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Loading CCGT for industrial extraction steam turbines

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Abstract

This paper considers the issue of industrial bleed steam utilization to increase the capacity of combined cycle gas turbine plants. The feasibility of transition to a steam turbine compressor drive is also investigated.

Keywords: Combine Cycle, Industrial bleed steam, Gas turbine

1. Introduction

Due to changes in the industrial production structure, which requires superheated steam of high parameters, industrial bleeder turbine plants operating without steam bleed-off have lost competitiveness in the energy market.

There are two approaches to solving the problem.

The most radical solution is the complete replacement of industrial extraction steam turbines with new condensing or cogeneration turbines. But this entails large material expenditures, since the assembly of a new type of turbine requires the almost total dismantling of the turbine equipment, even including the foundation.

Total redesign of the turbine flow part while maintaining the existing turbine casing and auxiliary equipment of the plant is much less expensive.

From the viewpoint of specific problems this is the most feasible solution, but it ignores the probable developmental prospects of both the power plant and the industry. Since development is impossible without increasing heat and power production, we will inevitably face an energy deficit, so there is an urgent need to start preparing to cover the coming shortfall.

Accordingly, the costly liquidation of existing industrial extraction turbines will in the long term cost even more time and expense in terms of recouping the lost possibility of industrial-purposed steam production at thermal power plants.

Hence it appears more reasonable to consider the variants of industrial steam extraction utilization to produce extra power directly at the plant.

From the viewpoint of material expenditures, this variant is commensurate with the assembly of a new turbine rotor with a redesigned flow part, and the extra costs, considering the current energy prices, will be recovered relatively quickly through additional power production by the parallel steam turbine and the higher efficiency of industrial extraction steam turbines.

Reference is made to the commonly-used turbine: PT-80-130 LMZ (Fig. 1), whose basic characteristics are shown in Table 1.

In this case a small back-pressure turbine can be used as an extra loading turbine, with the exhaust-steam discharging to the heating extraction.

A much more interesting variant is industrial steam bleed-off utilization using a “loading” combined cycle gas turbine (CCGT), when extraction is used to produce power in its steam turbine [2]. This is the subject of consideration in this article.

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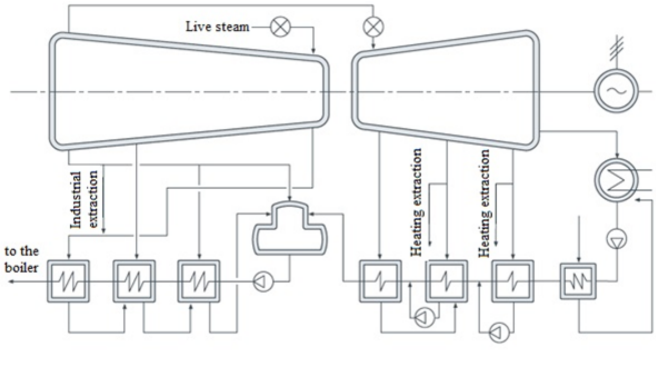

Figure 1: Thermal scheme of turbine PT-80-130

Table 1: [1]

Rated/maximum power, MW	80/100
Initial steam parameters	
Pressure, MPa	12.8
Temperature, °C	555
Rated steam flow, t/h	470
Industrial steam extraction value, t/h	223.2
Industrial steam extraction pressure, MPa	1.3
Industrial steam extraction temperature, °C	244.5
Condenser pressure, kPa	4

2. CCGT with outer extra steam supply

The problem is in the impossibility of full capacity operation of the boiler, since industrial steam extraction is not carried out while the steam flow, which is increased by the value of the bleed-off, is unable to pass through the flow part of the low pressure cylinders.

Considering the combined cycle gas turbine as a loading installation at a thermal power plant with unclaimed industrial steam extraction, the most appropriate variant is to use single-shaft CCGTs, which possess a number of advantages over two-shaft ones.

Indeed, according to various estimations, they demand 10...20% lower capital costs than two-shaft installations. Moreover, they have only one electric generator, a joint lubrication system and require less production area. The thermal scheme of a single-shaft CCGT without disconnectable clutch is shown on Fig. 2, and its basic characteristics are shown in Table 2.

