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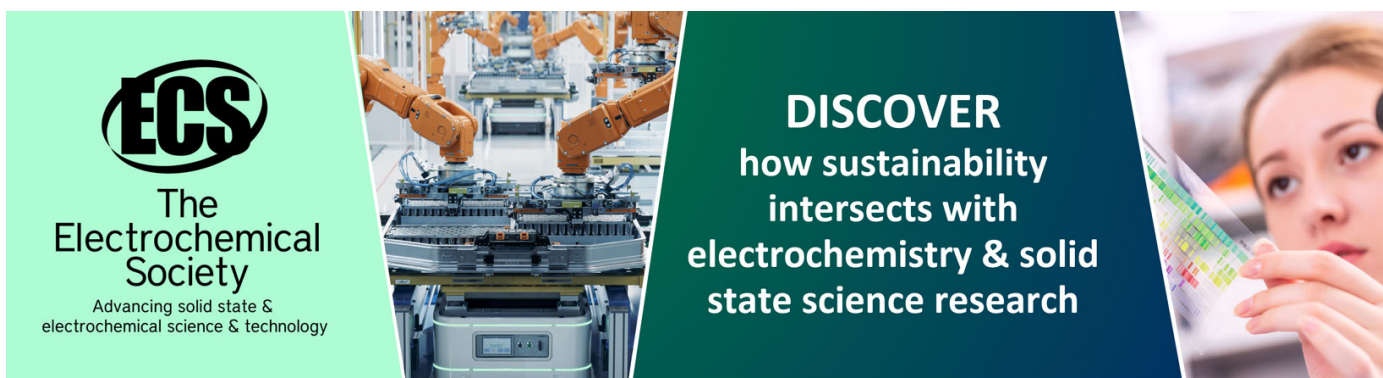
## Program control of the group of boilers at chp plants (chpps)

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# Program control of the group of boilers at chp plants (chpps)

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**Abstract.** At Krasnoyarsk CHPP-2, there emerged a necessity of supplying heat to consumers faster in cold months because even short-term absence heating can be critical. The main challenge is to execute complex control process for all boilers at the same time to ensure their gradual heating or cooling. In order to solve this problem, it is suggested to create program control. The software that needs to be created should quickly (7-9 minutes) change the power and control their operation in a timely manner in case of any changes, taking into account the individual specifications of each boiler. Final testing and examination are proposed to be carried out on the created CHPP model.

## 1. Introduction

The purpose of work is to create a program solution for the effect of false buildup of boilers. The program must respond to load change in a timely manner in order to try to prevent even minimal effects of buildup of boilers.

The controlled unit is a system consisting of six boilers, a turbine and a main steam lead. It is worth to remark that boilers have different sizes and loading capacities. Therefore, their inputs into the temperature and pressure of the entire system as a whole are different. For example, with an increase in coal feeding by 1%, a large boiler causes a much greater variation in temperature and increase in pressure than with an increase in the feeding of a small boiler by 1%.

These conditions complicate the control task, in which the program must control and maintain the pressure in the main steam lead, regardless of the parameters of each boiler in particular, and their number.

The relevance of this work lies in the fact that boilers at cross-connection CHPPs are controlled manually. An operator is assigned to each boiler and monitors it.

Boilers that exist at the moment of this study are very inert. A lot of time is needed to heat the boiler up or to decrease its temperature by reducing the coal feeding. This is done in order not to overcontrol them in aggregate and to prevent large pressure differentials in the main steam lead [1]. Operators slowly bring them to full operating capacities (22 minutes) and, in the same way, manually control them while maintaining a specified pressure.

There emerged a necessity of supplying heat to consumers faster in cold months because even short-term absence heating can be critical. But until the whole system is controlled manually and quite uncentralised it is not possible to meet this need.

