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Optimizing management of the condensing heat and cooling of gases compression in oxy block using of a genetic algorithm

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Abstract This paper presents the parameters of the reference oxy combustion block operating with supercritical steam parameters, equipped with an air separation unit and a carbon dioxide capture and compression installation. The possibility to recover the heat in the analyzed power plant is discussed. The decision variables and the thermodynamic functions for the optimization algorithm were identified. The principles of operation of genetic algorithm and methodology of conducted calculations are presented. The sensitivity analysis was performed for the best solutions to determine the effects of the selected variables on the power and efficiency of the unit. Optimization of the heat recovery from the air separation unit, flue gas condition and CO_2 capture and compression installation using genetic algorithm was designed to replace the low-pressure section of the regenerative water heaters of steam cycle in analyzed unit. The result was to increase the power and efficiency of the entire power plant.

Keywords: CO_2 capture and compression; Air separation unit; Flue gas conditioning; Genetic algorithm

1 Introduction

The main source of energy used in the production of electricity in Poland is coal. Its share in 2010 was almost 87% [1]. The popularity of this energy

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source mainly results from the large deposits, the availability and the low prices compared to the other fuels. The development of the clean coal technology is an key objective of the Polish energy sector. The increase of the net efficiency of electricity generation from coal, taking into account the environmental status allows the realization of this purpose [2,3].

The European Union specifies requirements for the reduction of the carbon emission. To meet the requirements is necessary to use the carbon capture and storage (CCS) installation. This technology allows for near zero emission of electricity production from coal. European trading system (ETS) for the CO_2 emission affects the development and introduction of CO_2 capture and storage [4].

The use of the carbon capture and storage is associated to the decrease of the net efficiency of the units. It is necessary to search for innovative concepts to increase the efficiency of the power plant. The development of the new separation methods, the use of the ultra-supercritical steam parameters and the search for less energy intensive chemical sorbents can greatly increase the net efficiency of the unit [5–8]. Another way to increase the power and efficiency of the unit is the management of heat recovery. The results of the optimizing management of the condensing heat and cooling of gases compression in oxy block using a genetic algorithm are presented in this paper.

2 Characteristic of the supercritical oxy unit

The oxy-type coal-fired unit is composed of a steam cycle, a pulverized coal-fired boiler [9], an air separation unit (ASU), a flue gas conditioning system (FGC) and a CO_2 capture and compression installation (CCI). Figure 1 shows a scheme of the supercritical oxy unit. The steam temperature at the inlet to the high-pressure part of the steam turbine is 873.15 K and a pressure is 29 MPa. The reheated steam has a temperature of 873.15 K and a pressure of 4.8 MPa at the inlet to the intermediate-pressure steam turbine. The temperature of the feed water at the inlet to the pulverized boiler is 570.15 K. Table 1 summarizes the characteristic values for the oxy coal unit on the supercritical steam parameters without heat integration. The values of parameters in the table have been determined on the basis of the unit shown in the literature [10]. The structure of the steam cycle of the supercritical oxy coal-fired plant was modeled in the commercial software GateCycle [14].

