Gas turbine selection for hot windbox repowering on 200 MW fossil fuel power plant

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Abstract

In the present paper the concept of hot windbox repowering in existing steam cycle power plant was discussed. Using commercial software, for that process based on the fraction of oxygen within exhaust gases nine different models of gas turbines has been tested in power plant model with fossil boiler. Then thermodynamic analysis of power plant model before and after hot windbox repowering, has been investigated. The intention of this work is to choose the most suitable gas turbine for hot windbox repowering on 200 MW fossil fuel power plant, as well as to understand the effect of hot windbox repowering. In this case nine different models of gas turbines with different net electrical power (from 50 to 125 MW) has been tasted and finally has been selected General Electric production GE Energy Oil&Gas MS9001E SC (GTW 2009) 123 MW gas turbine as the most suitable for the model of power plant and after repowering the summary power of power plant has been reached up to 398 MW. Calculations were performed with 2 stages: 1) calculation and comparison of the thermodynamic parameters as well as carbon dioxide emissions of power plant model before and after repowering with nine different gas turbines, 2) calculation of thermodynamic parameters of the combined cycle power plant model before and after repowering in values 100 %, 90 %, 80 %, 70 %, 60 % of fossil boiler heat loads.

Keywords: fossil boiler, hot windbox repowering, combined cycle power plant, CO_2emissions, GateCycle^{TM}.

1. Introduction

According to remarkable increase in global electricity consumption especially in developing countries, because of increasing population and industrialization, rise of using fossil fuels and consequent environmental pollution, global warming and exhaustibility of nonrenewable resources makes it necessary to analyze methods of enhancing power and efficiency of electricity generation using these fuels and methods of decreasing pollutants emissions from such power plants [1]. In that case one of the most suitable solving method is repowering.

1.1. Combined cycle power plants

Combined cycle can be defined as a combination of two thermal cycles in one plant. When two cycles are combined, the efficiency that can be achieved is higher than that of single cycle. Thermal cycles with the same or with different working media can be combined; however, a combination of cycles with different working media is more interesting because their advantages can complement one another. The concept of a steam and gas turbine (GT) cooperating in a common system essentially arises directly from a review of the main advantages and disadvantages of steam and gas systems treated separately. The advantage of the steam turbine is its very low ratio of compression work to expansion work (due to water condensation which runs at a constant temperature, only slightly higher, 5...7 $^{\circ}$C, than ambient temperature). The disadvantage of this system is the process of heat supply, implemented through a metal wall, mechanically and thermal loaded. Substantial heat transfer surfaces are needed, forcing a reduction in the temperature used in the live steam to below about 570 $^{\circ}$C. The most efficient solution from the viewpoint of the efficiency of the system is the classical Gas Turbine Combined Cycle (GTCC) [2, 3].

1.2. Repowering of steam Power Plants

Repowering (RP) is broadly defined as an addition to or replacement of existing power plant equipment, re-

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taining serviceable permitted components to improve generation economics, extend life, improve environmental performance, enhance operability and maintainability, and more effectively use an existing site [4]. Repowering is the way to make it possible to continue using at least parts of older steam power plants that have become uneconomical. Moreover, repowering to a combined cycle can improve the efficiency of an existing plant to a level relatively close to that of new combined-cycle plants [5].

Repowering existing power plants with gas turbines can be a competitive option to increase power plant capacity, to improve efficiency and to decrease the environmental load for a better compliance with the more strict Environmental Regulations.

Repowering can lead to a better utilization of existing facilities and may save capital costs and costs for site development and licensing [6].

1.3. Repowering Methods

There are several alternatives to combine and integrate a gas turbine into an existing steam power plant. Repowering methods have two categories which are applicable in fossil fuel power plants.

A choice for one of the repowering options is on one side based on the size and the technical condition of the existing plant (i.e. the remnant life) and on the other side based on the typical needs of the utility [6].

1) repowering of nonsolid fuel power plants

2) repowering of solid fuel power plants

These methods can be divided into two main categories:

1) complete repowering

2) partial repowering (PR)

And partial repowering (PR) includes the following methods:

1) hot windbox repowering (HWBR)

2) feed water heating repowering (FWHR)

3) supplementary boiler repowering (SBR) [7].

1.4. Hot windbox repowering (HWBR)

Hot windbox repowering (HWBR) can be applied using 3 methods [8].

