Determination of the Average Specific Capital Consumptions of CCPP with Gas Turbine of 30-125 MW and Put into Operation at TPPs of the Russian Federation from 2015 to the First Quarter of 2021

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Abstract. Research was carried out on the volume of gas turbine commissioning in the range of unit capacities of 30–125 MW at TPPs of the Russian Federation operating as part of a CCPP in the period from 2015 to the first quarter of 2021. The purpose of the research was to determine the average specific capital investment in construction and the average specific fuel consumption for the supply of electricity and heat for the CCPP introduced over the years in the united energy systems of the Russian Federation. Gas turbines are classified by electrical capacity into three groups: from 100 to 125 MW, from 60 to 99 MW and from 30 to 59 MW. An assessment of the quantitative distribution of gas turbines over the interconnected energy systems of the Russian Federation has been carried out. The results of the comparison of the quantitative commissioning of gas turbines are shown in the period from 2010 to the economic crisis of 2014 and in the period from 2015 to the present. A preliminary estimate of the increase in average specific capital investments in the construction of CCPP, which included gas turbines of the same electric power, was made for these periods.

1. Introduction
Gas turbine units (GTU), as part of a combined cycle power plants (CCPP) or operated as a separate power equipment are actively used in the power industry, both in Russia and in other countries. GTUs have advantages over traditional steam turbine units (STU), despite the fact that the steam turbine included in STU has higher reliability and longer service life than a gas turbine, and less scarce materials are needed to manufacture a steam boiler and steam turbine than making a gas turbine. GTUs are characterized by shorter construction and commissioning periods, compactness, lower operating costs and production costs, higher efficiency, and environmental friendliness [1-5]. In addition, GTUs are characterized by flexibility in the choice of operating modes. These installations can be operated both as part of thermal power plants, and as a separate energy production, supplying the generated products to general electrical and heating networks. The climatic conditions in which the gas turbine plants are operated often require the provision of consumers not only with electricity, but also with thermal energy, this justifies the expediency of operating these units in the cogeneration mode [6-8].
2. Problem statement and research results

Currently, the share of GTU and CCPP in the unified energy system of Russia is relatively small. But in recent years, there has been a tendency to increase the commissioning of gas turbines. This is due to lower capital investments in the reconstruction or new construction of thermal power plants (TPP) in comparison with steam turbine power plants, shorter construction times, etc. The main production of power gas turbines is concentrated in joint ventures with foreign partners such as Siemens, General Electric, etc. The main problem of domestic CCPP and GTU is the lack of capacities for the production of the required range of these units.

In this work, we studied the volume of commissioning of gas turbines at TPPs of the Russian Federation (RF) in the range of unit capacities of 30–125 MW, operating as part of a CCPP, in the period from 2015 to the first quarter of 2021. The purpose of the research was to determine the average specific investment in the construction and average specific fuel consumption for the supply of electrical and thermal energy for the CCPP introduced over the years for the integrated power systems (IPS) of the RF.

In the period from 2015 to the first quarter of 2021, 36 gas turbines in the range of unit capacities of 30–125 MW were put into operation on the territory of the RF [9–19]. The commissioned gas turbines are classified according to their electrical capacity into three groups: from 100 to 125 MW, from 60 to 99 MW and from 30 to 59 MW. Their distribution is presented in Table 1.

| IPS of   | The total number of commissioned gas turbines, pcs. | Number of gas turbines by power range, MW |
|---------|---------------------------------------------------|------------------------------------------|
|         |                                                   | 100–125 | 60–99 | 30–59 |
| North-West | 6                                               | –       | 4     | 2     |
| Centre | 3                                               | –       | 3     | –     |
| Middle Volga | 4                                               | 1       | 3     | –     |
| Ural | 10                                              | –       | 10    | –     |
| Siberia | 1                                               | –       | –     | 1     |
| East | 11                                              | –       | 1     | 10    |
| South | 1                                               | –       | 1     | –     |
| Total | 36                                              | 1       | 22    | 13    |

