Cogeneration Plant Optimization

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Abstract. As the analysis of publications on cogeneration shows, most authors present it as a way to increase the efficiency of existing power generation plants by utilizing the generated heat. It is shown in the work that cogeneration is a complex system that allows maneuvering the proportion between the received thermal and electrical energy. In this regard, it seems promising to develop a cogeneration system in which this proportion could be regulated. There have not been such systems in the published patents yet. Regulation of the proportion between heat and electricity can be carried out in accordance with the changing tariffs for these two types of energy, as well as depending on production tasks. Existing cogeneration systems are usually adaptations of existing power plants optimized for optimal electrical energy consumption. Cogeneration systems should be optimized for the maximum total consumption of heat and electricity at a minimum cost. Apparently, in the conditions of existing calculation methods, this problem has not been solved yet. Therefore, the optimal values for cogeneration should be sought outside the currently accepted design parameters and operating modes of power plants.

1. Introduction

Recently, cogeneration systems have been considered as an essential element of saving energy resources. Cogeneration is a technology that represents a single process of producing heat and electricity.

In the work R. R. Absalyamova with co-authors examines the issues of obtaining cogeneration effect for serial gas turbine, operating in conditions of the Far North [1]. A. E. Yutuaev with co-authors suggests using cogeneration to utilize associated gas in the development of coal deposits [2]. At the same time, the authors allow this effect to be obtained both during the operation of piston installations and turbine ones. Obviously, there are prospects for the introduction of cogeneration in small enterprises producing polymer containers, since these productions are characterized by a large consumption of electrical and thermal energy [5].

As a rule, the economic effect of cogeneration is obtained as a result of reducing losses during transportation of thermal energy. For a similar process, electrical energy does not have such a problem, its losses are significantly less. In this regard, low-power turbines and piston machines of low power, which provide energy to relatively small industrial and residential areas, are of great
importance. In this case, the loss of transportation of thermal energy is minimal – it is consumed where it was produced. In this regard, for example, V. N. Dorofeev sees great prospects from the use of cogeneration when using mini-thermal power plants for autonomous power supply of residential buildings or small industries [3]. It is obvious that cogeneration also has great prospects in agriculture [6], since such enterprises are usually far from major energy producers.

However, the smaller the power plant, the longer the payback period from the application of the cogeneration effect. Therefore, at present, low-power plants practically do not use it [4]. This is the main paradox of cogeneration – it is not used where it could give the maximum effect.

2. Cogeneration as a way to maneuver energy flows
Previously, we proposed a new method to assess the efficiency of implementation a cogeneration plant based on changing tariffs for different types of energy [7]. Its essence lies in the fact that the existing methods of justifying investments in the fuel and energy sector of a small enterprise, which are laborious and time-consuming, nevertheless do not take into account the specifics of operating cogeneration plants.

In order to understand the effect of introducing cogeneration in a small enterprise, one needs to know the average annual and monthly consumption of different types of energy. In general, we can talk about cogeneration, trigeneration, etc., but in relation to cogeneration, this is thermal and electrical energy.

The average monthly calculation of thermal consumption, if it is not involved in technological processes, can be carried out not during 12 months, but only during 8 months, since in the summer thermal energy is most often not required. This, of course, reduces the efficiency of use and increases the payback period.

When calculating the implementation, it is usually forgotten that the cogeneration plant is an energy converter, and in fact it can regulate the balance of the received electrical and thermal energy in a certain range. And then to assess the efficiency of implementation and assess future profits, it is necessary to know the existing tariffs. These may be tariffs \( T \) for:
- diesel fuel \( T_1 \),
- electricity \( T_2 \),
- water for technological needs \( T_3 \),
- heat (as for water heated to a certain temperature, for example, to 95°C) \( T_4 \),
- tariffs for emissions of harmful substances \( T_5 \).

And then the possible profit from the implementation of the cogeneration plant \( P \) will be determined according to an obvious formula, depending on the volume of resource consumption or energy production \( V_i \):

\[
P = \Sigma (V_i T_i).
\]

The "plus" is placed if the resource is produced, and "minus" is put if it is consumed.

Taking into account seasonal fluctuations or fluctuations in tariffs in the long term, you can choose an individual cycle of the cogeneration plant, changing the proportion between the electrical and thermal energy.