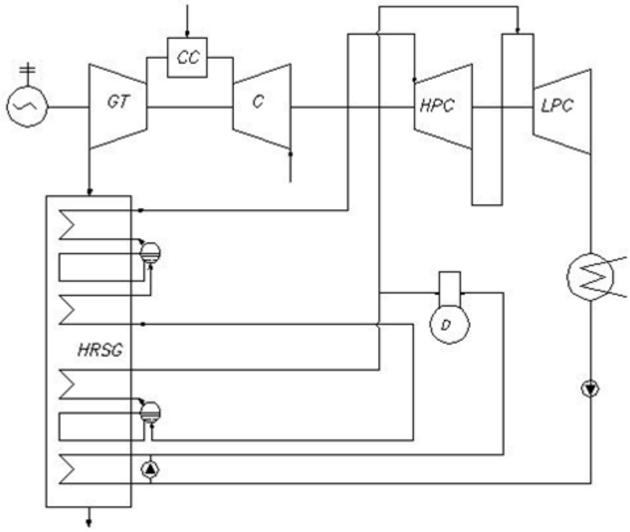

Figure 2: Thermal scheme of a single-shaft CCGT

The solution of the above mentioned problem is in the provision of joint operation of steam turbine PT-80-130 LMZ and a single-shaft CCGT (Fig. 3)

In this case the boiler provides the turbine's maximum steam flow: 470 t/h, which with the parameters of 555°C and 13 MPa is supplied to the high pressure cylinder (HPC) of the steam turbine, where it expands to the pressure of 1.3 MPa. Having passed the HPC, the steam splits into two streams, one is supplied to the PT-80-130 turbine's low pressure cylinder and the other (LPC) mixes with the CCGT's low pressure steam and is then directed to the LPC of the CCGT's steam turbine. To realize this process it is necessary to raise the pressure in the CCGTs low pressure circuit from the optimum value of 0.6 MPa to the extraction pressure (1.3 MPa). But this solution leads to decreasing the CCGT's efficiency. To maintain the highest possible efficiency level it was decided to preserve the low pressure circuits parameters, and supply the extra steam to the mixing chamber, organized in the HPC, with the pressure of 1.3 MPa. Another constructive solution that allows the turbines design pressure to be adjusted up to the extraction pressure is to place in a separate cylinder the medium-pressure part of the CCGT's steam turbine. This makes the construction more complicated, but makes it possible to maintain a high level of efficiency [3].

After the condensate of the steam, which was addi-

Table 2:

Gas turbine	
Compression ratio	11.46
Turbine exit temperature, °C	539.7
Electrical capacity, MW	162.6
Efficiency	34.29
Steam turbine	
Initial steam parameters	
Pressure, MPa	7.75
Temperature, °C	510
Steam pressure in low pressure circuit, MPa	0.6
Electrical capacity, MW	90.2
Deaerator pressure, MPa	0.6
Condenser pressure, kPa	4
Combined cycle gas turbine plant	
Electrical capacity, MW	245.9
Efficiency	51.83

Table 3:

Separately			
	PT-80-130	CCGT-225	In all
N_e, MW	68.8	245.8	314.6
Jointly			
	PT-80-130	CCGT-225	In all
N_e, MW	86.6	290.3	376.8

tionally supplied to the CCGT, passes the waste-heat boilers economizer, it is removed from the cycle and supplied back to the scheme of the PT-80-130 turbine before the condensate pump.

The final result of the above solution is:

- Firstly, an increase in the CCGT's electrical capacity;
- Secondly, a significant increase in the initial steam turbine unit's electrical capacity;
- Thirdly, it enables the industrial bleeder turbine to operate in rated conditions with a quiet constant "loading" of industrial steam extraction.

