air cooling in poultry houses, and intensive operation of refrigeration and freezing units where products are stored, etc. More northern poultry farms are providing chilled poultry meat and fresh dietary eggs for beyond-the-Arctic Circle Murmansk, near-the-Arctic Circle Arkhangelsk, a whole line of a regional centers located 6-9° from the Arctic Circle: Syktyvkar, St. Petersburg, Kirov, Perm, Tyumen and others. An important factor is the risk of epizootics.

For example, in Canada, 83% of poultry facilities are located between 45° and 54° north latitude, which is equivalent to the latitude between Krasnodar and Tula. Northwardly than the 54° there are no such enterprises as the Sinyavinsky complex, the Borovskaya, Yakutskaya, Permskaya, and many other poultry farms. In the USA, poultry farming is in even warmer latitudes. Therefore, the costs of farms for heating and cooling are significant and their minimization is a promising area of energy safety.

During the reform of the Unified Energy System of Russia, it was assumed that the separation of generation, suppliers and marketers, by creating the market conditions for the consumer, would allow the latter to freely choose suppliers according to the “price-quality” criterion and reduce costs for this expense item. However, a number of difficulties, in particular related to the specifics of stock-raising production, deprives the manufacturer of choice [5-7]. Nevertheless, manufacturers carry out energy-saving measures that can significantly reduce energy costs, and this immediately affects the increase in profitability and competitiveness by reducing the cost of products or services.

With the involvement of independent specialists at the poultry enterprises of the Vologda Oblast, a series of works was carried out to comprehensively evaluate possible options, production verification and implement the most effective method of reducing electricity costs through the use of heat-saving technologies and means of "small" energy. To solve the problem of reducing energy consumption, several cost reduction options were modeled: switching to multi-zone tariffs with the installation of ASCME (automated system of control and metering of energy resources) systems, switching the farm's power supply to a higher voltage, “small generation”, etc. “Small” energy is understood as local (autonomous for enterprises, settlements) power systems, including the ones used traditional fuels.

2. Materials and methods

Energy saving in poultry farming has been the subject of many research works. The solutions on energy saving in the field of lighting, which give a good economic effect when implemented (Bagaev, K.I., Zhilin, A.S., Bayneva, I.I., etc.), of heat saving, in particular, to reduce heat losses from structural elements of the buildings and ventilation air (Gubaiddlin, N.M., Melnik, V.A., Gusev, V.A., Koroleva, N.A., etc.), of autonomous heating and power supply, including with the use of “small” generation facilities (Chilikov, A.A., Nikolaev, V.I., Dolgov, I. Yu. et al.) are more widely covered. The works devoted to the modernization of the enterprise’s energy system based on heat-saving technologies using the means of "small” energy were not found.

The most common resource-saving methods are replacing lighting and ventilation systems with more energy-efficient ones, however, the effects of introducing the less energy-consuming equipment are for the most part one-off and gradually decrease with an increase in the cost of energy resources.

At the Cherepovets poultry mill (the city of Cherepovets, Vologda Oblast in Russia), the task was set to reduce electricity costs. With the involvement of independent specialists, workers of APK-OGO OJSC agro-holding carried out a series of works on a comprehensive assessment of possible options, modeling, production verification and implementation of the most effective method of reducing electricity costs.

Previous successful experience in introducing a heat recovery unit (developers - Minaev V.I., Mokhov V.V. and others) in one of the poultry houses of this mill showed its high efficiency. The large-scale introduction of a heat recovery system in 81% of buildings made it possible for the household to reduce annual heat consumption by a third and save significant amounts of heat and gas for heating. One of the steam boilers DKVR (double-drum, vertically-water-tube reconstructed unit) at
the boiler of the poultry mill was released from the load. This made it possible to install a steam
turbine generator (STG) for 1.25 MW (PJSC Proletarsky Zavod, St. Petersburg) in a separate room
and to eliminate all problems of limits on the volumes and connections of mini-CHPs in the gas part
[8, 9].

3. Results
To solve the problem of reducing energy consumption, the following ways to reduce costs were
considered while providing the poultry mill with the required annual amount of electricity: switching
to multi-zone tariffs with the installation of an automated information and measuring system for
commercial electricity metering (ASCME), switching the mill's power supply to a higher voltage, and
the poultry mill entering the wholesale electricity and capacity market, change of the guaranteeing
supplier, “small generation” using the traditional fuels also, i.e. production of a part of the required
annual volume of electricity at prices less than the network ones at the mill.