Gas turbines with a capacity of 60–99 MW were commissioned at TPPs of the IPS of the RF in the largest number (Table 1). The largest number of turbines among the IPS under consideration was commissioned in the IPS of the Ural and the East – 10 and 11 turbines, respectively. Gas turbines introduced into the IPS of the RF during this period are mainly of foreign production: General Electric, Siemens, Ansaldo Energia. The average efficiency of gas turbines and CCPPs determined according to manufacturers' data was: for gas turbines with a capacity of 100 to 125 MW 37.2% for a gas turbine and 52.0% for a CCPP, for gas turbines with a capacity of 60 to 99 MW - 37.5% and 53.5% and for turbines with a capacity of 30 to 59 MW - 37.9% and 52.4%, respectively.

As a result of the analysis of information obtained from documents and projects on the development strategy of the energy sector of the RF and information from the official websites of generating companies and regions of the RF on the Internet, the average specific investment in the construction of CCPP was calculated, which includes the gas turbines described above, specific fuel consumption of CCPP for the supply of electricity and heat for each IPS. It was determined that the construction costs of a CCPP for each power range (gas turbines included in them) were approximately at the same level, therefore, the average specific investment in the construction of a CCPP is considered depending on the range of gas turbine capacities. The cost of construction of
CCPP and GTU commissioned at condensing power plants was approximately the same as at combined heat and power plants (CHPP). Perhaps this is due to the regional peculiarities of the construction of these power plants and the use of existing buildings and necessary infrastructure at some CHPP, which significantly reduces capital investments. Therefore, when determining the average specific capital investments in the construction of CCPP, investments in condensing power plants and CHPP were taken into account together. The obtained technical and economic indicators for each IPS for three groups of power ranges of the introduced gas turbines are presented in table. 2-8. When converting specific capital investments in the construction of CCPP/GTU from rubles to dollars, the average annual dollar exchange rate was used for the period from the beginning of 2015 to the first quarter of 2021 (after a sharp rise in the dollar exchange rate 2014).

At the power plants of the IPS of the North-West: 4 gas turbines with a unit capacity of 66 MW, 2 gas turbines GT-50 with a capacity of 50 MW each (Table 2). All turbines have been commissioned at the CHPP.

**Table 2.** Technical and economic indicators of CCPP IPS of the North-West, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators                                      | Number of gas turbines by power range, MW |
|------------------------------------------------------|------------------------------------------|
|                                                      | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kW h | –        | 250.2 | 251.5 |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | –        | 147.1 | 151.8 |
| Specific capital investments on CCPP construction, USD/kW | –        | 1571.6 | 1450.8 |

CCPPs commissioned at TPPs of IPS Centre have an electrical capacity of 125 MW. Turbines are equipped with gas thermal power plants (GTPP) and CHPP (Table 3). The GTPP (Shcherbinka) will make it possible to compensate for the shortage of heat capacity in the regions of Shcherbinka and Yuzhnoye Butovo and in the adjacent territories. The GTU CHPP-1 of the North-West region of Kursk was reconstructed and put into operation. At the power plants of the IES of the Center, the lower value of the indicator of the average specific capital investment in the range of gas turbine capacities of 60–99 MW in comparison with the previous table of the IPS of the North-West is explained by the commissioning of gas turbines at the existing power plants. These power plants have buildings for the installation of equipment and the necessary infrastructure (electrical substations, switchgears, technical water supply systems, fuel supply systems, etc.).

**Table 3.** Technical and economic indicators of CCPP IPS of the Centre, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators                                      | Number of gas turbines by power range, MW |
|------------------------------------------------------|------------------------------------------|
|                                                      | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kW h | –        | 270.0 | –     |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | –        | 149.6 | –     |
| Specific capital investments on CCPP construction, USD/kW | –        | 1290.5 | –     |
CCPP were put into operation at TPP of the IPS of the Middle Volga, they included gas turbines of two power ranges: 100–125 MW and 60–99 MW (Table 4). All inputs were carried out at Kazan CHPP-1, built at the beginning of the 20th century. Therefore, it was necessary to renovate the buildings to install equipment and additional infrastructure. This fact explains the higher indicators of average specific capital investments in the construction of CCPP of the IPS of the Middle Volga than the indicators of the IPS of the Center.

