Electrical distributed generation for industrial power supply

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Abstract. Distributed energy generation (DEG) is currently a promising direction in the energy sector. The article outlines the possibilities of using distributed generation for power supply to an industrial enterprise, and highlights the significant advantages of DEG for industry. As a result of the performed studies, calculations of economic indicators and comparison of delivery options for gas piston units of various capacities were carried out. The practicability of using mini-thermal power plants (mini-TPP) in the power supply system of the enterprise has been proved. The balance of active and reactive power of the generating equipment has been fulfilled. The calculation of the reduction of carbon dioxide emissions has been carried out.

1. Introduction

A promising direction for increasing energy efficiency is the use of cogeneration units. Cogeneration provides the combined production of electricity and heat with one unit. At classic electric power stations, heat is emitted into the environment when generating electricity. The cogeneration plant uses this heat for heating or technological needs, and thus saves fuel and money needed to purchase it [1].

The production of electricity is accompanied by harmful factors for human health. Energy facilities have an intense impact on the environment and cause negative irreversible consequences. Electricity production provokes emissions of pollutants into the atmosphere, discharges of polluted wastewater into water bodies, uses a significant amount of water and land resources, and pollutes the surrounding territories [1]. Emissions of greenhouse gases, including CO2, have a particularly negative impact. According to the IPCC, published in the 2007 Final Report on Climate Change, since the beginning of the industrial revolution, our planet has "warmed" by 0.74 °C and this process is intensifying.

To achieve maximum efficiency, it is necessary to balance the consumption of heat and electricity. If approximately the same power is required in operation, then this mode is ideal for a cogeneration plant.

It is very profitable to install cogeneration plants as sources of electricity for small industrial enterprises, schools, hospitals, shopping centers, etc. The small capacity of the units fully meets the need for electricity [2]. The heat generated by the units is used for heating facilities and provide hot water supply (DHW).
The mini-TPP will be able to partially provide electricity to the enterprise powered through the input power lines, making up the shortfall transit capacity or closing peak loads. Let us consider a number of technological and operational factors in the project for the reconstruction of the power supply system of ZAO “Plywood Plant “Vlast Truda” in the Nizhnelomovskiy district of the Penza region.

The company produces construction and finishing materials, components, and the technological cycle uses electrical energy, heat energy and water. Supply of electric energy in the amount of 7.5 million kilowatt-hours per year is centralized, through the distribution networks of the Nizhnelomovskiy PO (Industrial association) “Penza-Energo”. Thermal energy is generated in a local natural gas boiler house. The annual consumption of heat energy for heating is 4300 Gcal, for technological needs - 22 thousand Gcal. The company uses about 1.2 million cubic meters of natural gas per year. Total energy costs account for 56 million rubles.

The main task is to abandon centralized energy supply and apply the concept of cogeneration. Thermal energy is used in production processes. This expands the possibilities of using gas piston plants as an autonomous energy source [2]. The total average annual demand for electric energy of the consumer is 7.5 million kWh, the peak power is 2.1 MW. The daily load schedule on weekdays and weekends in summer and winter is shown in Fig. 1.

![Daily schedule of consumer loads](image)

**Figure 1.** Daily schedule of consumer loads

### 2. Materials and methods

To assess the economic efficiency and compare various options for completing the mini-TPP, a mathematical model was developed that takes into account the technical and economic indicators of equipment and material and financial flows. The analysis of daily schedules shows that during the working shift the power consumption reaches 2 MW, and during non-working hours and on weekends the average power is reduced to 240 kW. To generate electric power during the day, you will need high-power energy generation gas piston units - 2 MW or 2 pcs. 1 MW each. Operation of such units at night is technically and economically unprofitable. Therefore, for power supply at night, another unit with a capacity of 300 - 500 kW will be needed. The night tariff for the supply of electricity is 30% less than the daytime tariff, so at night you can receive electricity through external power lines.

To implement the project, 3 options for the complete set of the installation were offered for mini-TPP:

1. One unit of 2000 kW for work during working hours. Overnight deliveries are centralized.
2. Two 1 MW units for daytime operation and one 500 kW unit for night operation.
3. Four installations with a capacity of 500 kW, at night - only one works. The results of modeling the operating modes of the mini-TPP per day in the summer are presented in Table 1. The time of day is divided into intervals with the same equipment load factor. The 4th column shows the generation power, 5th - the electricity consumption in the selected interval. The last bar shows the amount of natural gas required to generate electricity at the mini-TPP.

The plant consumes 18.5 thousand kWh of electricity per day, including 15.8 thousand kWh during working hours and 2.7 thousand kWh during non-working hours. To generate such volume of electricity, 5 thousand cubic meters of natural gas will be required. At the same time, 24 Gcal of thermal energy is supplied to the engine cooling system.