1) In the first method, the exhaust gas from a gas turbine is fed into the original boiler, and the oxygen (O_2) content of the exhaust gas is generally enough to fire the fuel particles. However, due to the high temperature of the exhaust gas, the burner section has to be upgraded with high-temperature-resistant materials. This method is called direct hot windbox repowering (Fig. 1)

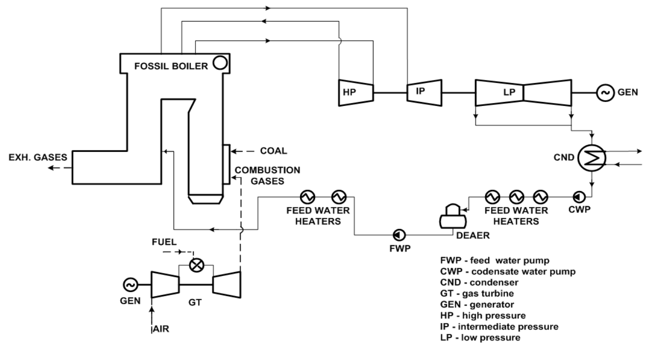

Figure 1: Direct hot windbox repowering

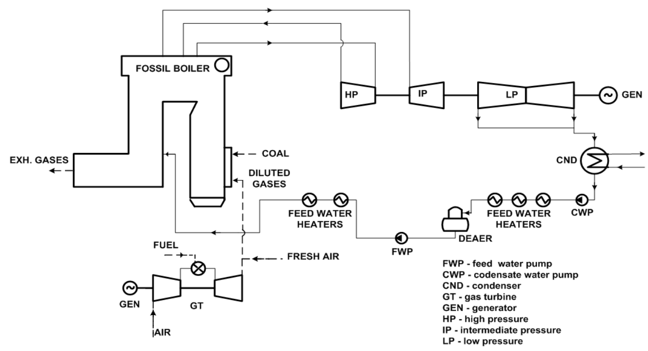

Figure 2: Fresh air dilution hot windbox repowering

2) In the second method, the exhaust gas can be diluted by fresh air to decrease the temperature of the combustion gases and to increase the oxygen (O_2) content of the gas stream. This method is called fresh air dilution hot windbox repowering (Fig. 2).

3) In the third option, to decrease temperature of exhaust gases and to avoid from costs for upgrade the burner section with high-temperature-resistant materials, the economizer is installed after gas turbine to obtain heating for feed water. This method is called precooling hot windbox repowering (Fig. 3).

In comparison to simple combined-cycle installations hot windbox repowering has some advantages:

- coal can be burned in the steam generator,
- part load efficiency is very good.

and the disadvantages:

- lower efficiency,
- higher investment costs,
- more complex installations, more difficult to operate and maintain, especially if the steam generator is coal-fired [9].

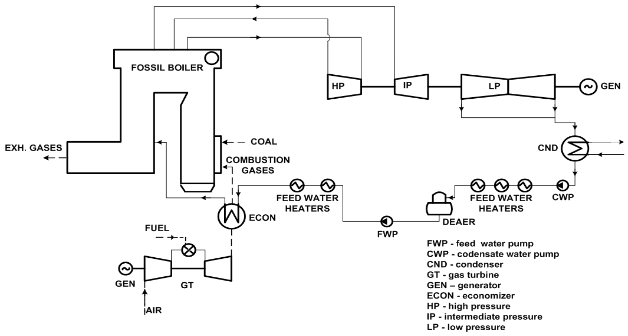

Figure 3: Pre-cooling hot windbox application

In this paper the first and the second methods of boiler hot windbox repowering have been researched, i.e., *direct hot windbox repowering and fresh air dilution hot windbox repowering*.

2. Software used for simulation

Mathematical modeling is the perfect way to establish the characteristics of the object, as well as to evaluate the technical optimization. For this purpose commercial General Electric software GateCycle [10] is used for design and performance evaluation of thermal power plant system at both design and off-design points. There is library with more than 100 gas turbines along with saved correction curves. This allows mathematical modeling of the power plant (gas turbine) to determine performance for conditions other than ISO or for variable load without the need for detailed data from vendor. In this paper the selected nine different gas turbines is applied using the GateCycle™ library. Although using the ready – made gas turbine models from GateCycle library the results of calculation are not very closed to the real parameters, because of some details have not taken into account (expander and combustion chamber cooling models), the paper has been written for academic case only and the purpose of the paper is to show the selecting process of the right gas turbine for repowering.

3. Description of the model before repowering and after repowering (design point)

The choice of gas turbine size and features for repowering an existing steam power plant depends on the behaviour of the steam plant when it is fed by both the existing fossil fuel source as well as by extra inlet thermal energies. As a consequence, it is necessary a preliminary analysis concerning the evaluation of the performance and the new working conditions of the steam plant when the thermal power discharged by the Brayton cycle gas turbine is supplied to the steam generator [11].

