Efficient operation and reliability issues in operation of mini-CHP

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The article presents practical data on the operation of cogeneration mini-CHP plants in the energy sector of the Far East using imported low-power GTU as the main generating equipment. This type of power station is an example of decentralized distributed energy that has become widespread in Western Europe, and is first introduced in the energy sector of the Far East. Mini-thermal power plants based on GTU with the use of cogeneration have a great economic potential for application in the energy sector of the Far East, taking into account the positive and negative sides indicated in this article.

The energy system of the Far East (FE) is noticeably distinguished in the energy sector of the Russian Federation, especially due to high wear and tear of equipment and territorial and technological reasons, it is assigned to the second non-price zone. Operation of power equipment in a number of regions of the far East is carried out in difficult climatic conditions, which leads to accelerated wear and additional costs for repair and restoration. The current technical condition of energy and utility facilities in most regions of the Far East represents a real threat of increasing accidents and energy security. In the district, 70% of the generating capacity is in operation for 20 to 40 years, their wear is more than 60%, and 30% of the equipment has been used for more than 40 years. The total share of efficient equipment is only 22.8% [1]. Over the past 30 years, there have been no significant changes in the energy sector of the far East: the total installed capacity of generating sources has not changed at all; power generation in 1991 was the maximum – 33,605 million kWh, in the early years of "perestroika", it decreased, for known reasons, and only in 2015, electricity generation reached the perestroika value-33,970 million kWh; centralized heat production to date has not yet been recovered (30 389 thousand Gcal in 2015).

One of the most dynamically developing regions of the far East is Primorye territory with the regional capital – the city of Vladivostok. The period from 2008-2012 became an impetus for the renovation of energy facilities in the region, it is associated with the beginning of the gasification process in the region. The result of gasification was the conversion of power stations and a number of large boilers in Vladivostok to natural gas combustion, as well as the commissioning of new facilities. The reconstruction was carried out at Vladivostok TPP-2 (TPP-2, 497 MW, 1,051 Gcal / h) and TPP-1 (TPP-1, 350 Gcal/h), the Severnaya boiler house (400 Gcal/h), the Severnaya mini-CHPP (3.6 MW, 10.8 Gcal/h), the Tsentralnaya mini-CHPP (33 MW, 123.3 Gcal/h), and the Oceanarium mini-CHPP (13.2 MW, 29.54 Gcal/h) were built. In 2018, GTU-CHPP Vostochnaya (139.5 MW, 432 Gcal/h) was put into operation.
The scope of reconstruction at vtez-2 included the conversion of 10 of the 14 boiler units that burned pulverized coal fuel to natural gas. At the facilities of VTEC-1 and the Severnaya boiler house, which used fuel oil as the main fuel, cyclone-vortex preheaters were modernized for the most part [2]. The new energy facilities were three mini-thermal power plants built on the island of Russian. The reasons for the construction of mini-TPP were due to the holding of the APEC summit in 2012 and subsequent plans to create on the Russkiy island international scientific, educational and technological cluster. The built mini-CHP plants have a simple thermal scheme without steam and high pressures, provide heat supply according to a closed scheme with quantitative regulation of heat output with parameters 98/70° C and work in parallel with the power system of the Far East.

The main fuel for the station is natural gas, and diesel fuel is provided as a backup fuel. For the production of electric energy and heat at mini-CHPP, GTU is used, which in combination with the utilization heat exchanger (EF) provides a high fuel utilization rate (CIT) of up to 85% [5]. GTU 6.6 MW, used at mini-CHP " Tsentralnaya " and mini-CHP "Oceanarium", 2009. output with a declared efficiency of 30% in nominal mode, the degree of pressure increase in the compressor is 1: 16. To cover peak heat loads, thermal Technology TT100 water-heating heat-tube boilers with Finnish Oilon burners are installed at the stations. The choice of the main equipment as a GTU made it possible to make a simple and compact layout of the power plant and provide a minimum of auxiliary equipment. During commissioning, mini-CHP plants faced a typical problem for new CHP plants, as associated with an erroneous determination of the actual and prospective heat load of consumers, and as a result, the presence of an overestimated installed heat capacity of the stations. As a result, it was necessary to preserve the Severnaya mini-CHPP, which is currently not used due to the lack of infrastructure development of the thermal power district allocated for it. Mini-CHP plants "Tsentralnaya" and "Oceanarium" were found to have significantly overestimated installed capacity relative to actual thermal loads.