**Table 1. Technical and economic indicators of generation at Mini-TPP**

| Time interval | Load factor | Power kW | Power consumption Thous. kWh | Power consumption MJ | Efficiency | Energy MJ | Gas cubic meters |
|---------------|-------------|----------|-----------------------------|----------------------|------------|----------|-----------------|
| 0 – 6         | 6           | 0.03     | 144                         | 867                  | 3123       | 0.25     | 8923            |
| 6 – 8         | 2           | 0.25     | 1205                        | 2410                 | 8676       | 0.35     | 24788           |
| 8 - 12        | 2           | 0.42     | 1928                        | 3856                 | 13881      | 0.4      | 34704           |
| 12 – 13       | 1           | 0.25     | 1205                        | 1205                 | 4338       | 0.32     | 13556           |
| 13-15         | 2           | 0.35     | 1687                        | 3374                 | 12146      | 0.4      | 30366           |
| 15-17         | 2           | 0.32     | 1542                        | 3084                 | 11105      | 0.35     | 31729           |
| 17-20         | 3           | 0.3      | 1446                        | 4338                 | 15616      | 0.3      | 31233.           |
| 20-24         | 4           | 0.03     | 144                         | 247                  | 884        | 0.25     | 2527            |

During the working shift 15857 57088 4.183
During non-working hours 2655 9560 0.807
Result 18513 4.990

3. Results and Discussion

Modern mini-TPPs are designed to generate electricity and heat (cogeneration), as well as electricity, heat and cold (three-generation). The structure of the mini-TPP based on gas piston units for the production of electricity and heat includes:

1) Internal combustion engines (gas piston).
2) Generators of direct current or alternating current.
3) Recovery boilers.
4) Heat exchangers in the engine cooling system.
5) Engine cooling system.
6) Control systems.
7) Ventilation systems.
8) Automatic fire and alarm systems.
9) Oil addition systems (oil tanks with pumps).
10) Reserve fuel tank.
As the main source of the first variant of the project implementation, it is proposed to use a gas piston unit MWM TCG 2020 V20 manufactured by MWM GmbH (Germany). The company is one of the world's leading suppliers of highly efficient and environmentally friendly power generation plants. The total costs for the implementation of this investment project are estimated at 52.8 million rubles including VAT. Table 2 shows its technical characteristics.

For the implementation of the second option, it is proposed to supply two Liebherr 1000 gas-piston power plants with an electrical power of 1000 kW and one MAN E3262 LE202 gas-piston power plant with an electrical power of 500 kW. The third option involves the supply of four MAN E3262 LE202 gas-piston power plants with an electric power of 500 kW. The MAN E3262 LE202 generator is supplied with an output voltage of 0.4 kV, does not require the supply of a step-down transformer and can be connected to in-shop power supply systems.

Table 2. Technical characteristics of GPU of different complete set options

| Engine type          | TCG 2020 V20 | Liebherr G9620 | MAN E3262 LE202 |
|----------------------|--------------|----------------|-----------------|
| Electrical power, kW | 2000         | 1000           | 500             |
| Thermal power, kW    | 1985         | 1200           | 600             |
| Rotation speed, rpm  | 1500         | 1500           | 3000            |
| Voltage, kV          | 0,4 or 6,3/10,5 | 0,4 or 6,3/10 | 0,4             |
| Average oil consumption at full load, g / kWh | 0,2 | 0,12 | 0,08 |
| Gas pressure, mbar   | 20-200       | 20-200         | 20-200          |
| Unit price, Euro     | 402000       | 286000         | 178000          |
| Option cost, Euro    | 402000       | 752000         | 712000          |
| Savings, Euro        | 140000       | 140000         | 118000          |
| Payback period, Euro | 3            | 5              | 6               |

The daily balance of consumed and generated power can be traced according to the graph in Fig. 2. The maximum generation capacity for all three projects is 2 MW.

Figure 2. Daily balance of the power system.
The power consumption by the energy system of the enterprise changes during the day. The main condition for the stability of the power system is the presence of a power reserve, which allows for a short-term supply of power to the grid that is more than nominal [6].

For generating equipment, the manufacturer allows the issuance of 20% overcapacity within 2 hours. According to the graph in Fig. 2, it can be seen that the power reserve ensures the stable operation of the mini-TPP during the work shift or all day. On the second shift after 15:00, there is excess capacity in the energy system of the enterprise, the generation of electricity must be limited.

If the enterprise is connected to the district power grid, if there are contracts for the supply of electricity, excess capacity can be sold on the wholesale electricity market [6]. In this case, a power flow is observed in the power transmission line during the work shift and out of working hours. At night, the company supplies electricity from the grid at night rates. In the evenings, excess power is fed into the grid. As a result, the enterprise will pay the difference between the received and delivered energy to the supplier. Such a scheme would be cost-effective.

Table 3 shows the results of calculating the economic indicators of the project. Currently, the plant pays 42 million rubles for electricity. With fully autonomous generation, it will pay 12 million rubles for natural gas. In the second option, the payment for electricity will be 5 million rubles, and for natural gas - 9.4 million rubles. At the same time, the enterprise completely covers the needs for heat energy.