In the first, there was an existing steam cycle power plant with 200 MW nominal electric power, which consists of a fossil boiler with 0.55 GW heat load and 165 kg/s steam generating capacity and one 200 MW condensing steam turbine with 130 bar and 535 ^{o}C live steam parameters. Then based on the fraction of oxygen within exhaust gases, nine different gas turbine models were selected from GT Library for hot windbox repowering on that existing steam cycle power plant:

1. Centrax Gas Turbine Trent 60 DLE SC (GTW 2009) - A,
2. Alstom GT8C2 50Hz SC (GTW 2009) - B,
3. Hitachi PG6101(FA) SC (GTW 2009) - C,
4. Ansaldo Energia V64.3A SC (GTW 2009) - D,
5. GE Energy Heavy Duty PG7121 (EA) SC (GTW 2009) - E,
6. Westinghouse 401 (97 GT World) - F,
7. Siemens V84.2 -98 Vendor Data - G,
8. Mitsubishi M501DA SC (GTW 2009) - H,
9. GE Energy Oil&Gas MS9001E SC (GTW 2009) - I.

(In Fig. 6 - 10 selected gas turbines have been marked with letters from A to I).

In case of *direct hot windbox repowering* method the volume of oxygen within exhaust gases must be correspond oxygen consumption by fossil boiler. But in case of the second- *fresh air dilution hot windbox repowering* it is not necessary, because the quantity of diluted fresh air replenish that consumption.

Ambient parameters for all models of gas turbines are the same, inlet pressure and temperature are equal to 1.0132 bar and 15 ^{o}C, respectively in 60 % value of relative humidity. The fuel which has been used here is 100 % CH_4 and has 50044 kJ/kg Lower Heating Value (LHV).

In Table 1 performance parameters of these GTs were shown, where: Nel. - Net electrical power, Eff. - Gas turbine efficiency, CPR - Compressor pressure ratio, COT - Combuster outlet temperature, $G_{ex.g.}$ - Mass flow of exhaust gases after turbine, TAT - Temperature of exhaust gases after turbine, $O_{2\ m.\ fr.}$ - Oxigen mole fraction in exhaust gases.

Boiler part was developed by modeling fossil boiler and

Table 1: Performance parameters for GTs

	Nel.	Eff.	CPR	COT	Gex.g.	TAT	O2m.fr.
GT	MW	%	-	^{o}C	kg/s	^{o}C	%
1	50.5	38.7	35.9	1321.6	150.4	447.3	14.4
2	55.1	33.4	17.5	1211.3	195.4	511.4	14.1
3	69.9	34.1	14.9	1322.3	205.2	593.7	12.9
4	75.5	35.5	17.0	1352.7	211.6	590.1	12.9
5	82.8	32.1	12.6	1190.2	296.7	541.5	13.9
6	89.6	37.8	19.0	1366.7	227.2	582.3	12.6
7	107.7	33.6	10.9	1176.1	357.7	550.6	13.7
8	113.5	34.8	13.9	1249.5	345.6	543.6	13.3
9	122.9	33.2	12.5	1210.9	413.9	547.2	13.7

Table 2: Design parameters of fossil boiler

Heat load	GJ/s	0.55
Live steam pressure	bar	130
Live steam temperature	^{o}C	535
Steam generating capacity	kg/s	165.23
Secondary steam pressure	bar	29
Secondary steam temperature	^{o}C	535
Total fuel flow	kg/s	21.66

heat exchangers separately. The equipment was used as follows: fossil boiler, high pressure super heater (HPSH), intermediate pressure super heater (IPSH), economizer (ECON). There were also installed drum, splitters, pipes and temperature control mixers, which control steam temperature after HPSH and IPSH. The GT exhaust gas duct was connected to the boiler burners and supply oxygen for burning process. In steam cycle regime air is supplied to the boiler through two ducts: primary air duct and secondary air duct. But in combined cycle regime when the oxygen quantity within GT exhaust gas is enough for burning process in the boiler, those ducts were closed, but when it is not enough the primary air duct was partial opened.
In Table 2 were shown the design parameters of fossil boiler.

The steam turbine (ST) consists of three parts: high-pressure part (HPST), intermediate-pressure part (IPST) and low-pressure part (LPST). The efficiency of particular parts was calculated using the Design Efficiency Method and the Isentropic Expansion Efficiency was equal to 0.9 for all parts. The inlet steam pressure for all parts of steam turbine was calculated using the Design Pressure Method. For high pressure part the inlet pressure was fixed 130 bar but for next two parts was calculated automatically. These all calculation methods are available in GateCycle software. Steam turbine part