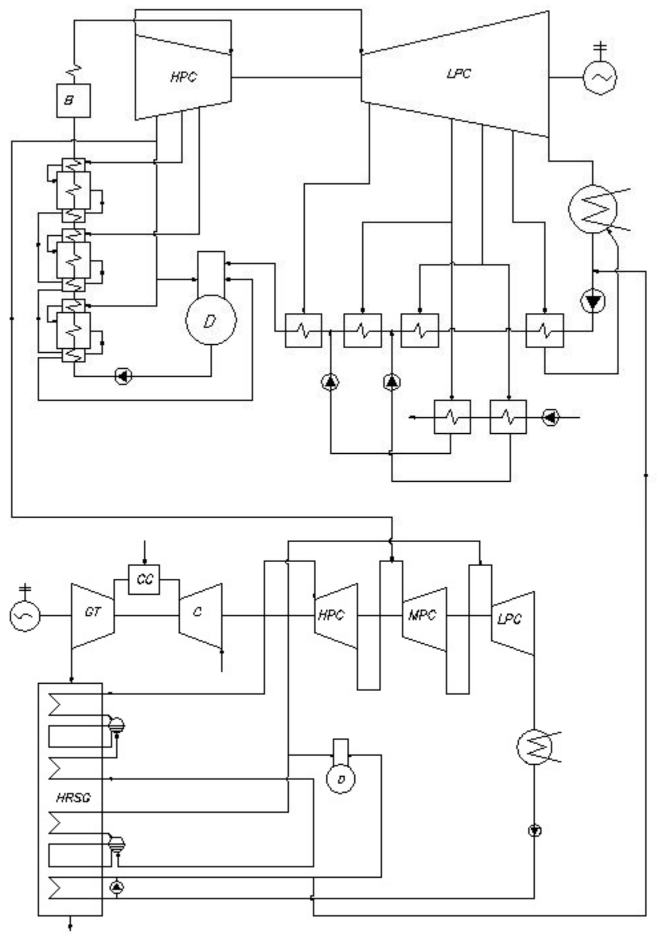

Figure 3: Thermal scheme of a hybrid energy complex based on a turbine with unclaimed industrial bleed-off

The electrical capacities of the installations, operating separately and jointly, are shown in Table 3.

In this case the increase in the electrical capacity of combined installations results from three elements:

- power, produced by the extra steam stream through the HPC of PT-80-130, which can be found as follows:

$$\Delta N_{ST}^{(1)} = G_{extr} \left(h_0 - h_{extr}\right) \eta_{0i}\,; \qquad (1)$$

- power, produced by the bleed-off steam flow, but with higher relative internal efficiency of the turbine:

$$\Delta N_{ST}^{(2)} = G_0^{init} \left(h_0 - h_{extr}\right) \Delta_{3_{0i}}\,; \qquad (2)$$

- power, generated by the bleed-off steam in the CCGT's steam turbine:

$$\Delta N_{CCGT} = G_{extr}\left(h_{MPC}^{inlet} - h_c\right)_{3_{0i}}. \quad (3)$$

where: h_0—initial steam enthalpy, h_{extr}—extraction steam enthalpy, h_c—steam enthalpy at the last stage of the turbine, h_{MPC}^{inlet}—steam enthalpy at the inlet of MPC, G_0^{init}—steam flow in the steam cycle, excluding the bleed-off, $_{3_{0i}}$—the turbine's relative internal efficiency (the coefficient, that describes the difference between the real expansion process in the turbine and the adiabatic one), $\Delta_{3_{0i}}$—difference in the relative internal efficiency of the cogeneration steam turbine HPC.

The pressure in both of the turbine condensers was measured at 4 kPa.

In this particular case, the capacity of the CCGT increased by 45.4 MW. The increase in capacity of the industrial extraction steam turbine, representing the sum of capacities $\Delta N_{ST}^{(1)}$ and $\Delta N_{ST}^{(2)}$, was found to be 17.8 MW. Thus, the total capacity increase in the hybrid power plant is 63.2 MW.

3. Loading CCPP with a steam turbine-driven compressor

The next stage of development of industrial extraction steam turbine and CCPP joint operation technology could be a transition to a CCGT with a steam turbine-driven compressor. The thermal scheme of this facility, working in conjunction with the PT-80-130 turbine, is shown in Fig. 4.

Transition to the steam turbine drive of the compressor can only be achieved if an additional amount of steam allows steam turbine capacity to equal the power consumed by the gas turbine compressor [4].

According to the results of calculations, the power required to drive the gas turbine compressor is 165 MW, 20 MW more than the steam turbine can produce. Thus, in the case of the PT-80-130 turbine, its extra power is insufficient to drive the compressor, so it becomes necessary to decrease the required capacity by reducing the compression ratio.