**Table 4.** Technical and economic indicators of the CCPP of the IPS of the Middle Volga, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators | Number of gas turbines by power range, MW |
|-----------------|------------------------------------------|
|                 | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kW h | 261.2 | 265.2 | – |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | 145.1 | 149.5 | – |
| Specific capital investments on CCPP construction, USD/kW | 1691.6 | 1595.9 | – |

Gas turbines with a capacity of 60–99 MW were commissioned at TPPs of the IPS of the Ural (Table 5). The indicators of average specific capital investments in the construction of CCPP of the IPS of the Ural have higher values in comparison with the indicators of CCPP of the previous IPSs. The reason is that the commissioning of CCPP was carried out at TPPs built in the 40-60s. of the last century, such as Ufimskaya CHPP-2, Ufimskaya CHPP-3, Salavatskaya CHPP, Perm CHPP-9. These CHPPs required renewal of the power plant infrastructure. In addition, the regional location of power plants is important during construction.

**Table 5.** Technical and economic indicators of the CCPP of the IPS of the Ural, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators | Number of gas turbines by power range, MW |
|-----------------|------------------------------------------|
|                 | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kW h | – | 263.3 | – |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | – | 148.3 | – |
| Specific capital investments on CCPP construction, USD/kW | – | 1902.7 | – |

The commissioning of CCPP-90 was completed at Omsk CHPP-3 of the IPS of Siberia during the period under review. The CCPP includes gas turbines with a unit capacity of 31 MW (Table 6). The high rate of specific capital investments in the construction of CCGT unit can be explained by the peculiarities of construction in the regions of Siberia and the initially high cost of the gas turbine equipment introduced.
Table 6. Technical and economic indicators of the CCPP of the IPS of the Siberia, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators                                      | Number of gas turbines by power range, MW |
|------------------------------------------------------|-------------------------------------------|
|                                                      | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kWh | –        | –      | 249.1 |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | –        | –      | 159.5 |
| Specific capital investments on CCPP construction, USD/kW | –        | –      | 2040.2 |

11 gas turbines were put into operation at TPPs of the IPS of the East in the period from 2015 to the first quarter of 2021. The indicator of average specific capital investments in the construction of gas turbines in the range of gas turbine capacities of 30–59 MW is given in Table 7, since it was the GTU that were not part of the CCPP that were commissioned there. This fact explains the lower specific capital investment for gas turbines in the 30-59 MW power range.

Table 7. Technical and economic indicators of the CCPP of the IPS of the East, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators                                      | Number of gas turbines by power range, MW |
|------------------------------------------------------|-------------------------------------------|
|                                                      | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kWh | –        | 259    | 262.0 |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | –        | 146.5  | 145.4 |
| Specific capital investments on CCPP construction, USD/kW | –        | 1751   | –     |
| Specific capital investments on GTU construction, USD/kW | –        | –      | 1150.5 |

The CCPP was commissioned at the TPP of the IPS of the South. The CCPP unit includes a gas turbine in the power range of 60–99 MW (Table 8).