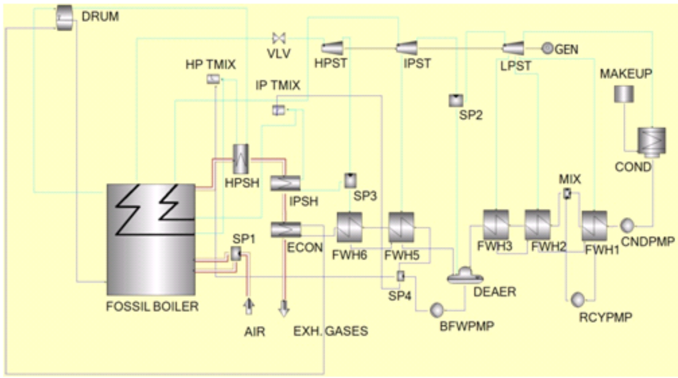

Figure 4: Model diagram of simulated power plant Before Repowering (BR): HPST - high pressure steam turbine, IPST - intermediate pressure steam turbine, LPST - low pressure steam turbine, COND - condenser, CNDPMP - condensate pump, RCYPMP - recirculation pump, MIX - mixer, FWH1,2,3,5,6 - feed water heaters №1,2,3,5,6, DEAER - deaerator, BFWPMP - boiler feed water pump, SP1,2,3,4 - splitter №1,2,3,4, ECON - economizer, HPSH - high pressure super heater, IPSH - intermediate pressure super heater, GEN - steam turbine generator AIR - ambient air, EXH. GASES - exhaust gases

was equipped with regeneration system, which consists of five feed water heaters (FWH) and deaerator (DA). Two FWH from five were installed in the high pressure part of feed water and three of them - in the low pressure part.

In Fig. 4 and in Fig. 5 there were shown accordingly model diagrams before repowering (BR) and after repowering (AR).

4. Results of calculations and analyzes (off- design)

In this section analyzes and calculation results of thermodynamic parameters of the model are presented after hot windbox repowering in off-design mode. The off design model is used mostly to simulate the behavior of a particular system in conditions different from the designed in order to access crucial parameters of that system in variable conditions.
1) Analyzes of thermodynamic parameters as well as carbon dioxide (CO_2) emissions of the power plant with selected nine different gas turbines after hot windbox repowering. Selection of the most suitable gas turbine for hot windbox repowering on 200 MW fossil fuel power plant.
2) Calculations of thermodynamic parameters of the power plant after repowering with selected GT in values 100 %, 90 %, 80 %, 70 %, 60 % of fossil boiler heat

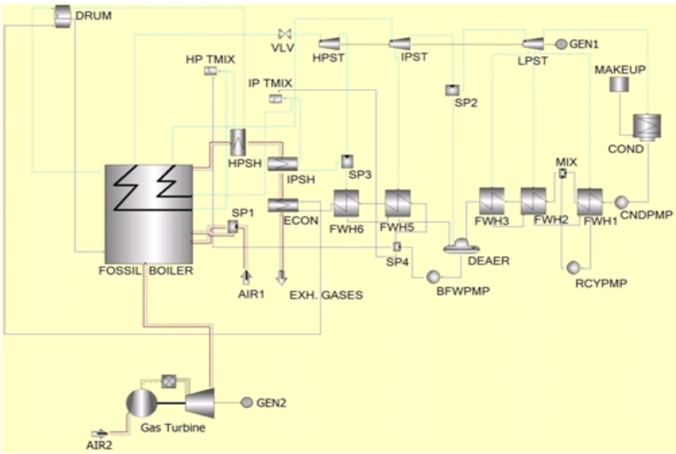

Figure 5: Figure 5: Model diagram of the simulated power plant After Repowering (AR): HPST - high pressure steam turbine, IPST - intermediate pressure steam turbine, LPST - low pressure steam turbine, COND - condenser, CNDPMP - condensate pump, RCYPMP - recirculation pump, MIX1,2,3 - mixer №1,2,3, FWH1,2,3,5,6 - feed water heaters №1,2,3,5,6, DEAER - deaerator, BFWPMP - boiler feed water pump, SP1,2,3,4 - splitter №1,2,3,4, ECON - economizer, HPSH - high pressure super heater, IPSH - intermediate pressure super heater, HP TMIX - temperature control mixer in high pressure part, IP TMIX - temperature control mixer in intermediate pressure part, GEN1 - steam turbine generator, GEN2 - gas turbine generator, AIR - ambient air, EXH. GASES - exhaust gases

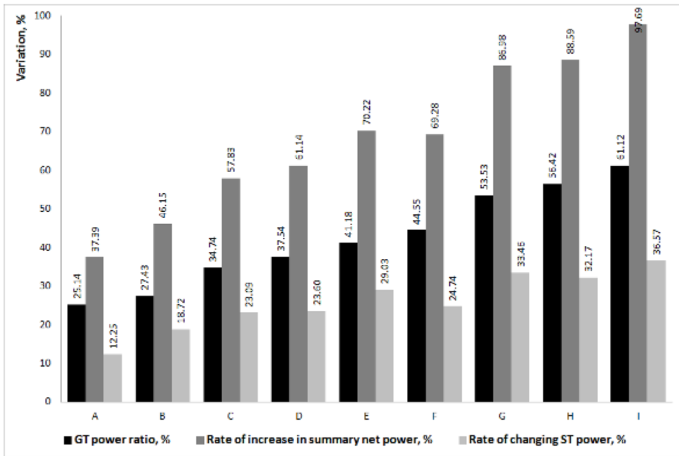

Figure 6: The variation of GT power ratio, rate of increase ST and CCPP power after repowering

load to show the advantage of hot windbox repowering in part loads.