Unfortunately, the patent search revealed the absence of any systems that could regulate the proportion between the generated electrical and thermal energy, which makes it difficult to maneuver freely when using cogeneration.

3. Modernization of existing equipment
In addition to introducing new equipment, a cogeneration plant can also be obtained by reequipping an existing one. It offers great prospects for small enterprises, since such modernization will be much cheaper in any case.

In our opinion, there are two possible ways to modernize, for example, gas-piston installations. First, an additional cogeneration effect can be obtained by replacing the classic radiator. In the basic
configuration, the air blown through the radiator grille is heated and goes out. When modernizing, it should be replaced with a conventional liquid-to-liquid heat exchanger and used for heating the coolant.

The second way is less obvious, but it can also have an effect. This is the removal of heat from exhaust gases. In this case, a heat exchanger is also placed on the output collector, but it is of the gas-liquid type. This way is more difficult, since the exhaust gases have high acidity, and as a result, the heat exchanger must be performed in an acid-resistant version.

The prospects of work in each of these two ways can be assessed by the thermal balance of the engine. Thus, a diesel engine without turbocharging transfers approximately 35% of the supplied heat into mechanical energy. 34% goes into the cooling system, 27% - with exhaust gases. The rest is unaccounted for losses. For a turbocharged engine, this ratio changes by 40%, 29%, and 30%, respectively [9]. It would seem that a large percentage of heat which goes out with exhaust gases makes it promising to remove heat there. But it should be remembered that at the outlet of the heat exchanger, the gas temperature should not allow condensation of water vapor, which will have a low pH during condensation, and as a result, high aggressiveness. This significantly reduces the possibility of heat removal. And thus, the radiator modernization will be the most effective.

It is also possible to use water from the circuit of the engine itself as a coolant. It can save heat during conversion, but it is unlikely to contribute to technological efficiency – the liquid from both circuits may have different requirements.

4. Cogeneration plant optimization during design
As the review of the designs of currently used cogeneration plants showed [10, 11], these are mostly conventional power units that have additional cogeneration units. However, this approach, although it makes it possible to create a cogeneration plant with minimal technological costs, is hardly advisable.

The fact is that the criterion for the quality of the power plant is the maximum of electricity produced with a minimum of fuel costs. And this pattern is not observed for cogeneration. Thus, it is appropriate to optimize the plant taking into account the maximum amount of heat and electricity with a minimum of fuel costs.

At Izhevsk State Technical University, a student S. A. Pershin tried to find the optimal value of the sum of thermal and mechanical energy on the example of a QSX15G8 diesel on the basis of the calculation algorithm used in the design of diesel engines [8]. It turned out that with an increase in the diameter of the piston for all permissible revolutions (he varied them in the range from 1500 to 1800 rpm), the heat transferred to the coolant was constantly growing. This is quite a predictable result, because in this case, the overall engine power is growing as well. He also received quite predictable results in terms of the number of revolutions and the cetane number of fuel used.

As for varying the stroke of the piston, the results showed that with its increase over the entire range of shaft revolutions, the heat removed increases, but the value of the first derivative decreases. It can be predicted that with a further increase in the stroke of the piston, the heat removed could reach an extreme, but its finding, if it really exists, is already beyond the applicability of the method used. In this connection, it can be assumed that for optimal plant cogeneration, it makes sense to use cylinders with an increased stroke, but not with the stroke accepted in the engine industry.

Thus, it should be admitted that the optimal values of the cogeneration plant may lie outside the currently accepted ranges of optimal power plants. Because of this, it may be necessary to reconsider the calculation methods, which have a large number of empirical coefficients that are not suitable for the range of the optimal cogeneration plant.

5. Conclusions
A cogeneration plant is not just a system for utilizing emitted heat. This is a complex system that allows maneuvering the proportion between the received thermal and electrical energy. In this regard, it is promising to develop a cogeneration system that could change this proportion. There have not been such systems in the published patents yet. Regulation of the proportion between heat and
electricity can be carried out in accordance with the changing tariffs for these two types of energy, as well as depending on production tasks.

Existing cogeneration systems are usually adaptations of existing power plants optimized for optimal electrical energy consumption. At the same time, cogeneration systems should be optimized for the maximum consumption of heat and electricity at a minimum cost. Under the existing calculation methods, this problem does not seem to have a solution. Therefore, the optimal values for cogeneration should be sought outside the currently accepted design parameters and operating modes of power plants.

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