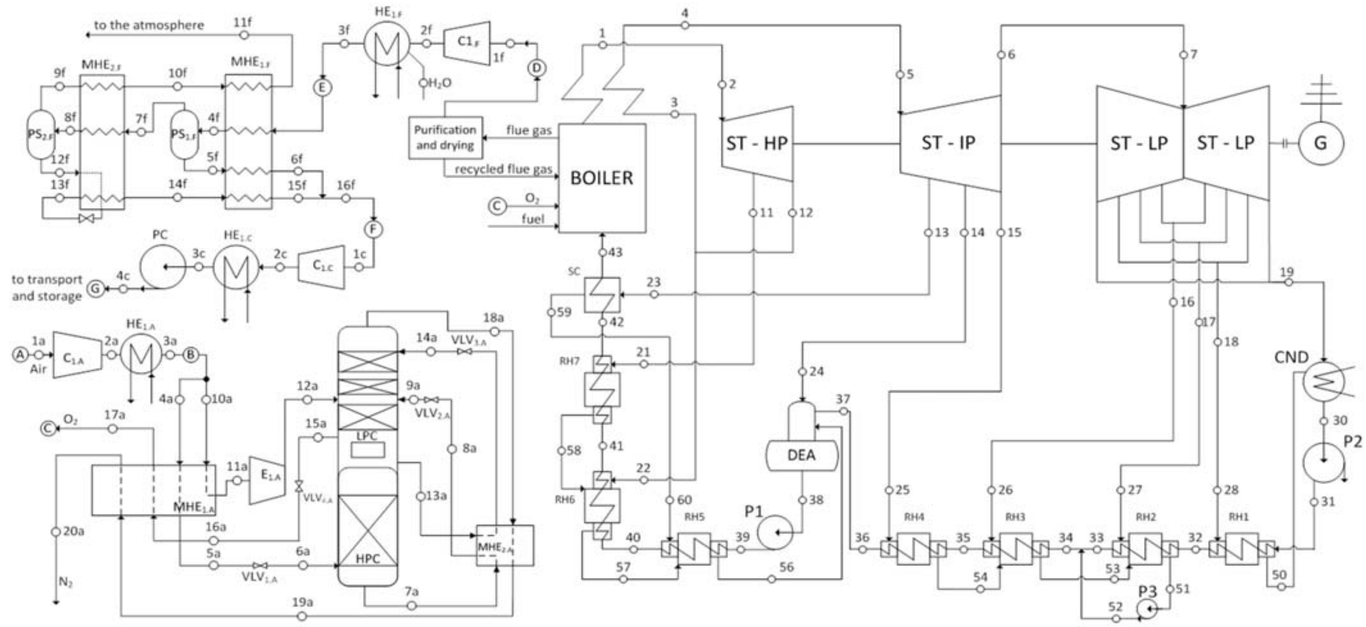

Figure 1. Scheme of the supercritical oxy coal-fired unit with cryogenic oxygen plant and CO_2 capture and compression installation. Steam cycle: Boiler – pulverized coal-fired boiler, ST – steam turbine (HP – high-pressure, IP – intermediate-pressure, LP – low-pressure), G – generator, DEA – deaerator, CND – condenser, $P_{1\div3}$ – condensate pump, $RH_{1\div4}$ – low-pressure regenerative heaters, $RH_{5\div7}$ – high-pressure regenerative heaters; FGC: $C1_f$ – gas compressor, HE_{1f} – heat exchanger; CCI: MHE_{1f-2f} – multi heat exchanger, $PS_{1f\div2f}$ – phase separator, C_{1c} – gas compressor, HE_{1c} – heat exchanger, PC – pump liquid CO_2; ASU: C_{1a} – air compressor, HE_{1a} – heat exchanger, $MHE_{1a\div2a}$ – multi heat exchanger, E_{1a} – expander, LPC – low-pressure column, HPC – high-pressure column, $VLV_{1a\div4a}$ – throttle valves.

Net electrical efficiency of the unit ($\eta_{el.n}$) depends on the gross electrical efficiency of the unit ($\eta_{el.g}$), the overall rate of power demand of the compressors (δ_1) and the rate of the auxiliary power demand (δ_2) according to the formula:

$$\eta_{el.n} = \eta_{el.g} \left(1 - \delta_1 - \delta_2\right) \ . \tag{1}$$

Table 1. Characteristic values of the oxy combustion supercritical unit (BASE variant).

Parameter	Value
Gross power, MW	460.00
Heat flux to the steam cycle, MW	911.50
Boiler efficiency, %	93.12
Chemical energy of fuel, MW	978.85
Gross efficiency, %	46.99
Auxiliary power of ASU, MW	83.27
Auxiliary power of FGC, MW	34.08
Auxiliary power of CCI, MW	15.80
Total auxiliary power of compressors, MW (Eq. 3)	133.15
The all compressor auxiliary power rate, % (Eq. 2)	28.95
Auxiliary power of remaining installations, MW	28.66
The rate of auxiliary power of remaining installations, %	6.23
Net power, MW	298.21
Net efficiency, % (Eq. 1)	30.46

The auxiliary power of the compressors (δ_1) has been calculated as the ratio of the total power demand of compressors (N_1) to the gross electrical power ($N_{el.g}$)

$$\delta_1 = \frac{N_1}{N_{el.g}} \ . \tag{2}$$

The total power demand of the compressors was calculated as a sum of the power demand of the gas compression installation ($N_{aux.ASU}$, $N_{aux.FGC}$, $N_{aux.CCS}$) according to the equation:

$$N_1 = N_{aux.ASU} + N_{aux.FGC} + N_{aux.CCI} \ . \tag{3}$$

Auxiliary power rate results from the auxiliary power of pumps in the steam cycle and in boiler area from the auxiliary power of coal mill and fans.

3 Characteristics of the optimization objects

Integration of the supercritical coal-fired unit with the installation of air separation and the CO_2 capture and compression installation causes a decrease of the net efficiency to the level of 30.46%. In order to increase the power and the net efficiency of the unit a few concepts of the heat management were implemented.

In the block structure shown in Fig. 1 we can indicate three heat recovery locations. The first such a place is the section of the air compression in the air separation unit. Next location is to recover heat from the compression section of the exhaust gases to the conditioning system (FGC), located just before the installation of CO_2 capture. Another heat recovery source is the section of gas compression (mainly CO_2 – 92.37%) for the preparation of carbon dioxide for the transport.