Since April 2015, mini-CHP plants have received permission from the system operator to operate in the retail electricity and capacity market. Since this period, electric power generation at the Tsentralnaya mini-CHPP has been carried out almost permanently during heating periods. During the four years of active operation, a number of features and problems in the operation of mini-CHPP, which are not typical for the Far Eastern power system, can be identified. At the beginning of operation of Tsentralnaya mini-CHPP, heat was generated from Equivalent fuel in summer period (figure 1.) at the rated load of the GTI in the basic mode. In summer, the heat load released to the hot water supply provides a load of Equivalent fuel GTU no more than 30%. Due to underutilization of the Equivalent fuel in summer, the temperature of the outgoing gases in the bypass flue reaches 480 ° C. Despite the fact that the outer and inner walls are separated by thermal insulation, the outer surface of the steel chimney began to show burnouts and paint peeling. In addition, the operation of GTU in summer makes it difficult to operate an air-type oil radiator. Taking into account the summer outdoor temperatures and due to the placement of GTU inside the CHPP building, the temperature in the engine room rises significantly and oil cooling becomes ineffective, while the technological protection for the oil temperature after the radiator is 60 ° C.

At the same time, there is a problem with oil exhausters that divert oil vapors to the engine room, which leads to the appearance of an oil film on the surface of the radiator and further deterioration of the cooling of the GTU oil. From figure 1. it is seen that throughout the year there are various combinations of work equipment: work only boilers, the work of the gas turbine with Equivalent fuel ,work of the gas turbine with Equivalent fuel and boilers to bring the temperature graph to the set parameters. Analysis of these modes for 2019 shows that the maximum fuel utilization rate of the station is 88% (in the 1st GTU and PWHB operation mode), but the specific indicators are approximately the same and even higher (125.5 kg/Gcal, 262 g/kWh) than in the mode with the KIT 83%, when the heat load is fully covered by the utilization heat exchangers of the GTI (101.6 kg/Gcal, 231.91 g/kWh).
Figure 1. Average hourly heat load of mini-CHP "Tsentrnalnya" in the WHP 2016-2017.
1 - the generated load from Peak water heating boiler;
2 - the loss of heat load from EF to the atmosphere;
3 - the generated heat load from the EF.

The heat transferred to the consumer from the mini-CHP equipment is performed directly without heat exchangers between the EF, Peak water heating boiler and the consumer circuit, that is why there is a necessity for permanent control of constantly changing consumption of water with the help of working equipment.

Since the equipment has a maximum water temperature at the outlet of 115 °C, working according to the design schedule of heat release of 115/70 °C led to frequent disconnections of EF and PWLB by the action of protection at the maximum temperature due to the rapid reduction of network water consumption. To improve reliability, the temperature schedule was revised to 98/70 °C parameters.

When working at the retail electricity market, an hourly deviation from the plans previously submitted by the station of more than 3% is "fined". This makes it necessary for the station to "insure", using an understated setpoint for the hourly release of electrical energy from the GTU, the power of which depends on the temperature of the outside air.

Due to the specific peculiarities of the region’s climate and the location of the mini-CHP, weekly temperature changes reach up to 10 °C. In winter it can lead to a deviation from the hourly vacation plan by 500 kW. Therefore, the amount of power reserve is quite significant in winter. Its absence would provide an 8% savings in GTU operating hours when implementing the plan.

Due to the small capacity of the GTU, one of the main advantages of the GTU- mobility and maneuverability- is not used, since in the current operating conditions they are absolutely unclaimed. After switching on the GTU, it is set the base load corresponding to the nominal one and within 3 to 5 months the GTU is in operation. Thus, the average number of turbine starts at the Tsentrnalnya mini-CHP plant per year is 15 (excluding inclusions for testing after defects are eliminated).

Some of the results of repairs (inspections) recorded over 8 years of operation can be attributed to the features of servicing GTU at mini-CHP "Tsentrnalnya". During the first inspections, small radial gaps were noted in the compressor and turbine stages and, as a result, traces of touching by the rotor parts the inner surface of the turbine stator. Presumably, these impacts occurred during the natural cooling of the GTU during the operation of the shaft-turning device, since the vibration of the GTU
during operation was maintained at the minimum values relative to the manufacturer's tolerances, and its abrupt increase by personnel and automation was not recorded during operation.

