Prospects of Application of Dual-Fuel Combined Cycle Gas Turbine Units

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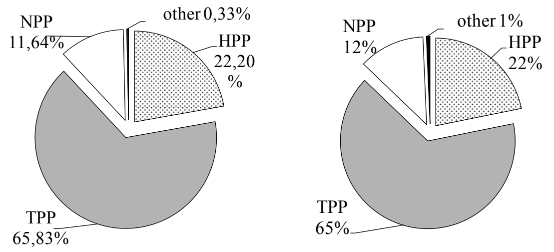
Abstract. Dual-fuel combined cycle gas turbine units, including power units on the parallel scheme with predominant coal combustion are considered in the paper. The basic equations for determining the energy efficiency of dual-fuel combined-cycle power units are described. The interdependence of the efficiency of the gas turbine and steam turbine parts of the combined-cycle plant for the efficiency of the combined-cycle plant with a variable binary coefficient is presented. It is shown that 55-56% efficiency is achievable for parallel type combined cycle gas turbine units T with predominant solid fuel combustion on the basis of this interdependence between efficiency and binary coefficient. Comparison of competitiveness in the ratio of fuel prices for gas / coal with traditional coal technology and theoretical rejected combined cycle gas turbine units with an efficiency of 60% for dual-fuel combined cycle gas turbine units with the implementation of the Rankine cycle for subcritical (13 MPa) and supercritical (24 MPa) steam parameters is carried out. It is shown that the dual-fuel combined cycle gas turbine units are preferable to traditional coal steam turbine power units in the case when the ratio of the price of fuel does not exceed 5, binary rejected combined cycle gas turbine units, when the ratio of the prices by more 0,5.

1 Introduction

Analysis of the Russian energy sector over the past decade shows that the country's energy sector is characterized by a steady increase in capacity from 200 GW in 2007 [1-3] to 244 GW in 2017 [4]. It should be noted that the structure of the generation has not changed much over the past period, which indicates the proportional development of the market for each type of installation (Fig. 1).

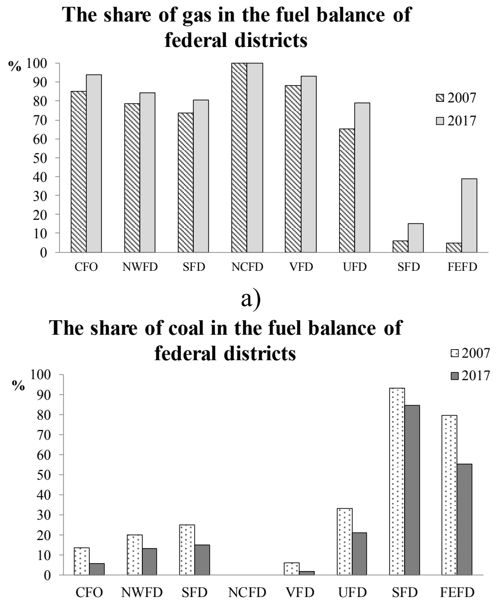


a) 2007 b) 2017

Fig. 1. Structure of the generation in Russia: TPP – Thermal power plant, NPP – Nuclear power plant, HPP – Hydroelectric power plant.

At the same time, the structure of the fuel balance of the regional energy sector has changed in the direction of increasing the share of gas (Fig. 2), in consequence of that CCGT are much wider used in domestic energy [5].

However, the introduction of purely binary steam and gas installations remains impractical in areas with coal energy, such as the Siberian Federal district, the far Eastern Federal district and partially the Ural Federal district.



a)

b)

Fig. 2. Structure of the fuel balance in Russia: CFO – Central Federal District, NWFD – North-West Federal District, SFD – Southern Federal District, NCFD - North Caucasian Federal District, VFD – Volga Federal District, . SFD – Siberian Federal District, Far Eastern Federal District.