The objective of the optimizing management of heat recovery is replace the low-pressure section of regenerative heat exchangers (RH 1–4) in the steam cycle of the analyzed unit. The replacement of the low-pressure section of regenerative heat exchangers causes the power increase as well as the net efficiency of the unit. Figure 2 shows the increase of the gross power due to the replacement of one, two, three or four low-pressure heat exchangers in the steam cycle of the supercritical plant. The gross power of the unit is plotted against water flow fraction from steam cycle directed to the installation of heat recovery.

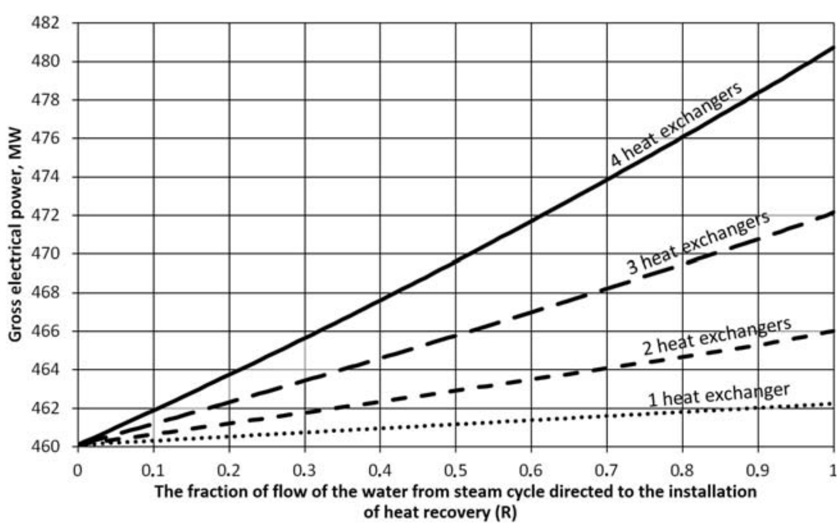

Figure 2. The gross power of the block as a function of the water flow fraction from steam cycle directed to the installation of heat recovery.

In the case of the replacement of the four low pressure regenerative heat exchangers there is an increase of the gross power of the unit of 20.7 MW.

The fraction of the water flow R from the steam cycle directed to the installation of heat recovery is defined as the water flow ratio (see Figs. 3, 4, and 5 respectively for ASU, FGC and CCI):

$$R_{ASU} = \frac{\dot{m}_{120}}{\dot{m}_{31}} , \tag{4}$$

$$R_{FGC} = \frac{\dot{m}_{140}}{\dot{m}_{31}} , \tag{5}$$

$$R_{CCI} = \frac{\dot{m}_{160}}{\dot{m}_{31}} , \tag{6}$$

where $\dot{m}_{31}$ is the water stream directed to the low-pressure regenerative heaters in steam cycle, $\dot{m}_{120}$, $\dot{m}_{140}$, and $\dot{m}_{160}$ are the water streams directed to the heat recovery from the gases compression section (ASU, FGU and CCI), respectively. The water temperatures in two characteristics points of low-pressure regenerative system are the same regardless of the optimization results. It is assumed that the water temperature at the inlet of the first heat exchanger and at outlet of the fourth heat exchanger are respectively: 306.13 K and 423.33 K.

Gas compression sections in commercial software GateCycle [14] were modeled. Optimizing management of the condensing heat and cooling of gases compression for the three variants of gas compression (four, three and two gas compressors) was considered. The isentropic efficiency of the gas compressors at the level 0.85 was assumed. The optimization of the heat recovery in relation to the water flow fraction directed from the steam cycle to the heat recovery installations ($R_{ASU}, R_{FGC}, R_{CCI}$) was conducted. In Fig. 3 the structure of air compressor with cooling system is shown. A scheme of a heat recovery section of the gas compressors which is part of the flue gas conditioning system is shown in Fig. 4, and in Fig. 5 a scheme of the section of gas compressors in CCI is presented respectively. In each section, the compression in the installation of heat recovery uses subcooling exchangers ($\text{HE}_{1.1X}$, $\text{HE}_{2.1X}$, $\text{HE}_{3.1X}$, $\text{HE}_{4.1X}$, where X denotes ASU, FGC, CCI, respectively) in order to better subcooling of the gas at the inlet to the compressor. Received heat is dispersed in the environment.