Reducing the compression ratio leads not only to a drop in gas turbine power, consumed by compressor, but also a rise in the temperature of the gas turbine flue gases, which provides higher steam parameters and, thus, achieves an additional increase in steam turbine power.

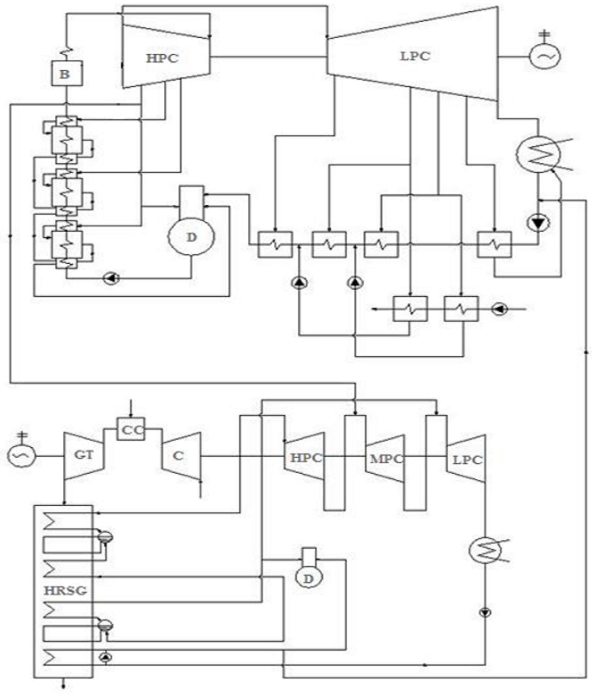

Figure 4: Thermal scheme of PT-80-130 and CCPP with steam turbine-driven compressor joint operation

The Siemens SGT5-2000E gas turbine engine, which was taken as the calculation basis, has a compression ratio of 11.47. If we assume that the inlet steam temperature remains constant at 510°C, the rise in temperature of the gas turbine flue gases affects only the temperature of the steam in the low pressure cycle, which marginally increases steam turbine capacity. In our case, to implement the steam turbine-driven compressor scheme, the compression ratio should be reduced by 2.53.

At the pressure of 8.93 bar behind the compressor, the steam turbine capacity increases to 141.9 MW, which completely matches the condition of scheme realization. If the steam temperature at the HPC and LPC inlet is not strictly regulated, it is defined by the superheater temperature difference; so the necessary pressure reduction will be slightly lower due to more rapid growth in capacity of the CCPP steam part and will be equal to 1.83. Thus, equality of the steam turbine capacity and the compressor power consumption is set at the air compression ratio, which is 9.64.

Table 4:

PT-80-130 power, MW	86.6
CCPP power, MW	290.3
Gas turbine compressor power consumption, MW	141.9
Total hybrid plant capacity, MW	376.8

The operational details of the above described installation are shown in Table 4.

To conclude, the use of external vapor sources, such as the steam of existing industrial steam extraction turbines or additional power boiler steam, makes it advisable to separate the entire turbine-driven compressor from the gas turbine. Moreover, the availability of a constant exterior steam source eliminates the problem of running a single-shaft CCGT without a pivoting arm sleeve.

The use of a steam turbine-driven compressor will provide a quantitative CCGT power output regulation; allow one to construct a compressor with maximum high performance at reduced steam turbine speed and to increase the electrical capacity of CCGT on the basis of one gas turbine up to 800...1,000 MW, using dual-flow gas turbines. At the same time, maintaining the linear equipment configuration, which is typical for the single-shaft CCGT, allows one to eliminate the problem of long shafts.

4. Conclusions

1. This article considers the variant of loading an industrial extraction steam turbine with an unclaimed bleed-off by constructing a hybrid energy complex, which includes the main steam turbine unit with industrial steam extraction and a combined-cycle plant, using for its operation additional steam flow from the steam turbine bleed-offs.
2. It was shown that implementation of the proposed solution provides a substantial increase in electrical capacity, generated both by utilizing the industrial extraction steam and by increasing the internal relative efficiency ratio of the bleeder turbines. In this case, electrical power rises by 63.2 MW.
3. Joint operation of the PT-80-130 turbine and CCPP with steam turbine-driven compressor. Total electrical power of this hybrid energy complex is 376.8 MW.

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