The introduction of dual-fuel steam-gas plants (CCGT) is proposed to consider as one of the options for

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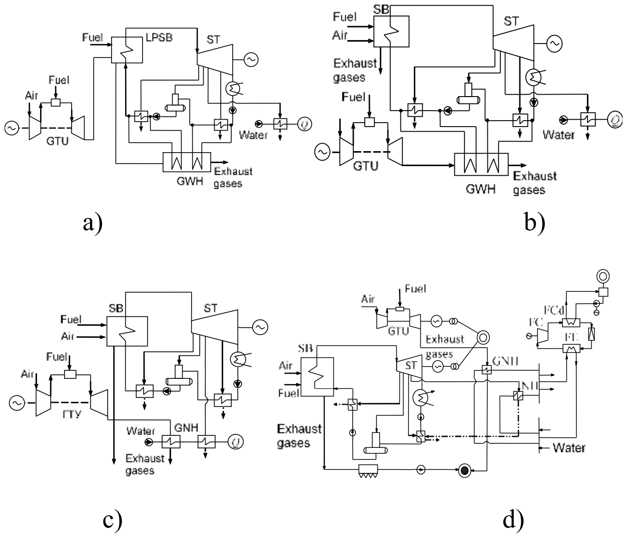
the long-term development of energy in such regions, in which one type of fuel is used for the combustion chamber, and to provide additional energy supply – another. These settings allow you to engage the coal to combined-cycle technology and to ensure the most efficient from using this type of fuel

2 Method of evaluation of energy efficiency of dual fuel CCGT

There are various schemes of dual-fuel CCGT (Fig. 3), for example, with the utilization of exhaust gases in the GTU as an oxidizer (due to the presence of about 18% of oxygen) in the furnace of a steam coal boiler, or as a coolant in a special heat exchanger included to the thermal scheme of the power unit; with the discharge of the heat flow of the exhaust gases in the GTU into the network installation (to the special gas network heater) with the displacement of the steam turbine corresponding thermal selections while maintaining the thermal scheme of the power unit; with the utilization of exhaust gases in a gas network heater installed in parallel with the network heater for heating water by selecting a steam turbine; CCGT with coal gasification [6, 7].

The choice of the most favorable parameters and schemes of CCGT is due to the technology prospects and high efficiency and to the variety of possible combinations of both commercially available units and installations, and the possibility of designing new equipment. In addition to the above schemes, it is proposed to consider a variant of dual-fuel combined cycle gas turbine units (CCGT) with a parallel scheme, Fig. 4



a) b)

c) d)

Fig. 3. Schemes of dual-fuel combined-cycle plants with a low-pressure steam generator (a); with gas water heater (b); with gas heater (c); with gas heater and freon thermotransformer (d): LPSB - low pressure steam boiler; SB - steam boiler; ST - steam turbine; GTU - gas turbine unit; GWH – gas and water heater; GNH - gas network heater; FCd - freon condenser; FC - freon compressor; FE - freon evaporator.

Table 1. Main technical specification of CCGT-370 with afterburning

Indicator	Value
GTU capacity, mW	130
STP capacity, mW	240
CCGT capacity, mW	370
GTU net efficiency (with air temperature -5 °C), %	38,7
Sharp steam pressure, MPa	12,8
Sharp steam temperature, °C	540
The pressure of the reheated steam, MPa	2,7
The temperature of the reheated, °C	500
Exhaust gas temperature, °C	514
CCGT net efficiency, %	46,5
CCGT specific fuel consumption, kg.ef/kWh	0,264
Equivalent fuel specific consumption for GTU, kg.ef/kWh	0,318
Natural fuel consumption (gas with $Q_{\text{н}}^{\text{р}}$ = 36 MJ/m3), thousand m^3/h	33,6
Conventional fuel consumption for STP, t.ef/h	53,4
Natural fuel consumption (coal with $Q_{\text{н}}^{\text{р}}$ = 22 MJ/kg), t/h	71,2
Binary coefficient	0,44

Fig. 4. Thermodynamic diagram (a) and dual-fuel CCGT with coal afterburning thermal scheme (b): GTU – gas turbine unit; SB – steam boiler; HR – heat recovery boiler; D– deaerator; CP – condensate pump; FW – feed pump; Q_{SUP}^{GTU} , $Q_{\text{SUP}}^{\text{STP}}$ – supplying to GTU and STP heat; Q_{remove}^{GTU} , Q_{remove}^{STP} – removing from GTU and STP heat; NGTU, NSTP – electric capacity of GTU and STP.