In each of the three analyzed heat recovery variants, a bypass has been applied. Its function is to maintain the required water temperature at the outlet of the low pressure section of the heat exchangers (423.33 K). When the refrigerant temperature at the outlet of the heat recovery section ($T_{130/150/170}$) has a temperature higher than the predetermined temperature

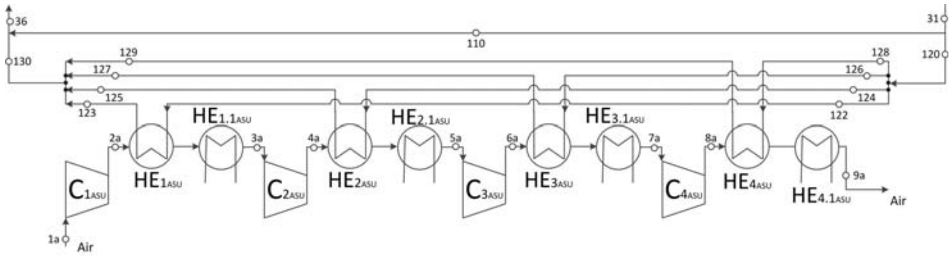

Figure 3. The air compressors section in ASU installation.

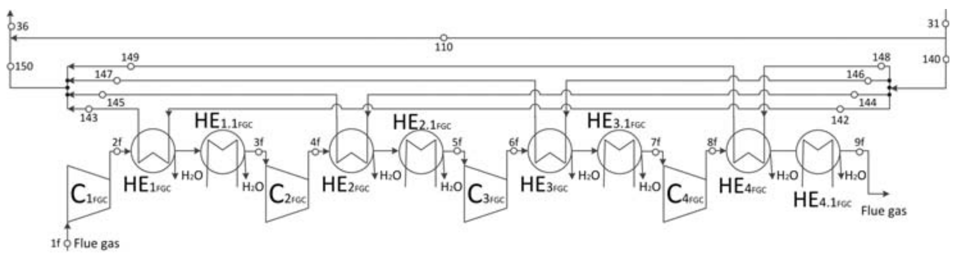

Figure 4. The gas compressors section in FGC installation.

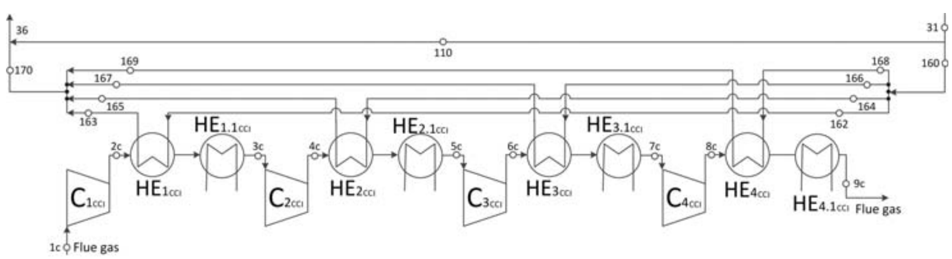

Figure 5. The gas compressors section in CCI installation.

of the steam cycle (T_{36}) the bypass is activated. In the bypass the fluid having temperature (T_{31}) and the mass flowrate (m_{110}) is added so that the mixing of streams of water reached temperature (T_{36}), which results from the initial temperature profile of the condensate flowing through the system of regeneration in the reference unit. Table 2 summarizes the parameters for all considered installation, while Tab. 3 shows the molar composition of the gases compressed in FGC and CCI.

Table 2. The parameters of the compressed gas in ASU, FGC and CCI.

Quantity	ASU	FGC	CCI
Gas temperature at the inlet to the installation, K	288.15	319.22	306.75
Gas pressure at the inlet to the installation, kPa	101.33	101.33	2424.00
Gas flow at the inlet to the installation, kg/s	361.64	102.62	92.24
Gas temperature at the outlet of the installation, K	303.15	303.15	303.15
Gas pressure at the outlet of the installation, kPa	600.00	3648.00	15000.00
Gas flow at the outlet of the installation, kg/s	361.64	98.10	92.24

Table 3. Composition of the gas at the inlet to the compressor $C1_{FGC}$ (at the point 1_f) and to the compressor $C1_{CCI}$ (at the point 1_c).