Ad. 1.

In the first part thermodynamic parameters of the power plant model before and after repowering with selected nine different gas turbines were analyzed and then as a result were made charts, which describe the effect of direct hot windbox repowering, as well as the effect of fresh air dilution hot windbox repowering. Also carbon dioxide (CO_2) emissions were calculated before and after repowering. In the Figure 6, are shown values of GT power ratio (%), as well as rate of increase in steam turbine (ST) power (%) and increase in summary net power of combined cycle power plant (CCPP) (%) after repowering in case of nine different GT models.

-GT power ratio can be defined as the power value of added GT for repowering to the power value of existed steam cycle power plant (SCPP) before repowering, given in Eq. (1).

$$GT_{power\,ratio} = {}^{N_{GT}}/_{N_{SCPP BR}} \times 100\% \qquad (1)$$

The subscripts SCPP and BR symbolize steam cycle power plant after and before repowering, respectively.

-The rate of increase in ST power and the rate of increase in summary net power of CCPP can be defined as the power values of ST and whole power plant before repowering to the corresponding values after repowering.

So according to these charts after repowering in nine different cases, GT power ratio is changed from 25.14 % to 61.12 %, and the highest values of GT power ratio and the rate of increase in ST and CCPP power are available in case of GE Energy Oil & Gas MS9001E SC (GTW 2009) gas turbine (123 MW). They are equal to 61.12 %, 36.57 % and 97.69 % accordingly.

Actually after repowering (after adding a new gas turbine in the existing steam cycle) there is available the effect of increasing heat energy provided to the steam turbine, because of increasing the amount of heat energy provided to the steam boiler from gas turbine side.

There are two versions to use this effect:

- To stay stable with the fuel mass flow to the steam boiler and then to modernized the equipment of steam boiler and steam turbine. It means for example to enlarge the surface of heat exchange, to change the installation of steam turbine electrical generator and so on. In the result of this the power of steam turbine will be increased and therefore the power of combined cycle will be increased too.

- To decrease value of fuel provided to the steam boiler till the level in which case the power of steam turbine will be the equal to the previous one before repowering. In the result of this there is available the economy of fuel value to the steam boiler and increase the efficiency of combined cycle power plant.

In this paper the first version has been presented. As

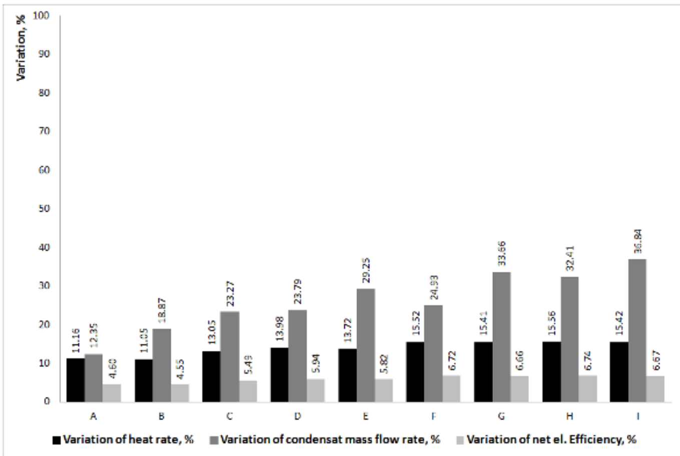

Figure 7: The variation of LHV heat rate, rate condensate mass flow rate and net electrical efficiency of CCPP after repowering in nine different cases

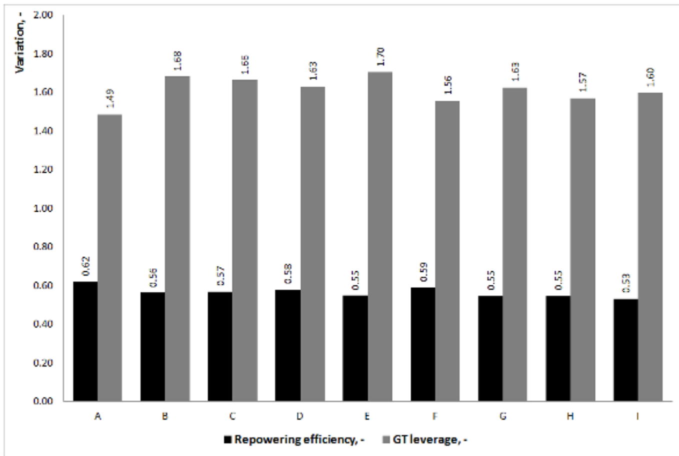

Figure 8: Repowering efficiency and GT leverage in nine different cases

it was above mentioned the authors wanted to show the effect of repowering on the power of steam turbine for academic case only.