Tracking mode is a mode, in which everything is controlled by programmatic means. The load of certain boilers is kept unchanged in order to eliminate unnecessary fluctuations. Theoretically, operators



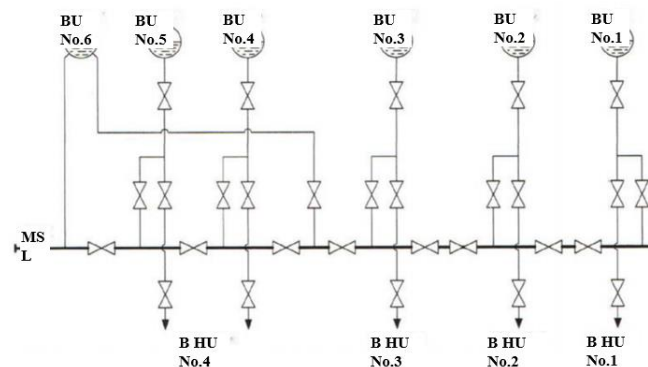
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can increase the rate of heat supply by increasing the turbine speed. But this is prohibited by management. Power fluctuations on the turbine are economically unprofitable and reduce the efficiency of the system increasing energy consumption. Also wear of equipment increases.

The software that needs to be created should quickly (7-9 minutes) bring them to full operating capacities and control their operation in a timely manner in case of any changes, taking into account the individual specifications of each boiler. For example, when changing the load of the turbine or when it is necessary to turn off one of the boilers, it is necessary to evenly distribute the load between the remaining boilers [2].

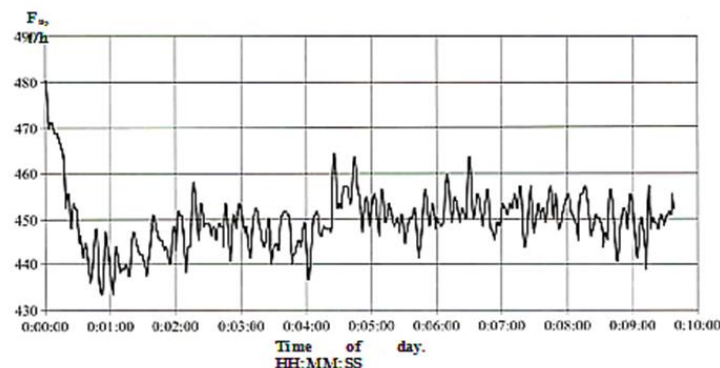
6 boilers of Krasnoyarsk CHPP-2 have different performances. 4 of them are small and 2 are large. The model represents 4 boilers only. A written script must easily and flexibly adapt to any number of boilers.

The flow sheet of the main steam lead of Krasnoyarsk CHPP-2 is shown in figure 1. It can be seen from the flow sheet that the boiler units can operate both on a common steam lead and separately (unit-type). During unit-type switching ON or OFF of the main steam lead sections, each of its separate sections shall maintain constant pressure [3].

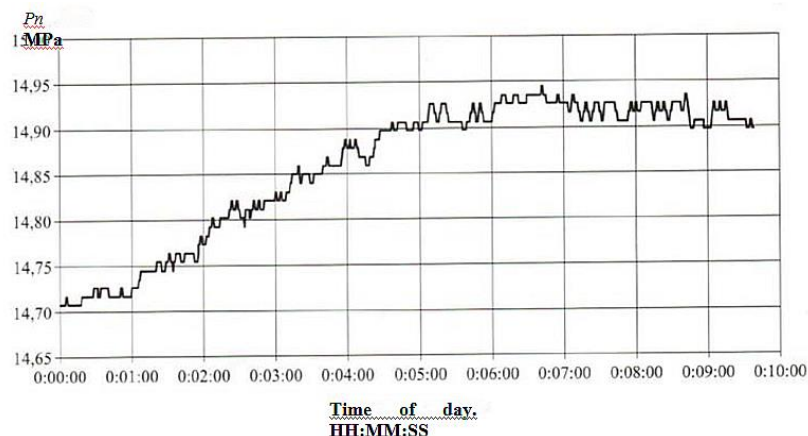


**Figure 1.** Boilers at CHPP-2.

The control systems for the heat load of boilers are implemented according to the “task - heat” scheme. The “heat” signal is formed from two signals: steam flow and pressure variation rate in the boiler drum. The principal drawback of such structure of controller is that when the pressure in the main steam lead (external disturbances) changes, the pressure in the boiler drum changes with a significant delay, which makes it impossible to achieve signal invariance in terms of “heat” to external disturbances.