Substance	FGC	CCI
Carbon Dioxide	0.790	0.924
Oxygen	0.050	0.034
Nitrogen	0.016	0.007
Sulfur Dioxide	0.006	0.007
Water	0.100	0.003
Argon	0.038	0.025

4 Thermodynamic objective function of the genetic algorithm

The genetic algorithm objective is to minimize the auxiliary power (N_{aux}) of the gas compression section in the heat recovery installations (ASU, FGC CCI) at a given water flow fraction ($R_{ASU}, R_{FGC}, R_{CCI}$):

$$(N_{aux.ASU})_R \rightarrow \min \;, \tag{7}$$

$$(N_{aux.FGC})_R \rightarrow \min \;, \tag{8}$$

$$(N_{aux.CCI})_R \rightarrow \min \;. \tag{9}$$

In order to facilitate the work of the genetic algorithm the form of the objective function was converted. In this way, the objective function is defined as the difference ($N^*_{el.n}$) between gross power when replacing respective amount of low-pressure regenerative heat exchangers at the given water flow fraction ($R_{ASU}, R_{FGC}, R_{CCI}$) and auxiliary power of respective installation of compressed gases:

$$[N_{el.g} - N_{aux.ASU}]_R = N^*_{el.n.ASU} \rightarrow \max \;, \tag{10}$$

$$[N_{el.g} - N_{aux.FGC}]_R = N^*_{el.n.FGC} \rightarrow \max \;, \tag{11}$$

$$[N_{el.g} - N_{aux.CCI}]_R = N^*_{el.n.CCI} \rightarrow \max \;. \tag{12}$$

The objective function is to maximize the difference represented by Eqs. (10), (11) and (12) for the optimization algorithm is a function of the following decision variables:

- The fractions of water stream r_Y, for Y = 122, 124, 126, 142, 144, 146, 162, 164, 166) from the steam cycle of power plant directed to the heat exchangers (HE_{1X}, HE_{2X}, HE_{3X}, where X denotes ASU, FGC, CCI) in heat recovery systems.
- The pressure ratios (β_{C1X}, β_{C2X}, β_{C3X}) in gas compressors (C_{1X}, C_{2X}, C_{3X}), where $\beta_{C1\text{-}3X} = \sqrt{p_{out}/p_{in}}$ (p_{out} – the pressure at the outlet of the compressor, p_{in} – the pressure at the inlet of the compressor).
- The effectiveness ($\varepsilon_{HE1X}, \varepsilon_{HE1.1X}, \varepsilon_{HE2X}, \varepsilon_{HE2.1X}, \varepsilon_{HE3X}, \varepsilon_{HE3.1X}$, ε_{HE4X}) of heat exchangers (HE_{1X}, $HE_{1.1X}$, HE_{2X}, $HE_{2.1X}$, HE_{3X}, $HE_{3.1X}$, HE_{4X}).

The parameter r means the water flow fraction directed to the heat exchanger in heat recovery installation. The water flow fraction (r_{128}, r_{148}, r_{168}) directed to the heat exchanger HE_{4X} is treated as a variable dependent on the resultant of the three water flow fractions directed to the other heat exchangers. A similar situation exists when the pressure ratio in the gas compressor C_{4X}, which depends on the other three decision variables (the pressure ratios) in gas compressors ($\beta_{C4X} = \beta_A/(\beta_{C1X} \cdot \beta_{C2X} \cdot \beta_{C3X})$). The effectiveness of the heat exchanger $HE_{4.1X}$ in the decision variables in the thermodynamic optimization was not included, since it does not affect the auxiliary power of installation. However, the effectiveness of this heat exchanger in the economic analysis will be affected. The decision variables and their range of variation for the respective installation are shown in Tab. 4.

The optimization calculation conducted using the genetic algorithm were conducted with the following constraints:

Table 4. The ranges of values of dimensionless decision variables.

No.	Decision variables	ASU		FGC		CCI	
		min.	max	min	max	min	max
1	$r_{122,142,162}$	0	1	0	1	0	1
2	$r_{124,144,164}$	0	1	0	1	0	1
3	$r_{126,146,166}$	0	1	0	1	0	1
4	β_{C1}	1	5.921	1	36.002	1	6.188
5	β_{C2}	1	5.921	1	36.002	1	6.188
6	β_{C3}	1	5.921	1	36.002	1	6.188
7	ε_{HE1}	0.5	0.99	0.5	0.99	0.5	0.99
8	ε_{HE2}	0.5	0.99	0.5	0.99	0.5	0.99
9	ε_{HE3}	0.5	0.99	0.5	0.99	0.5	0.99
10	ε_{HE4}	0.5	0.99	0.5	0.99	0.5	0.99
11	$\varepsilon_{HE1.1}$	0.5	0.99	0.5	0.99	0.5	0.99
12	$\varepsilon_{HE2.1}$	0.5	0.99	0.5	0.99	0.5	0.99
13	$\varepsilon_{HE3.1}$	0.5	0.99	0.5	0.99	0.5	0.99

- The water temperature at the outlet of the heat recovery system T_{130}, T_{150}, $T_{170} \geq T_{36}$.
- The vapor quality at the outlet of the heat exchangers $X_Z = 0$ (where $Z =$ 123, 125, 127, 129, 143, 145, 147, 149, 163, 165, 167, 169)
- The total pressure ratio (β_{AX}) of gas compressors:
  - for ASU: $5.921 \geq \beta_{C1ASU} \cdot \beta_{C2ASU} \cdot \beta_{C3ASU}$,
  - for FGC: $36.002 \geq \beta_{C1FGC} \cdot \beta_{C2FGC} \cdot \beta_{C3FGC}$,
  - for CCI: $6.188 \geq \beta_{C1CCI} \cdot \beta_{C2CCI} \cdot \beta_{C3CCI}$,
    when $\beta_{C1X} \cdot \beta_{C2X} \cdot \beta_{C3X} = \beta_{AX}$ than $\beta_{C4X} = 0$.