Thermal energy is supplied to two places of thermodynamic cycle in the dual-fuel combined cycle gas turbine units (CCGT), Fig.4a. On the one hand – to the burner with using natural gas, on another hand – to the steam boiler (processes FW-0, SH1-SH2), where we can use coal. [8-13]. High temperature pressure sharp steam is achieved in the steam boiler (SB) due to the fuel combustion (in particular coal). The CCGT with coal combustion makes it possible to get the cyclic process efficiency, which is not achievable in other power generation technologies applied to this fuel type. [12].

The turbine exhaust gas goes into the heat recovery steam generator to generate steam, which then goes to the steam turbine plant (STP). This technology allows to increase the total efficiency of the unit, fig.4. Steam flows from the steam boiler and heat recovery steam generator go to the turbine in parallel. These schemes are called parallel.

Net efficiency for the gas turbine unit and steam turbine plant:

$$\eta_{GTU}^{net} = \eta_{GTU}\eta_{los}^{GTU}\eta_{aux}^{GTU}\,; \qquad (1)$$

$$\eta_{STP}^{net} = \eta_{STP}\eta_b\eta_{ST}\eta_{em}\eta_{aux}^{STP} = \eta_{STP}\eta_{los}^{STP}\eta_{aux}^{STP}\,. \qquad (2)$$

Where η_b steam boiler and heat recovery steam generator efficiency; η_{ST}, η_{em} – steam turbine and electromechanical efficiency; η_{los}^{GTU} , η_{los}^{STP} – irreversible losses efficiency; η_{aux}^{GTU} , η_{los}^{STP} – consideration of auxiliaries.

Table 2. Efficiency and fuel consumption by different plants with their installed capacity of 300 MW

Indicator*	STP	CCGT(d)	CCGT(b)
CCGT net efficiency**	0,4/0,42	0,49/0,52	0,6
Specific consumption of reference fuel, kgfe /(kWh)			
Coal	0,307/0,292	–	–
Gas	–	–	0,205
Second consumption of reference gross fuel, kgfe/s			
Coal	23,8/22,7	12,74/11,9	–
Gas	–	7,21/7,21	16,8
The annual consumption of reference fuel, thousand tons.fe			
Coal	428/408	229/214	–
Gas	–	129/129	302
Sum	42/408	358/343	302
Gas/coal price ratio with equal economic efficiency **	Compared technology pairs		
	STP and CCGT(d)	CCGT(d) and CCGT(b)	CCGT(b) and STP
	5,09/4,82	0,53/0,49	1,41/1,35

* index "d" – dual-fuel;" b " – binary;
** in numerator for 24 MPa, in denominator for 13 MPa

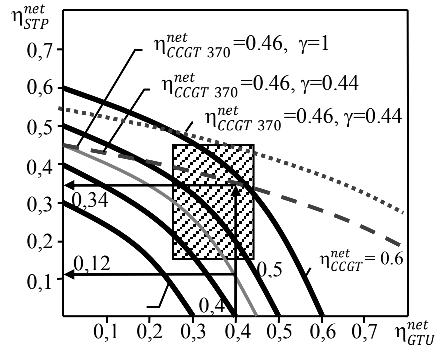


Fig. 5. Interdependence η_{STP}^{net} от η_{GTU}^{net} for different η_{CCGT}^{net}.

Whereupon, by using method [14]:

$$\eta_{CCGT}^{net} = \eta_{GTU}\eta_{los}^{GTU}\eta_{aux}^{GTU}\left(1-\eta_{STP}\eta_{los}^{STP}\eta_{aux}^{STP}\right)\gamma + \\ +\eta_{STP}\eta_{los}^{STP}\eta_{aux}^{STP}, \tag{3}$$

here γ – binary coefficient:

$$\gamma = \frac{Q_{\text{sup}}^{GTU}}{Q_{\text{sup}}^{CCGT}} = \frac{Q_{\text{sup}}^{GTU}}{Q_{\text{sup}}^{GTU}+Q_{\text{sup}}^{STP}}. \tag{4}$$

If η_{los}^{GTU} = η_{los}^{STP} = 0.9, and auxiliaries efficiency η_{los}^{GTU} = η_{los}^{STP} = 0.95, then equation for binary CCGT with afterburning efficiency:

$$\eta_{CCGT}^{net} = 0.855\eta_{GTU}\left(1-0.855\eta_{STP}\right)\gamma + 0.855\eta_{STP}. \tag{5}$$

This interdependence shows that CCGT efficiency coefficient at level 46 % for GTU with efficiency 40 % might be achieved by efficiency coefficient of STP 12% if the binary coefficient is one (Fig. 5) [15].