Table 8. Technical and economic indicators of the CCPP of the IPS of the South, introduced in the period from 2015 to the first quarter of 2021.

| Main indicators                                      | Number of gas turbines by power range, MW |
|------------------------------------------------------|-------------------------------------------|
|                                                      | 100–125 | 60–99 | 30–59 |
| Fuel consumption per unit of generated electric power, g c.e./kWh | –        | 259    | –     |
| Fuel consumption per unit of generated thermal energy, kg c.e./Gcal | –        | 146.1  | –     |
| Specific capital investments on CCPP construction, USD/kW | –        | 1751.0 | –     |

The data obtained allow us to draw the following conclusions. Gas turbines commissioned in the period from 2015 to the first quarter of 2021 are mainly of foreign production, which confirms the
urgent need to develop domestic gas turbines in the range of 30-125 MW. Gas turbines are needed that, in terms of their energy and economic characteristics, could compete with foreign manufacturers. Gas turbines with a capacity of 60–99 MW were commissioned to a greater extent at the power plants of the IPS of the RF. The size of the specific investment is influenced by regional and local differences in construction conditions. There is an increase in the values of indicators of average specific capital investments in the construction of CCPP in regions with colder climates.

The authors of [20] described studies of the volumes of gas turbine commissioning in the range of unit capacities of 30–125 MW at TPPs of the RF operating as part of a CCPP in the period from 2010 to 2014 (before a sharp rise in the dollar exchange rate in the Russia). The purpose of the research, as in this work, was to determine the average specific capital investment in construction and the average specific fuel consumption for the supply of electricity and heat for the CCPP introduced over the years by the IPS of the RF. This makes it possible to compare the commissioning of gas turbines in the period from 2010 to the economic crisis in 2014 and in the period after 2014 to the present. Table 9 shows the inputs of gas turbines for the period from 2010 to 2014.

**Table 9. Number of gas turbines commissioned from 2010 to 2014.**

| IPS of        | The total number of commissioned gas turbines, pcs. | Number of gas turbines by power range, MW |
|--------------|---------------------------------------------------|----------------------------------------|
|              |                                                   | 100–125      | 60–99      | 30–59      |
| North-West   | 8                                                 | –            | 8          | –          |
| Centre       | 23                                                | 2            | 2          | 19         |
| Middle Volga | 9                                                 | –            | 7          | 2          |
| Ural         | 16                                                | –            | 4          | 12         |
| Siberia      | 2                                                 | –            | –          | 2          |
| East         | 8                                                 | –            | –          | 8          |
| South        | 17                                                | –            | 8          | 9          |
| Total        | 83                                                | 2            | 29         | 52         |

The number of gas turbines put into operation in the period after the economic crisis of 2014 is 36 units of equipment (Table 1), which is almost 2.5 times less compared to the period of 2010–2014. (Table 9). Increase in average specific capital investments in the construction of CCPP, which include gas turbines of the same electrical capacity, put into operation in the period from 2010–2014. and in the period from 2015 to the first quarter of 2021, the average was: for the IPS of the North-West about 8%, for the IPS of the Center 0.3%, for the IPS of the Middle Volga 0.5%, for the IPS of the Ural 1%, for the IPS East 36%, for IPS South 6%. In general, the insignificant increase in the average specific capital investment in the construction of a CCPP (except for the commissioning of a gas turbine unit at the power plants of the IPS of the East) is explained by the fact that the implementation of many projects began in the period before 2014, but the commissioning of gas turbines was postponed due to economic instability.

### 3. Conclusion

The paper presents the results of studies of the volume of commissioning of gas turbines in the range of unit capacities of 30–125 MW, operating as part of combined cycle gas turbines in the period from 2015 to the first quarter of 2021 at TPPs of the Russian Federation. The purpose of the research is to determine the average specific capital investment in construction and the average specific fuel consumption for the supply of electricity and heat for the combined cycle power plants commissioned over the years in the UES of the Russian Federation. The gas turbines put into operation are classified according to their electrical capacities: from 100 to 125 MW, from 60 to 99 MW, and from 30 to 59
MW. An assessment of their quantitative distribution across the OES has been carried out. The results of a comparison of the quantitative commissioning of gas turbines in the period from 2010 to the economic crisis of 2014 and in the period after 2014 to the present are presented. An approximate estimate of the increase in average specific capital investments in the construction of CCGT units, which included gas turbines of the same electric power, is shown in the work.

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