5 The optimization of genetic algorithm

The objective of the optimization functions of several decision variables is to achieve the maximum value of the net electrical power of oxy unit (Eqs. (10)–(12)). The calculations of the genetic algorithm built in VBA (Visual Basic) environment in Microsoft Office Excel 2007 were conducted. Genetic algorithm with commercial GateCycle ver. 5.40.0.r program was integrated.

Genetic algorithms are random optimization methods. They are based on the rules of heredity and characterized by a high efficiency in multidimensional tasks. In the optimization algorithm there are three operators: selection, crossing and mutation [11–13]. Figure 6 shows a block diagram of genetic algorithm optimization activities. The work of the genetic algorithm starts by sampling the selection of the population of 20 individuals. The individual is a collection of 13 decision variables of which the values are within the ranges specified in Tab. 4. Members of the population (individuals) in which the decision variables did not obtain of the limiting conditions, were automatically eliminated from the process optimization. The objective function is assigned to each individual in the population. An individual featuring the extreme of the objective function is selected and moved on the road of elitism to the next population. Genetic operators create 19 new sets of variables (individuals). Every time, after creating a new population, the algorithm determines the value of the objective function for all elements of the population. An individual with a less preferred extreme is replaced by an individual with the best extreme of the population. In addition, the probability of mutation was set at 2% and the probability of uniform crossover of two progeny at 25%.

6 The results of thermodynamic optimization

Gas compression sections were studied for three variants gas compressors in relation to the water flow fraction ($R_{ASU}, R_{FGC}, R_{CCI}$) from a steam cycle of a power plant directed to the heat recovery unit. For each variant, the genetic algorithm chose the first generation of 20 individuals by drawing lots. In the absence of 20 individuals discovered in the 15000 draws for section of compression with a given amount of the compressor and the water stream fraction ($R_{ASU}, R_{FGC}, R_{CCI}$), no solution was stated. Then the optimization system was reduced by one gas compressor. In the case of the first population drawn for a given fraction of the water stream ($R_{ASU}, R_{FGC}, R_{CCI}$) the optimization followed, then the same variant of section of compression was optimized for increased water flow fraction by 0.1. In case over 300 generations, the algorithm could not find an individual with a more favorable extreme of the objective function – the optimization process was completed.

The genetic algorithm for all studied variants of gas compression sections in heat recovery installations generated optimal values of the decision variables for which the objective function showed the extreme. Table 5 summarizes the optimal values of the decision variables with heat recovery systems. Figure 7 shows the work result of a genetic algorithm in search of the objective function extreme. This result is for the air compression section with two compressors at the water flow fraction directed to heat

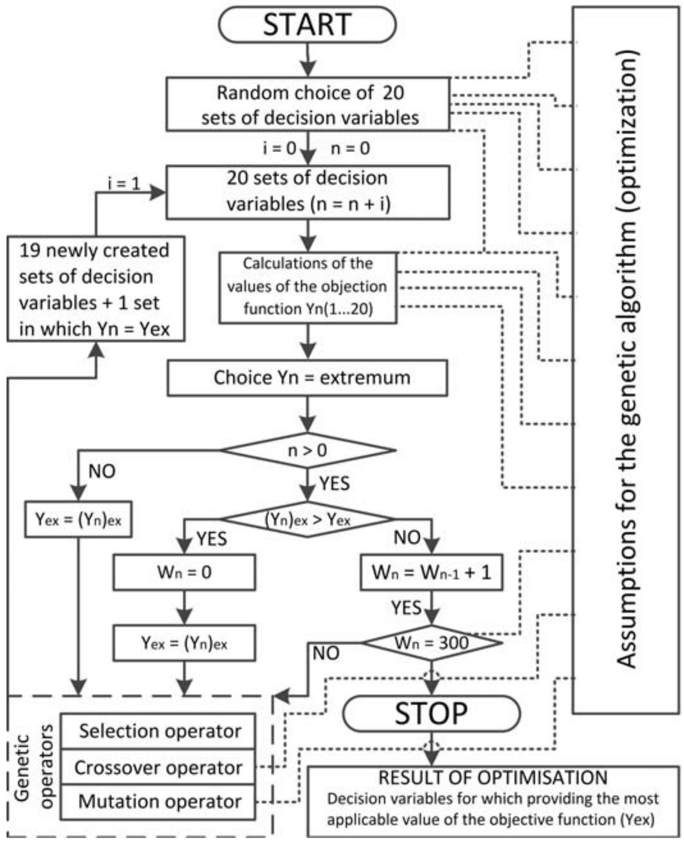

Figure 6. The block diagram of the genetic algorithm.

recovery system from ASU ($R_{ASU} = 0.5$).