For the first group, only zonation was analyzed (within the limits of the 1st and the 2nd price
categories), since the possible effect of 2-rate prices with payment for capacity is incomparably small.
Calculations for all options of 2- and 3-zone prices showed that the transition from 1-zone payment to
2 and 3-zone calculations does not save on electricity consumed for the poultry farm, which is
associated with the specifics of production - the main energy-intensive processes (ventilation, lighting,
heating of poultry houses with livestock, as well as incubation of eggs, the operation of refrigerators
and freezers, treatment facilities are around the clock and all-weather, excluding all the possibilities of
shifting these operations by time of day). Those few processes (for example, filling the pressure tower
reservoir, etc.) that can be transferred to night hours against the background of the total energy
consumption of the poultry farm are not significant in volume, and the cost of complicated metering is
disproportionately high [10].

Simulation of the conversion of the poultry mill to receive electricity from higher voltage networks
at preferential prices showed that tariffs do provide for differentiated payment for electricity
consumption by the consumer in four categories: high voltage (110 kV and higher), medium voltage -
MV1 (35 kV) and MV2 (20-1 kV) and low voltage - below 1 kV.

When modeling, the Sheksninskaya poultry mill (the village of Nifantovo, Vologda Region in
Russia) was included in the group of evaluated poultry farms, which for some objective reasons during
the construction was powered unconventionally - by deep input 110/10 kV and retained the assembly
service on the high side (The “high” side in the electric power industry is the voltage supplied to the
primary winding of the transformer from, for example, PTL). As a rule, this voltage is higher than that
removed from the secondary winding of the transformer in this transformer substation. The poultry
mill has qualified special staff with access to work with high voltage and pays for electricity at the
lowest rate. Prices at the annual consumption of more than 10 MVA for the purchase of 1 kWh for
MV2 are 20%, for MV1 - for 27% and for high voltage - for 37% less than for the low voltage. The
effective use of this benefit is convincingly confirmed by the long-standing practice of using a similar
scheme to save electricity costs at the Sheksna Poultry Mill.

But it should be noted that the widespread introduction of this method of saving at poultry mills is
unlikely - since 1991, many enterprises, having gone bankrupt, have lost not only transformer
substations with high voltage and MV1, but also the MV2, and operate only the 0.4 kV power lines. It
is unlikely to return high voltage transformer substations to poultry mills right now.

In order to enter the Register of Participants of the Federal Wholesale Electricity and Capacities
Market (FOREM), having received savings on the marketing premium, the consumer’s energy system
must meet a number of requirements, the main of which are: you must have 20 or more MVA of
connected capacity with at least 0.75 MVA of the most low-power transformer substation; equipment
of consumer electric networks with the ASCME system, etc.

The largest poultry mills in Russia meet the requirements for total capacity: Sinyavino, Volzhnin,
Roskar, Irtyshskaya and more than a dozen of egg enterprises with millions of laying hens in flocks, as
well as all broiler associations producing 100-150 and more thousand tons of meat per year
(Mikhailovsky, BZRK, PF-Severnaya, etc.). But the requirements of veterinary safety divided the territory of each poultry mill with a number of sanitary zones (300 m wide) to ensure the zooveterinary breaks. This led to the powering of the workshops in these areas through a network of 10 (6) / 0.4 kV transformer substations. As a result, even medium-sized poultry mills with connected capacity of 13-19 MWh have dozens of transformer substations (ShPF-19, ChPF-24) and a significant part of them with a capacity of up to 0.75 MW. The same situation is observed in large poultry mills, and in associations, and therefore their access to the wholesale market of electric energy and power, the wholesale electricity market (FOREM) is problematic [11, 12].

Modeling for a number of opportunities to save money on electricity by changing the guaranteeing supplier showed the following. A process of a supplier change is possible in any factory. The savings from changing the supplier itself may consist in reducing the value of the sales margin (on average 2-2.5% of the price of 1 kWh) and in the best case with cheaper delivery there will be the same addition for transportation. Such coincidences are possible (equidistance, the presence of parallel PTL-35, etc.), but in general it is a factor of rather limited capabilities [13].

The direction of "small" energy. The Russian Federation has more than 232 GW of generating capacities, of which two-thirds are the heat plants and most of them are gas-fired. “Small” energy refers to local (autonomous for enterprises, settlements) energy systems, including the ones on traditional fuels [14, 15].

The economic legitimacy of small systems is based on the fact that the calorific value of 1 nm$^3$ of gas (according to GOST 5544-2014) is 8000 kcal, which, without taking into account the transformation efficiency coefficient, is equivalent to $8000/860 = 9.3$ kWh of electricity. Taking into account the working range of the efficiency coefficient variation, the electric power generation at mini-power plants will be in the range of 2.5-3.8 kWh per 1 nm$^3$ of gas [16, 17].