**Figure 2.** Steam flow rate curve behind the boiler.



**Figure 3.** Steam pressure in the drum.

Steam flow rate curve behind the boiler and steam pressure chart in the drum of the boiler with increasing pressure in the main steam lead by 0.3 MPa (external disturbance) are shown in figure 2 and 3. It can be seen from the figures that in steady-state mode the steam flow rate behind the boiler decreases, although, during the testing, the heat load of the boiler did not change. As a result, in order to restore the previous steam flow rate behind the boiler, the heat load controller (HLC) will increase the fuel supply to the boiler furnace, while to reduce the pressure in the main steam lead, it is necessary to reduce the fuel supply to the boiler. This effect of the “false” operation of the heat load controller is due to the fact that with an increase in pressure in the MSL, the steam density increases and its volumetric flow rate decreases. The steam flow sensor behind the boiler actually measures the volumetric flow rate of the steam, not the mass flow rate [4].

Currently, the rated electric power of the station is 465 MW, the rated heat power is 1405 Gcal/h.

At the time of writing this work, the boilers at CHPP-2 are manually controlled. The operators spend about half an hour to heat up the boilers and bring them to their operating capacity. The target duration of this process is 7 minutes. One of the main obstacles to reach this speed is the false operation of the boilers.

Theoretically, the pressure can also be controlled by a turbine, which can quickly push the excess steam further through the system or, vice versa, by reducing its speed, allow the steam to accumulate in the main steam lead to reach the required pressure.

But the problem is that changes in the turbine speed are very undesirable for its correct operation and are very energy-consuming.

Usually, in order to maintain steam pressure in a common steam lead at cross-connection CHPPs, a control circuit is used when one of the boilers is in a control mode and, according to the pressure sensor installed in the common steam lead, maintains pressure in the main steam lead. The remaining boilers, being in the basic mode, maintain their specified steam loads [5].

The generally accepted structure of the main controller has not been widely used at cross-connection CHPP for the following practical reasons:

There is one pressure tapoff point in the main steam lead, which does not allow to effectively control the pressure with different composition of operating boilers and turbines, as well as with the release of sections of the steam lead for repair [6];

When changing operating boilers, it is necessary to adjust the coefficients of the main controller;

The values of the adjusting coefficients of the main controller for all boilers cannot be the same, since the dynamic properties of the cascade controller MC-HLC are different for all boilers, therefore the values are attached to the addresses. Code fragment:

```
# constants.py
WATCHDOG = 2000
GPM_PRESS_MUL = 150
```

```
GPM_PRESS = 2200
CONS_TURBINE_MUL = 10
CONS_TURBINE = 2201
CONS_ROU_MUL = 100
CONS_ROU = 2202
POWER_OUT_MUL = 10
POWER_OUT = 2203
RTN_MUL = 100
RTN_OUT = 2000
# address = param_address + k_num
K1 = 1
K2 = 2
K3 = 3
K4 = 4
RTN_ADD_TASK_MUL = 10
RTN_ADD_TASK = 2010
PSU_FREQ_MUL = 1
PSU_FREQ = 2210
CONS_STEAM_AFTER_MUL = 10
CONS_STEAM_AFTER = 2220
BAR_PRESS_MUL = 100
BAR_PRESS = 2230
INT_TASK_MUL = 10
INT_TASK = 2240
TRACE = 2100
AUTO = 2300
```