The analysis of figure 5 shows that for the parallel-type CCGT with the predominant solid fuel combustion, the efficiency at the level of 55-56% are achievable.

3 Compare dual fuel parallel type CCGT with auxiliary STP on coal and binary CCGT

Estimations of fuel flow rate for CCGT without afterburning (γ = 1) and with afterburning (γ = 0,44) under comparable conditions for a 370 MW unit (gas price is 5500 rubles/thousand m3 and coal – 2250 rubles/t) show that CCGT with afterburning saves more than 2 times gas, in the case of using coal in a steam boiler. (Table. 1).

This provides savings of more than 500 million rubles per year due to the difference in the cost of different types of fuels.

Given the difference in the cost of the two types of fuel for the considered dual-fuel CCGT, it is of interest to identify the competitiveness zone of different technologies in the ratio of fuel prices. Further, dual-fuel CCGT, binary CCGT (on gas) and traditional coal-fired CCGT are taken into consideration.

The ratio of gas price to coal

$$\delta = \text{P}_{\text{gas}}/\text{P}_{coal}, \tag{6}$$

which delivers equal efficacy of dual-fuel technology from «clean» coal and «clean» gas technologies with maximum efficiency is determined as part of the comparison. Meanwhile the compared variants are given to comparable form in terms of installed capacity and output. The task is analytical, it is designed to identify the prospects of application of the compared technologies in the context of changes in fuel prices.

For this purpose, each technology is compared in pairs by annual fuel consumption. In this case, the capital investment in the units is not taken into account. The calculations are carried out in reference fuel with the installed capacity of each of the compared units of 300 MW at 5000 hours of use.

For each pair, the total annual consumption of coal and gas is determined by two technologies, then the interrelation is determined

$$\delta = \sum_{i=1}^{2} B_{i\text{coal}}^{\text{year}} \Big/ \sum_{i=1}^{2} B_{i\text{gas}}^{year}. \tag{7}$$

Two different cycles were compared. In the first case, the Rankine cycle is performed on supercritical steam parameters (24 MPa), in the second – on subcritical (13 MPa), Table 2.

Parameter δ is a term that describes the price ratio between gas and coal, in which both technologies equally in the costs of fuel with equal electricity supply to the consumer.

By comparing the STP-CCGT pair (b), an increase of the gas price leads to an increase of δ, hence the coal technology is preferable.

Comparison of STP-CCGT(d) pair is as follows. If gas is more expensive than coal less than δ times ($\delta_{fact} < \delta_{calc}$.), the dual-fuel technology becomes preferable.

For a pair of CCGT(d)–CCGT(b): dual fuel technology is preferable in the case the gas is more expensive than coal more than δ times ($\delta_{fact} > \delta_{calc}$).

4 Conclusions

The structure of the regional energy fuel balance over the past decade has changed in the direction of increasing the share of gas, with the largest scale of the gasification process of the territory provided in the far Eastern Federal district, where the share of gas increased from 5 to 39 %. In the context of changes in the region fuel balance with reduce the cost of production improving the efficiency of the technology continues to be relevant.

Some variants of CCGT operating simultaneously on two types of fuel: coal and gas are considered. From the results of the calculation we can see that:

- the efficiency values at level of 55-56 % are achievable for parallel type CCGT with predominant solid fuel combustion.
- Dual-fuel parallel type CCGT is preferable to traditional pulverized coal power units in case the ratio of fuel prices of gas/coal does not exceed 5.
- Dual-fuel parallel type CCGT is preferable to binary discharge CCGT when the ratio of fuel prices gas/coal more than 0,49-0,53.

Thus, the development of dual-fuel combined cycle gas turbine units' technologies are a promising direction in the modernization and technical re-equipment of existing power plants in the coal regions.

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