Additionally, in order to illustrate the impact of each decision variable on the net power of the unit, as objective function of the above-described variant, the sensitivity analysis was performed. In the course of investigations subsequently each decision variable was varied within the range of relative values ($\frac{\Delta x_i}{x_{i_{opt}}} = \frac{x_i - x_{i_{opt}}}{x_{i_{opt}}}$, where x_i – deviation from optimal value, $x_{i_{opt}}$ – optimal value of decision variable) from -0.2 to 0.2, the other quantities remaining unchanged at the optimal level. The results shown in Fig. 8 reveal that the greatest influence on the objective function value is the pressure ratio in the first compressor and the effectiveness of the heat exchanger located just before the second air compressor.

Combinations of respective optimal solutions (see in Tab. 5) can be

Table 5. The optimal values of the decision variables.

		ASU					FGC					CCI		
Variant		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
Compressors		2					3		2			3	2	
Fraction of water flow (R)		0.1	0.2	0.3	0.4	0.5	0.1	0.2	0.1	0.2	0.3	0.1	0.1	0.2
1	$r_{122,142,162}$	1	1	1	1	0.91	0.14	0.03	0.94	0.72	0.53	0.96	1	1
2	$r_{124,144,164}$	–	–	–	–	–	0.86	0.96	–	–	–	0.02	–	–
3	$r_{126,146,166}$	–	–	–	–	–	–	–	–	–	–	–	–	–
4	β_{C1}	3.31	3.31	3.31	3.47	4.08	1.59	1.63	4.13	4.17	6.74	5.67	4.89	3.99
5	β_{C2}	–	–	–	–	–	5.5	11.2	–	–	–	1.06	–	–
6	β_{C3}	–	–	–	–	–	–	–	–	–	–	–	–	–
7	ε_{HE1}	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
8	ε_{HE2}	–	–	–	–	–	0.99	0.99	–	–	–	0.99	–	–
9	ε_{HE3}	–	–	–	–	–	–	–	–	–	–		–	–
10	ε_{HE4}	0.91	0.79	0.72	0.93	0.99	0.64	0.73	0.75	0.85	0.87	0.78	0.83	0.69
11	$\varepsilon_{HE1.1}$	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
12	$\varepsilon_{HE2.1}$	–	–	–	–	–	0.99	0.99	–	–	–	0.99	–	–
13	$\varepsilon_{HE3.1}$	–	–	–	–	–	–	–	–	–	–	–	–	–
Water flow in bypass, kg/s		0.02	0.02	0.03	0.15	0.21	0.03	0.01	8.21	9.61	0.01	0.85	4.65	2.60
Net power, MW		385.3	387.2	389.1	390.6	390.7	430.4	430.9	427.0	428.9	430.1	446.5	446.1	449.3
Auxiliary power demand, MW		76.53	76.50	76.48	76.92	78.91	31.46	32.82	34.87	34.82	35.54	15.41	15.73	14.42

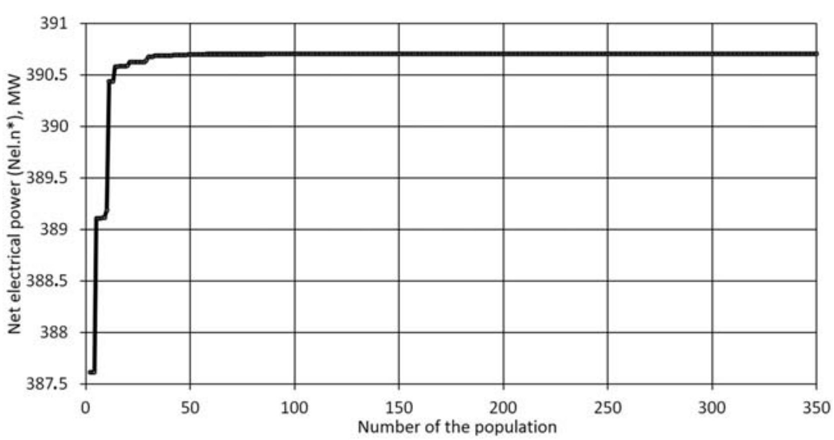

Figure 7. The result of the genetic algorithm optimization.