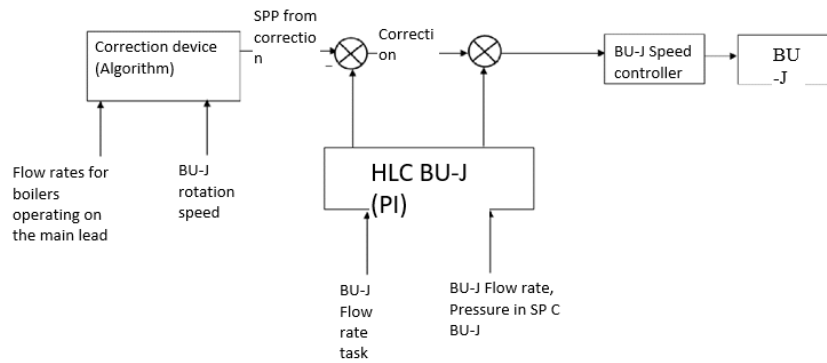
## 2. Preliminaries

When the turbine increases speed, part of the boilers also start to be fed with coal, the speed of the steam particles increases, the steam flow meter shows an increase in flow (according to the physical measurement principle of beaded flow-meters: particle speed increased - flow increased - volumetric steam flow). The proportional and integral parts begin to accumulate noncompliance with the specified task (exceeding this task). In this case, the HLC of the static boilers will begin to reduce the coal feeding speed - this is a false response, while the appropriate behaviour shall be at least to maintain the same rotational speed, since the mass flow rate of the steam remains the same. As a result of such false operation there is a decrease in mass flow rate and additional pressure drop that sums up with already existing pressure undershoot that was caused by the load set in accordance with the procedure. When the load is dropped by the turbine, a false response manifests in increased fuel rate triggered by the underrated flow rate (due to a decrease in the speed of the steam particles), while in the main lead the pressure begins to increase due to the decrease in the load of the turbines and, in addition, the pressure increases due to false operation [7].

The result is as follows:

- increased risk of pressure fluctuations beyond the acceptable thresholds, which are defined in technical specification as specified value  $\pm 2$ .
- regular false responses cause the threshold values of coal-pulverization system rotation rate to be not respected (above or below the threshold values) more often.
- longer time needed to reach nominal operation performances due to time spent for stabilisation. False responses affect the dynamics of boilers that change loads.
- wear. Excessive jogging of the operating mechanisms is unlikely to be beneficial, which indirectly shortens the interval between repairs.

CU (controlling unit) - tracking the current situation according to the process data (figure 4), an algorithm for calculating the correction value of SPP/PPL rotation speed for each boiler. The correction algorithm is activated only if external disturbances from other boilers are detected when the load of the station changes and is active only for boilers, the task for the HLC of which remains unchanged. Adaptive adjustment of HLC coefficients may or may not take place.



**Figure 4.** Integration chart for the correction algorithm with the operation of controllers.

### 3. Method

HLC correction algorithm to prevent false operation:

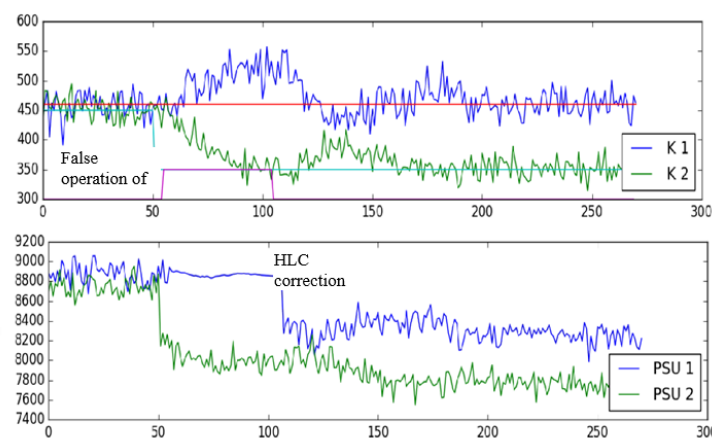
1. Calculation of the aggregate load of boilers (tasks for HLC).
2. Detection of points of significant change in the total tasks on the HLC.