In modeling the use of "small" energy, acceptable for most poultry mills, it is necessary to proceed from the following provisions:
- most farms own only low voltage electricity;
- the level of permissible replacement of network electricity by the electricity of the own generation should be such that the funds from the supply of the remaining electricity are sufficient for renovation of the entire network structure at the poultry mill (TS-6 (10) / 0.4 kV and power lines-6 (10) kV), for provision the salaries for employees and for a certain level of profit.

Modeling and calculations have shown that for quick payback of mini-CHPs, it is necessary to install it on separate workshops (sections) with an extremely high daily demand factor for connected current collectors, and it is also necessary to select the generator capacity for the loads of a specific section (parent flock, repair young stock or part of the goods platform).

For example, 18 floor broiler houses require 315 kW, etc. Under these conditions, mini-CHPs are capable of generating up to 2.4-2.7 million kWh per year, providing electricity for the production of 10 thousand tons of broiler meat, two such power plants - of 20 thousand tons, etc. The introduction of heat recovery units on the poultry houses allows the required number of mini-CHPs to be commissioned without obtaining permission from gas facilities to increase annual gas consumption.

Figure 1 shows the connection diagram of the container mini-CHP at the existing network transformer substation TS-6 (10) kV to the low voltage power line belonging to the poultry mill, with the isolator switched off on the low voltage buses of the transformer substation.
The heat recovery units introduced at the mill showed high efficiency: at an outside temperature of minus 15 ºС an air flow from 0ºС was supplied to the preheater. This allowed the mill to reconstruct the ventilation-heating system for heat exchangers over several years and to utilize heat in 81% of the houses at the poultry mill (45 buildings). Large-scale renovation made it possible for the household to reduce the annual heat consumption by one third (79 thousand Gcal instead of 119.7 thousand Gcal), in comparison with broiler mills of comparable capacity (13.5-15 thousand tons per year) of the same climatic zone.

In terms of the scale of only broiler production in Russia, the annual decrease in heat emissions during the installation of heat recovery units (in accordance with the Kyoto Protocol) will amount to 8.6 million Gcal, gas consumption will decrease by 1.075 billion m$^3$. This will allow enterprises to significantly reduce energy costs through mini-CHP.

The total heat savings at the Cherepovets poultry mill allowed to put into operation the required number of mini-CHPs without obtaining permission from the gas facilities to increase the annual gas consumption.

This technique was tested during the verification of the mini-CHP option at the Cherepovets poultry mill (the main co-executors are Minaev, V.I., Mokhov, V.V.). The factory began to save significant amounts of heat (and gas) by installing heat recovery units on a large number of poultry houses. One of the steam boilers DKVR (double-drum, vertically-water-tube reconstructed unit) at the boiler of the poultry mill was released from the load. This made it possible to install a steam turbine generator (STG) for 1.25 MW in a separate room near the boiler house and to eliminate all problems of limits on the volumes and connections of mini-CHPs in the gas part, according to the parameters, the steam turbine generator fits well with the DKVR at an outlet pressure of up to 2.5 MPa and a steam temperature of up to 370°C, as well as a pressure behind the turbine of 0.6-0.12 MPa [18, 19].

With the implemented scheme, it was necessary to solve the problem of mutual operation with the electric network because: it is impossible to transfer 1250 kW of electric power to several sections distant from the boiler house by more than 300 m via low-voltage lines, and the electric generators with a capacity of 1.25 MW are high-voltage.

The operation of the Mini-CHP for several years at the Cherepovets poultry mill with an annual production of 4 million kWh allowed to stably keep the prime cost of the generated kilowatt-hour three times lower than the network one.

The most effective scheme was shown in Figure 2 of a mini-CHP with a gas piston engine and an electric generator (GPE + EG), later implemented by the Sredneuralskaya poultry mill.

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**Fig. 1:** Scheme of connection to low voltage networks, where: 1 –6 (10) kV power transmission line; 2 - 6 (10) /0.4 kV transformer; 3 –0.4 kV power transmission line; 4 - electricity consumer (poultry houses); 5 - low voltage isolators: power grid and consumer (gas piston engine + electric generator); 6 - mini-CHP (gas piston engine + electric generator).
It should be noted that foreign gas piston engines (GPE) have quite high motor resources (Wilson production) in 170,000-180,000 operating hours (this is more than 21.1 years with two overhauls), domestic gas piston engines are close to them in terms of these indicators (Rybinsk Complexes, Russkiy Diesel, Balakovo).