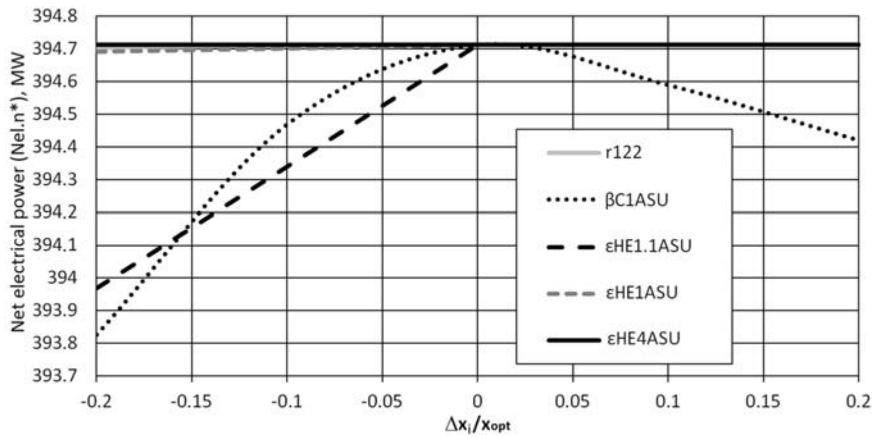

Figure 8. The sensitivity analysis of the decision variables on the value of the objective function.

implemented in the area of one system. Table 6 summarizes the three optimized combinations of variants (from Tab. 5) in relation to the basic unit (from Tab. 1), in order to compare the net efficiency gains of the unit.

Table 6. Summary of the characteristic parameters for the combination of heat recovery variants.

Parameter	Value			
Variant	BASE	D+J+M	D+G+M	E+G+M
Fraction of water flow (R)	0.00	0.90	0.80	0.90
Gross power, MW	460.00	478.33	476.05	478.33
Gross efficiency, %	46.99	48.87	48.63	48.87
Auxiliary power of ASU installation, MW	83.27	76.92	76.92	78.91
Auxiliary power of FGC installation, MW	34.08	35.54	32.82	32.82
Auxiliary power of CCS installation, MW	15.80	14.42	14.42	14.42
Total auxiliary power of compressors, MW	133.15	126.88	124.16	126.15
Aux. power of remaining systems of oxy-power plant, MW	28.66	28.66	28.66	28.66
Net power, MW	298.21	322.79	323.23	323.52
Net efficiency, %	30.46	32.98	33.02	33.05

7 Conclusions

Genetic algorithms allow optimization of multi-variable design parameters of installation and power units. For the analyzed unit genetic algorithm handled the 13 decision variables. As one of the random optimization methods, this method is characterized by high effectiveness.

In the optimization of the recovery of heat from the air compression section of the ASU in the variants with four and three-section air compressor no solutions were achieved which was caused by the lack of the first population of 20 individuals in 15000 draws of the algorithm. A variant with the two-sectional air compressor allowed for minimizing the auxiliary power of the optimized installation to the level of 78.91−76.53 MW at the fraction of mass flow directed to heat exchangers $R_{ASU} = 0.5$. Maximum net power at the unit for $R_{ASU} = 0.5$ is $N^*_{el.n} = 390.7$ MW.

To optimize the recovery of heat from the gas compression section of the FGC in variants with four-section gas compressor gave no results which was caused by the lack of the first population of 20 individuals in 15000 draws of the algorithm. A variant of the three-section gas compressor allowed for minimizing the auxiliary power of the optimized installation to approximately 32.82−31.46 MW at the fraction of mass flow directed to heat exchangers $R_{FGC} = 0.2$. Maximum net power for $R_{FGC} = 0.2$ is $N^*_{el.n} = 430.9$ MW. Auxiliary power of the FGC installation in variant with three-section gas compressor is 35.54 MW for $R_{FGC} = 0.3$.

The optimization of the recovery heat from the gas compression section in the CCI in variants with four-section gas compressor gave no solutions. Auxiliary power of the CCI for three gas compressors and water flow fraction $R_{CCI} = 0.1$ is 15.41 MW. In the case of two gas compressors and water flow fraction $R_{CCI} = 0.2$, the auxiliary power is equal to 14.42 MW.

In the case of the replacement of all four low-pressure water heaters in the steam cycle of the power plant with heat management from the installation of ASU, FGC and CCI – the net efficiency of unit can be increased by 2.59 percentage point to around 33.05%. Maximum net efficiency was reached for the combination of variants E+G+M (variants from Tab. 5) at approximately 33.05% for the fraction of water flow $R = 0.9$.

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