Verification that of condition for the detection of false response is met for the detection of false operation), and when it is carried out, the correction block for the HLC operation is switched on [8].

1. Correction of SPP speed for boilers, task for which did not change at the moments of significant change in the total tasks for the HLC: instead of SPP speed calculated by the controller, average SPP speed for a period of a given length before the moment of false response is given [9].

2. The number of SPP speed calculated by the controller is replaced by the average value of the number of speed for a given period before the start of the controller's false operation.

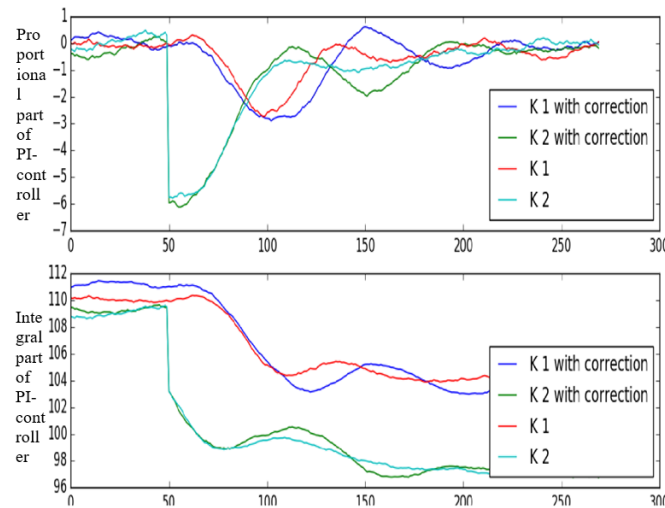
3. Correction continues for a given time period, after which the correction block is switched off (the time period for each boiler must be selected so as to reflect its dynamics). Or the switch-off time of correction is selected by the discrepancy of the boiler flow rate, for which the task is changing [10].



**Figure 5.** Diagram of the simulation model - Inclusion of a criteria, correction of speed, flow rate model at speed correction.

Example. Real data reflect the behaviour of the unit and its controllers (figure 5, 6) but in order to check the operation of the correction algorithm for the false operation of the HLC, the unit and the controller must be separated. Therefore, a simulation unit that consists of 2 boilers is considered: when changing the task for one of the boilers, the HLC of the second boiler starts to operate falsely [11].

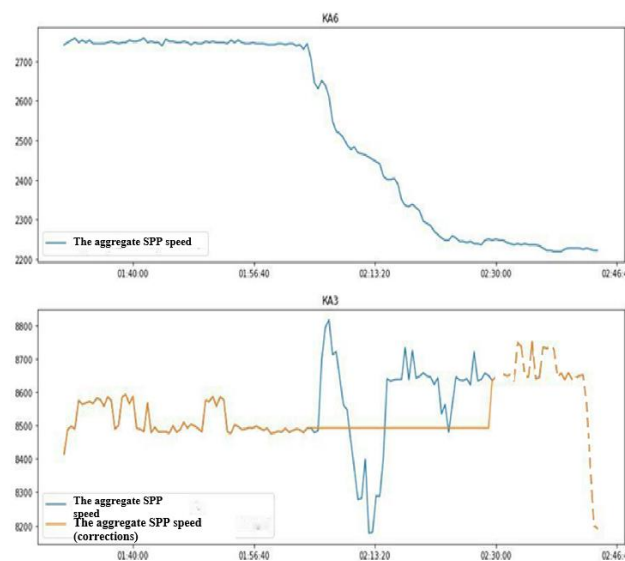
Moreover, the figures show the values of the proportional and integral components of the controller with switching on the correction of its false operation and without it.