The most significant defects identified during the entire period of operation during inspections were damages of the combustion chambers. Thus, during the operation of the GTI, 5 combustion chambers were replaced because of the destruction of a significant area of the thermal barrier coating and the burn-out of the edges of metal plates.

The most severe damage to the combustion chamber and the transition channel was caused by the failure of the fuel injector, which led to a through burnout of the deflector housing (about 80% of the surface area) and melting of the edges of the material of the first section in two places with dimensions of 100x15mm and 40x10mm (figure 2.). This defect did not manifest itself in terms of parameters during the operation of the GTI and was detected after dismantling of some parts during a borescope inspection at 500 Equivalent operating hours (EOH).

![Figure 2. GTU No. 4 combustion chamber defect for 500 hours of operating time.](image)

**a**-damage diagram

1-combustion chamber; 2-combustion chamber housing; 3-spark plug; 4-diesel fuel injector; 5-natural gas supply in the mode of diffusion combustion; 6,7-natural gas supply in the mode of DLE; 8-auxiliary natural gas supply. I – complete burnout of the thermal protective coating, traces of molten metal, II - burnout of 85% of the diffuser, III-burnout of the guide device.

According to the set of parts supplied by the manufacturer, no more than 4 turbine nozzles and 6 first-stage blades should be replaced "as of" 15,000 hours of operating time during the inspection of the hot part of GTI No. 4. In fact, as a result of an unacceptable condition, 19 nozzle devices and 15 blades of the first stage were replaced (figure 3.). The reasons for this increased wear of the turbine elements were not indicated by the manufacturer. Since the combustion chamber distributes the flow through the transition channel to 6 nozzles, and the damaged elements are located in different circumferential sectors and are located randomly on the body and disk of the 1st stage of the turbine, it
is impossible to unequivocally link the cause of such wear with a serious defect for 500 hours of operation (figure 2.). The increased number of worn parts relative to the delivered set "as of" has led to the need to find a reserve in the shortest possible time to complete repairs (inspection), conduct post-repair tests and include the GTU in the work in the WHP 2019-2020 gg. If the source of the reserve was not available, there would be a need to suspend repairs and wait for delivery of missing parts from 3 to 6 months (delivery time of the manufacturer).

Figure 3. Damage to the turbine blades
a-1st stage of GTU No. 4
b-1st stage of GTU No. 5

Figure 4. accident rate at mini-TPP shows a high percentage of accidents in the initial period of operation, when the first design flaws of the mini-TPP project, features of GTU operation, and personnel errors began to be identified.

The reasons for emergency shutdowns of GTU related to the design features of the turbines were associated with operating in the "low emission" mode (hereinafter - DLE), which consists in multi-nozzle combustion of gas fuel and maintaining a low (for GTU) air exuberance in the combustion chambers.

Failures in this mode were the result of a long downtime of the equipment after adjustment by the manufacturer of the GTU. In fact, the turbines "stood" on the site of the mini-TPP for 2 years before it was launched in permanent operation. However, some of the settings of the DLE mode were violated, and since the manufacturer does not allow you to make changes to the settings of this combustion mode, its correction was performed only later during scheduled maintenance of the gas turbine. Failure in this mode led to an incorrect distribution of fuel between the combustion chambers and, as a result, the failure and attenuation of the torch [3].

Frequent reasons for turbine failures during start-up (also refers to the definition of an accident) were the lack of tightness of the closure of the shut-off valves of natural gas, the tightness of which is checked by GTU automation during start-up operations. The reasons for the lack of tightness were the ingress of fine dust under the ball of the valve, causing an increase in its closing time by several seconds. Due to the extended closing time, the pressure in the section checked by automation had time to decrease, and the generated signal from the pressure switch informed the GTU control system about the gas path's leakiness. The presence of fine dust was explained by the implementation of the part of the gas pipeline from the filters to the container of the GTU made of steel that is subject to corrosion. Subsequently, this section was replaced and was made of stainless steel. Failures of GTU associated with the lack of tightness have stopped.
One of the main reasons for emergency shutdowns of the GTU at the beginning of operation was the rupture of sections of diesel fuel pipes inside the container of the GTU with the ingress of diesel fuel to the hot parts of the turbine body. The reason for ruptures of pipes in the places of their fitting connections was increased vibration, which appears after the output of the GTU at nominal speeds. The main diesel fuel pump of the turbine is driven by a gearbox and even when working on natural gas, it circulates diesel fuel along the circuit from the turbine to the fuel storage tanks (an open circuit with a backup from the consumption tanks).