| Table 1. Specifications of container-mounted mini-CHP running on gas and crude oil. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Indicators                      | Power Station Model             | EGP100K                      | EGN200K*                      | EGP200K                      | EGN315K*                      | EGP315K                      |
| Rated electric power (kW)       |                                 | 100                          | 200                            | 200                            | 315                            | 315                            |
| Rated voltage (kV)              |                                 | 0.4 / 0.22                   | 0.4 / 0.22                     | 0.4 / 0.22                     | 0.4 / 0.22                     | 0.4 / 0.22                     |
| Frequency (Hz)                  |                                 | 50                           | 50                             | 50                             | 50                             | 50                             |
| Heat recovery unit capacity (kW)|                                 | 150                          | 250                            | 250                            | 460                            | 460                            |
| including for exhaust gas utilization (kW) | | 55                           | 105                            | 105                            | 170                            | 170                            |
| Fuel consumption                |                                 | 35 nm³/h                     | 5.51/m³/h                      | 70 nm³/h                      | 8.01/m³/h                      | 110 nm³/h                     |
| Overall dimensions (LxWxH), m   |                                 | 4.2x2.4x2.6                  | 5.0x2.4x2.6                    | 5.0x2.4x2.6                    | 5.8x3.0x2.6                    | 5.8x3.0x2.6                    |

* Note - EGNs operate on the "crude" oil (reserve - furnace and diesel fuel), for the rest of - the main fuel is the network gas.

An alternative to gas ones can be mini-CHPs operating on crude oil (LLC Conver and OJSC Kolomensky Zavod [20, 21]). Technical characteristics of such power plants are given in Table 1, they have a fairly high economic efficiency (table 2).

| Table 2. Cost-efficiency of the EGP operation. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Indicators                      | Power Station Model             | EGP100K                      | EGP200K                      | EGP315K                      |
| The cost of EGP as a standard, thousand rubles | | 2,554.18                      | 3,776.82                      | 5,309.19                      |
| Total capital costs with local networks, thousand rubles | | 3,509.26                      | 4,731.90                      | 6,264.27                      |
| The total cost of EGP operation, thousand rubles | | 1,370.68                      | 2,056.51                      | 2,863.52                      |
| Annual production of own electricity, kWh | | 670,140                       | 1,340,280                     | 2,110,000                     |
| Cost of the annual volume of own electricity, thousand rubles | | 2,345.49                      | 4,690.98                      | 7,388.29                      |
| Cost of own electricity, rubles / kWh | | 2.046                         | 1.534                         | 1.357                         |
| Pay back period, years | | 3.65                          | 1.80                          | 1.38                          |

The long-term operation of the Mini-CHP at the Cherepovets poultry mill with annual production of up to a third of its own electricity (up to 4 million kWh with an annual electricity consumption of 12-13 million kWh) allowed to stably keep the cost of the generated kilowatt-hour three times lower than the network one. It confirmed the possibility of mutual operation of the PTL-6 (10) and transformer substations at the territory by the poultry mill and power lines. (it is necessary to measure the "overflows" and to plan the direction of the flows).

At enterprises that do not have network gas, mini-CHPs operating on crude oil can be used; their technical characteristics have high economic efficiency.
4. Conclusions
At the Cherepovets poultry mill, a comprehensive assessment of possible options was carried out, production verification and implementation of the most effective method of reducing electricity costs, the so-called "small generation" using traditional fuels, i.e. production at the factory of a part of the required annual volume of electricity at prices less than the network ones.

Modeling showed that for a quick payback, mini-CHPs need to be installed in separate sections with an extremely high daily demand factor for connected current collectors and the generator power should be selected for the loads of a specific site. Under these conditions, mini-CHPs are capable of generating up to 2.4-2.7 million kWh per year.

To commission a mini-CHP, it is necessary to connect to the network gas with the implementation of design and installation works. According to the connected capacity of mini-CHPs at 315 kW the gas demand will be 110 m$^3$/h, which can be obtained by reducing gas consumption when installing heat recovery units in them. The reception allows the poultry mill to commission the required number of mini-CHPs without obtaining permits to increase annual gas consumption.

The Cherepovets poultry mill began to save significant amounts of heat (and gas) by installing heat recovery units on a large number of houses, which relieved one of the DKVR steam boilers from the load. This made it possible to install a 1.25 MW steam turbine generator in a separate room near the boiler room and to eliminate the problems of limits on the volumes and connections of mini-CHPs in the gas part.

In a poultry mill where there is no network gas, mini-CHPs operating on crude oil can be used. The modernization allowed the Cherepovets poultry mill to annually generate up to a third of its own electricity through mini-CHPs, and to keep the cost of the generated kWh three times lower than the network ones. It confirmed the possibility of mutual operation of the PTL-6 (10) and transformer substations at the territory by the poultry mill and power lines.

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