In the Figure 7, LHV heat rate (%), condensate mass flow rate (%) and net electrical efficiency (%) variations were shown. According to the charts the highest variation or increase of net electrical efficiency was in case of Mitsubishi M501DA SC (GTW 2009) with 113.5 MW and was equal to 6.74 %. But for example the comparison of that value with variation or increase of net electrical efficiency in case of GE Energy Oil & Gas MS9001E SC (GTW 2009) gas turbine (6.67 %) which has the biggest capacity (123 MW), the difference is not so palpable, only 0.07 %.

Repowering efficiency and GT leverage were presented through charts in fig. 8. For the repowering analysis, gas turbine leverage and repowering efficiency are very important parameters. Repowering efficiency can be defined as the rate of increment in the electricity generation to the increment in the heat added to the cycle, given in Eq. (2).

$$\eta_{RP} = \frac{P_{AR} - P_{BR}}{Q_{in\,AR} - Q_{in\,BR}} \tag{2}$$

where P and Qin are the electric power and heat energy added to the cycle. Gas turbine leverage can be defined as the rate of increment in the electricity generation to the gas turbine installed capacity, given in Eq. (3).

$$\lambda_{GT} = \frac{\Delta P_{el}}{P_{el,GT}} = \frac{P_{AR} - P_{BR}}{P_{el,GT}} \tag{3}$$

The subscripts AR and BR symbolize after repowering and before repowering, respectively.

According to the charts in figure 8 the highest repowering efficiency was available in case of fresh air dilution hot windbox repowering with Centrax Gas Turbine Trent 60 DLE SC (GTW 2009) (50.59 MW) and was equal to 0.62, but the lowest repowering efficiency was available in case of direct hot windbox repowering with GE Energy Oil & Gas MS9001E SC (GTW 2009) (123 MW) and was equal to 0.53. The variation of GT leverage is changed from 1.49 to 1.70.

The charts in figure 9 show the values of mass flow of GT exhaust gases and primary air to the boiler, kg/s, as well as temperature of GT exhaust gases or GT exhaust gases and fresh air mixture (in case of the hot windbox repowering with fresh air dilution) directed to the burners of boiler.

According to these charts the GT models can be divided in two groups:

Hot windbox repowering with fresh air dilution group:

- Centrax Gas Turbine Trent 60 DLE SC (GTW 2009),
- Alstom GT8C2 50Hz SC (GTW 2009),
- Hitachi PG6101(FA) SC (GTW 2009),
- Ansaldo Energia V64.3A SC (GTW 2009),
- Westinghouse 401 (97 GT World),

And direct hot windbox repowering:

- GE Energy Heavy Duty PG7121 (EA) SC (GTW 2009),
- Siemens V84.2 -98 Vendor Data,
- Mitsubishi M501DA SC (GTW 2009),
- GE Energy Oil&Gas MS9001E SC (GTW 2009).

In the first case GT exhaust gases were diluted by fresh air. Last-mentioned decreases combustion gases

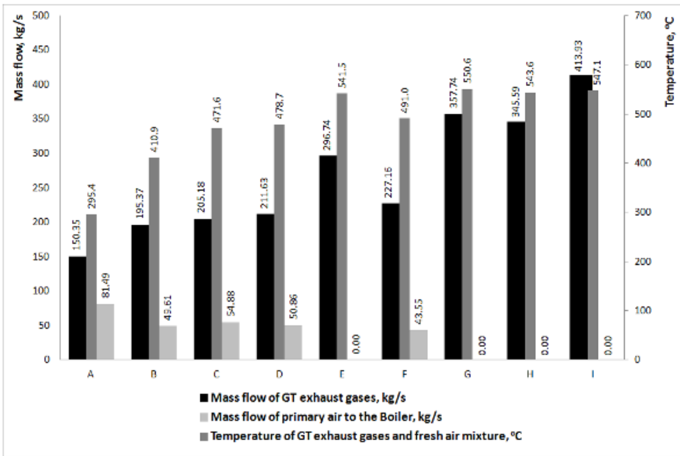

Figure 9: Variation of mass flow of GT exhaust gases and boiler primary air and the temperature of GT exhaust gases or GT exhaust gases and fresh air mixture (if it is needed)

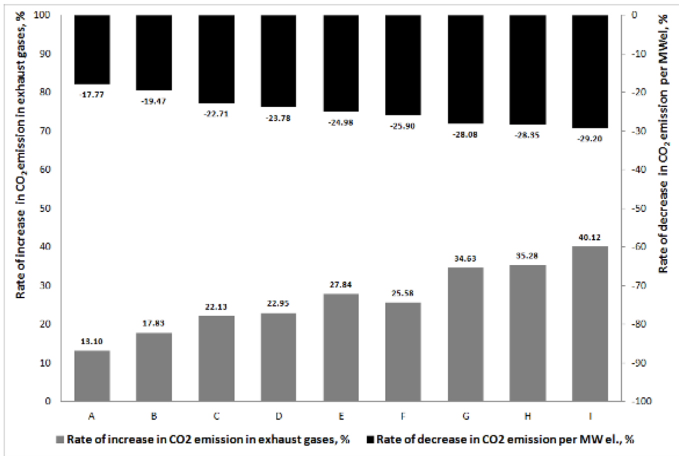

Figure 10: Rate of increase in carbon dioxide emission in exhaust gases and decrease in that emission producing per MW electrical power

temperature and increases the oxygen (O_2) content of the gas stream. In that case the burner section has not been upgraded with high-temperature-resistant materials, but disadvantage is that the spectrum of GT power is lower than in the direct hot windbox repowering.