**Table 3. Economic characteristics of GPU for different completing options**

|                      | Option 1                             | Option 2                             |
|----------------------|--------------------------------------|--------------------------------------|
|                      | electric power, W                    | electric power, W                    |
|                      | gas volume, V                        | gas volume, V                        |
|                      | price of electric energy             | price of electric energy             |
|                      | price of gas                         | price of gas                         |
| Per shift working    | Thousands of kilowatt hours          | Thousands of kilowatt hours          |
| hours                | Thousands of cubic meters            | Thousands of cubic meters            |
|                      | Thousands of rubles                  | Thousands of rubles                  |
|                      |                                      |                                      |
| Working hours        | 24                                   | 24                                   |
| Non-working hours    | 2                                    | 2                                    |
| Weekends             | 5                                    | 5                                    |
| Total non-work hours | 7                                    | 7                                    |
| Total                | 32                                   | 32                                   |
| Per year working     | 6170                                 | 6170                                 |
| hours                | 1673                                 | 1673                                 |
|                      | 37022                                | 37022                                |
|                      | 9367.2                               | 9367.2                               |
|                      | 0                                    | 0                                    |
|                      | 1673                                 | 1673                                 |
|                      | 0                                    | 0                                    |
|                      | 9367                                 | 9367                                 |
|                      |                                      |                                      |
| Non-working hours    | 610                                  | 610                                  |
| Weekends             | 551                                  | 551                                  |
| Total non-work hours | 1160                                 | 1160                                 |
| Total                | 7331                                 | 7331                                 |
|                      | 185                                  | 185                                  |
|                      | 2743.8                               | 2743.8                               |
|                      | 1037.6                               | 1037.6                               |
|                      | 610                                  | 610                                  |
|                      | 0                                    | 0                                    |
|                      | 2743                                 | 2743                                 |
|                      | 0                                    | 0                                    |
|                      | 5497                                 | 5497                                 |
|                      | 1915                                 | 1915                                 |
|                      | 1160                                 | 1160                                 |
|                      | 0                                    | 0                                    |
|                      | 5497                                 | 5497                                 |
|                      | 9367                                 | 9367                                 |
As capital costs are high and the use of bank loans is often questionable in the energy sector, energy service contacts have become widespread. The customer concludes a contract and makes an advance payment. The company issues a project, supplies equipment, carries out commissioning and hands over the mini-thermal power plant to the customer. But the ownership rights remain with the equipment supplier [3,5]. During operation, part of the net profit is used to pay off the contract. After payment of the entire amount, the ownership of the equipment is transferred to the customer.

With the timely fulfillment of obligations to pay for electricity, the monthly contractual price for the consumer is set 10% lower than the monthly limit level of the unregulated price of a certain price category determined by the guaranteeing supplier of electricity, depending on the voltage level of the consumer's connection to the grid organization. For the consumer, the price is set at 5.14 rubles. for 1 kWh with an average tariff for industrial enterprises of 6 rubles (including VAT), per 1 kWh. The project is cost-effective, the implementation period for option 1 is 4 years. The second and third options for the supply of equipment in an enterprise are less profitable.

As the experience of the implementation of distributed generation installations shows, the costs of energy resources and the costs of maintaining buildings and structures, and payments for housing and communal services are reduced by an average of 20-30%. Even taking into account the one-time capital costs for the construction of power plants and boiler houses and the repayment of loans to banks, such projects are economically profitable [3]. The most important advantage of distributed generation is the reduction of losses during the transportation of energy resources to the end consumer.

4. Conclusions

Thus, the introduction of mini-thermal Power Plants at an industrial enterprise is advisable. Advantages during the operation of mini-thermal power plants:
11) Profitability. The mini-thermal power plant generates 1 kW of electric energy and ~2 kW of heat, while consuming 0.3 cubic meters of gas per hour.
12) The possibilities of acquisition of equipment leasing.
13) Decrease in generation at the local power plant.
14) Possibility of installing mini-thermal power plants in containers.
15) Possibility of regulation of operating modes.
16) Possibilities of increasing electrical power by additional installation of power modules.
17) Flexibility, autonomy, quick change of load modes.
18) Environmental friendliness.

The commissioning of the Mini-TPP and the generation of electricity on the territory of the enterprise will make it possible to reduce the length of power lines (no more than 200-300 m) and thereby reduce transit losses [3]. In normal operation, losses in distribution grids should not exceed 10%, while the share of power lines accounts for about half. If it is possible to reduce transit losses by 3 - 5 times, this will save up to 3% of the total consumption of electricity. Reduction of electricity losses for transit will be:

$$\Delta W = 0.03 \times 7731 \text{ thousand kWh} = 234 \text{ thousand kWh}.$$ 

The inclusion of local generation has a tangible environmental effect. A decrease in electricity generation at CHPPs by the amount of reduction of losses for electricity transit across the enterprise will reduce the volume of burnt fuel oil by 18 tons per year, or the volume of coal – by 38 tons. Greenhouse gas emissions per year will decrease by 58 tons when operating on fuel oil and by 120 tons – when working on coal [7].

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