Improperly calculated by the project documentation value of the cavitation margin was caused by the vacuum suction pump diesel fuel, a gas turbine and, consequently, a higher vibration of pipelines. In order to avoid reconstruction of the diesel fuel pipelines of the entire shop, a bridge was installed at the outlet of the GTU between the pressure and suction lines of fuel, which eliminated the vacuum and vibration of the pipelines.

A typical cause of failures for GTU is failures in the fuel ignition control system installed on the combustion chambers. As a rule, flame detectors are cooled by compressed air (high-power gas turbine water) from the General station system. Poor-quality separation or filtration of compressed air from oil can lead to the formation of an oil film when throttling the flow in the flame detectors and triggering a false signal about the absence of a flame in the combustion chamber when the GTU is switched on. In rare cases, it is possible to form a plaque from the combustion chamber on the protective glass in front of the sensitive element of the flame detector. Frequent checks of flame detectors can lead to deterioration or loss of the detector contact after it is re-installed due to bending of the wire.

Gas turbines are characterized by a low electric power consumption for own needs. The largest consumption from the supporting mechanisms of the GTU turbine is related to the natural gas booster compressor station (100 kW) and the oil cooling fan (30 kW). On average, the value of the GTU's own needs is 2% of the rated capacity. The average level of electricity consumption for own needs of mini-CHP "Tsentralnaya" during heat loads is 5% in the mode with three working GTU, 7% in the mode with two GTU, and 10% when working with one GTU.

During the period of operation, it is possible to note the low oil consumption of GTU relative to alternative small cogeneration units - gas piston units (GPU). In fact, for 8 thousand hours of operating time, the GTU installed at the mini-TPP requires from 200 to 400 liters of oil for topping up.
same time, a complete oil change on the GTU in operation (since 2012) was not performed due to the positive results of tests of turbine oil by the licensed laboratory, performed on a regular basis. For example, the actual monthly (750 hours of operation) oil consumption of caterpillar G3616 HPA (3.65 MW) installed at the Anadyr GM CHP is from 600 to 1000 liters.

For operation of gas turbines requires a large amount of filtered air for oxidation of the incoming fuel installation. The rules of operation of gas turbines require the adoption of a number of measures to ensure reduction of dust content of air entering for combustion through the compressor gas turbines, such as seeding of available sites herbs, lawns, paving roads, construction of means of irrigation. When choosing the location of the mini-TPP "Tsentralnaya", relatively to the infrastructure being created on the Russkiy island, a number of these measures were not taken into account. As a result, with the onset of a snowless winter (2018), the increase in pressure drop and the number of air filter replacements of the 1st stage significantly accelerated.

During the operation of the GTU at the mini-CHPP, factory data on CO and NO\textsubscript{x} emissions were confirmed (figure 5.) [4]. The low level of emissions is provided only in the DLE mode, which is technically possible when the GTU load is more than 50%, when natural gas is burned, with the condition that the GTU operates in parallel with the power system.

![Figure 5. Results of measurements of CO and NO\textsubscript{x} emissions depending on GTU capacity](image)

Conclusions:

1. A low value of the installed capacity utilization rate due to the overestimated installed capacity is one of the main problems of mini-CHP plants built on the Russkiy Island.

2. The analysis of the given specific indicators for the period under review shows the possibility of working with low specific fuel consumption (SFC) for thermal 141.42 kg/Gcal and electric 233.45 g/kWh energy, in comparison with the average indicators of the Far East power system objects 172.0 kg/Gcal, 416.3 g/kWh.

3. In order to increase the average annual indicators, additional work is required on future mini-CHP projects that take into account the operation of GTU in summer period.

4. If the designed mini-CHPP is operating in the basic mode, select the gas turbine units giving preference to its performance indicators in nominal modes, but not to their maneuverability and mobility.

5. The existing technical deviations in the operation of mini-TPP are not significant and, in general, show high reliability of the GTU and good level of qualification of the staff.
6. The analyzed causes of accidents indicate that mini-CHP plants with low-power GTU are characterized by frequent accidents at the beginning of operation. Just as for other types and capacities of thermal power plants, there are accidents related to the specifics of equipment and circuit solutions of mini-TPP. At the same time, imported GTU did not prove to be trouble-free units and have design flaws.

7. The delivery of original imported parts (blades, nozzles, combustion chambers, etc.) by the manufacturer takes a long time, what can affect the readiness of the CHP for the heating period.

References
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