In the second case mass flow of primary air to the boiler is equal to 0, because the oxygen (O_2) content of the GT exhaust gas is generally enough to fire the fuel particles. So in that case although the fresh air fans for fossil boiler were switched off and service power of power plant was decreased, due to the high temperature of the GT exhaust gases, the burner section has to be upgraded with high-temperature-resistant materials, which are additional capital costs.

So must be selected the optimal version of selection the most suitable GT, which will has bigger value of GT exhaust gases mass flow and exhaust gases lower temperature.

The lowest temperature (295.4 ^{o}C) of GT exhaust gases and fresh air mixture is available in the first case (Centrax Gas Turbine Trent 60 DLE SC (GTW 2009), but the value of GT exhaust gases mass flow (150.35 ^{o}C) and the electrical power (50.59 MW) is not bigger.

For example in the sixth case (Westinghouse 401 (97 GT World)) although the temperature of mixture is over 56 ^{o}C lower than in the ninth case (GE Energy Oil&Gas MS9001E SC (GTW 2009), the rate of increase in summary net power of CCPP is less than 28.41 % (Figure 6).

In the Figure 10 there was shown an interesting fact that although the fraction of CO_2 was increased by variation from 13.10 % to 40.12 % after repowering, CO_2 emissions in boiler exhaust gases per megawatt power was decreased by variation from 17.77 % to 29.20 %. This finding may indicate that it is possible to increase the installed capacity with reducing the pollutants emissions by hot windbox repowering of thermal power plants.

So summing up the calculations, it is noteworthy to mention once again that the main purpose of repowering is to increase power of an existing power plant using at least parts of older steam power plants that have become uneconomical. And that is why finally the ninth case has been selected: GE Energy Oil&Gas MS9001E SC (GTW 2009) - 123 MW. The highest value of GT power ratio - 61.12 %, the highest rate of increase in ST power value - 36.57 % (274.81 MW) and rate of increase in summary net power of CCPP - 97.69 % (397.8 MW).

In that case:

- variation of LHV heat rate was 15.42 % (2.312 kJ/kW-s),

- variation of condensate mass flow rate was 36.84 % (164 kg/s),

- variation of net electrical efficiency was 6.67 % (43.25 %),

- repowering efficiency was 0.53, - GT leverage was 1.60,

- mass flow of combustion gases (GT exhaust gases) was 413.93 kg/s (without fresh air dilution),

- temperature of combustion gases (GT exhaust gases) was 547.1 ^{o}C,

- rate of increase in CO_2 emission in exhaust gases was 40.12 % (45.46 kg/s),

- rate of decrease in CO_2 emission in exhaust gases in per MW electrical power was 0.29 % (0.1142 kg/s per

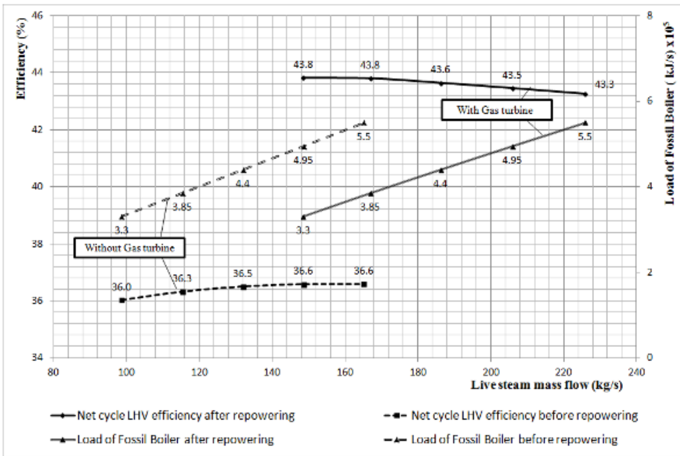

Figure 11: Variation of Electric Power in part loads

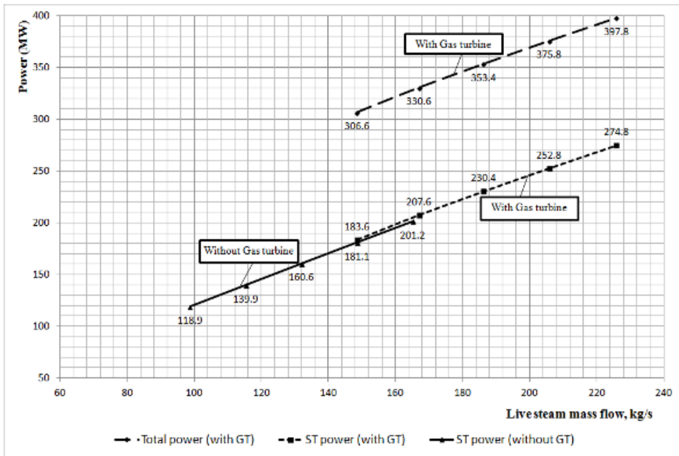

Figure 12: Net cycle LHV efficiency variation depending live steam mass flow in part heat loads of boiler

MW).

Ad. 2.

In the second part of analyzes after selected the most suitable GT for hot windbox repowering, fossil boiler heat load was decreased from 100 % to 60 % to establish the advantage of directed hot windbox repowering in part loads. Decreasing the heat load of boiler below from 60 %, gas turbine (GT) load have to be changed. In this paper only the effect of changing boiler heat load was discussed without changing GT load. To change the boiler heat load there was input manually the required value in “Boiler Load Method/Desired LHV Heat Load” section.

In the fig. 11 the electrical power values of steam cycle power plant (SCPP) were shown before repowering, as well as CCPP total electrical power and ST power values were presented after repowering depending on live steam mass flow in part loads of fossil boiler.

According to the curves in fig. 11 the variation of CCPP power was from 397.8 MW to 306.6 MW and within these limits live steam mass flow variation was from 225.9 kg/s to 148.5 kg/s.

In the last plot (Figure 12) were shown net cycle LHV efficiency (%) variation as well as fossil boiler heat load variation ((kJ/s)x10^5) in part loads before and after repowering. The highest efficiency was available in 60 % boiler heat load, and was equal to 43.8 %. In that case boiler heat load was 0.33 GW and live steam mass flow equal to 148.54 kg/s. This shows the advantage of Combined-Cycle power plants with direct hot windbox repowering. Such types of power plants have high efficiency in part-loads. It means during part-load regimes the heat of exhaust gases coming from GT can compensate heat balance when the mass flow of fuel at the inlet of boiler burner was decreased.

However the opposite fact of this effect is available. Without gas turbine, steam cycle power plant efficiency was decreased with decreasing boiler heat load. For example in 60 % boiler heat load the efficiency is decreased till 36.0 %, when live steam mass flow was 98.77 kg/s.

5. Conclusions

In this paper were presented analyses of the effect of hot windbox repowering of fossil fuel power plant with 200 MW and was selected the more suitable gas turbine for that power plant.

Calculations were performed in 2 parts:

1) Calculation and comparison of thermodynamic parameters as well as carbon dioxide (CO_2) emissions of power plant model before and after repowering in nine different cases (with nine different GT models).

2) Calculation of thermodynamic parameters of CCPP after repowering, i.e after adding GE Energy Oil&Gas MS9001E SC gas turbine with 123 MW in values 100 %, 90 %, 80 %, 70 % and 60 % of fossil boiler heat loads.

Based on the fraction of oxygen within exhaust gases, nine different gas turbine models were selected for hot windbox repowering.

For hot windbox repowering with fresh air dilution group:

- Centrax Gas Turbine Trent 60 DLE SC (GTW 2009),
- Alstom GT8C2 50Hz SC (GTW 2009),
- Hitachi PG6101(FA) SC (GTW 2009),
- Ansaldo Energia V64.3A SC (GTW 2009),

- Westinghouse 401 (97 GT World),

And for direct hot windbox repowering:

- GE Energy Heavy Duty PG7121 (EA) SC (GTW 2009),

- Siemens V84.2 -98 Vendor Data,

- Mitsubishi M501DA SC (GTW 2009),

- GE Energy Oil&Gas MS9001E SC (GTW 2009).

Then whereas the main purpose of repowering is to increase power of an existing power plant using at least parts of older steam power plants that have become uneconomical, has been selected *GE Energy Oil&Gas MS9001E SC (GTW 2009)* gas turbine with 123 MW.

In that case the highest value of GT power ratio was 61.12 %, the highest rate of increase in ST power value was 36.57 % (274.81 MW) and rate of increase in summary net power of CCPP was 97.69 % (397.8 MW). Net electrical efficiency of CCPP was 43.25 % (6.67 p.p. higher than before repowering).

Also CO_2 emission in exhaust gases was increased by 40.12 % (45.46 kg/s), was decreased by 0.29 % in per MW electrical power (0.1142 kg/s per MW) in comparison with results before repowering.

In part-loads net cycle LHV efficiency of combined cycle power plant was increased from 43.3 % to 43.8 %, when boiler heat load was decreased from 0.55 GW to 0.33 GW, whereas steam cycle LHV efficiency was decreased from 36.6 % to 36.0 %.

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