**Figure 6.** Diagrams of operation of boilers with and without correction.

Thus, when HLC and its correction is simultaneously switched on in automatic mode, the proportional part of the controller changes in accordance with the change in the flow rate at the corrected SPP value. The integral part of the controller accumulates, which affects the operation of the controller and leads to a sudden change in the boiler flow rate after switching off the correction [12].

4. The correction of SPP speed takes place until the end of the transition processes of boilers, for which the task for HLC was changed [13].



**Figure 7.** The result of the PPL speed correction algorithm.

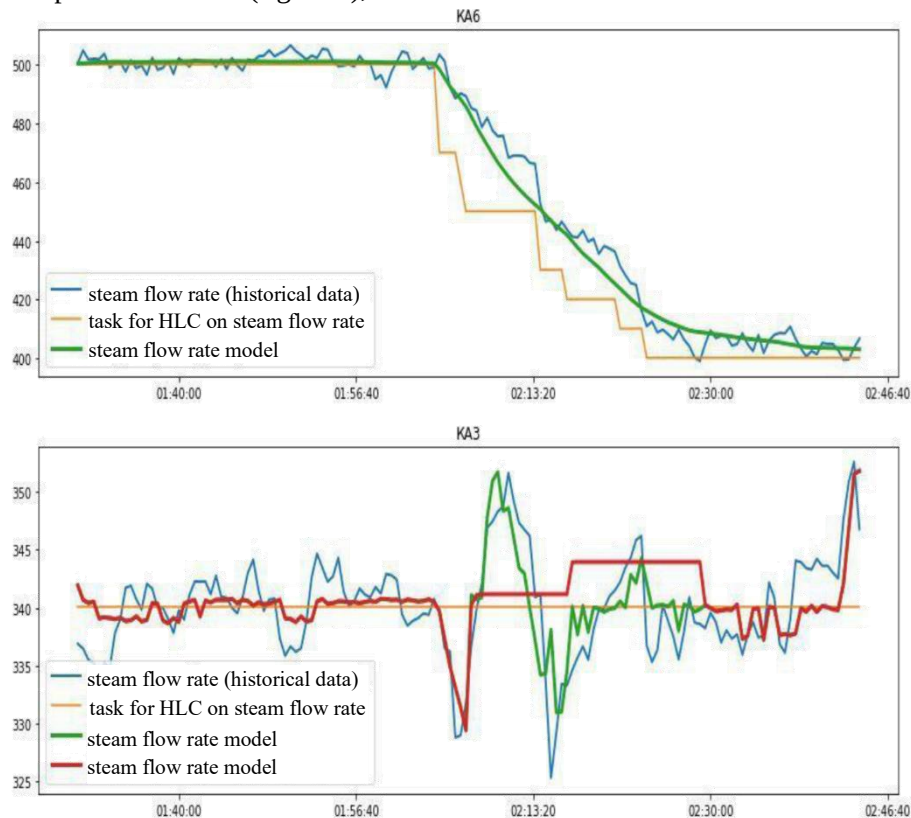


At the forced keeping of BU-3 speed at the moment of the BU-6 load change, there can be obtained the following scenario (a random error was not introduced in the speed correction section but the speed spreading mechanism will add it in practice).

In figure 7, the dashed line reflects the real PPL data, and not that obtained after switching off the correction of false response, since without a unit (or its model) it is impossible to simply calculate the change in PPL using data [14].

After stabilization of the BU-6 mode, the correction algorithm comes to the standby mode until the load changes by other boilers. The algorithm is connected to the HLC of each boiler, and, in a manner of speaking, protects against false response by monitoring the load of other boilers.

The estimate picture is below (figure 8), how the correction can affect the steam flow rate of BU-3:



**Figure 8.** The reaction of the model to the speed correction for BU-3.

In order to eliminate the described defects in the operation of heat load controllers, the following changes to the structural flowcharts of the controllers were proposed:

1. To use the mass steam flow rate as a steam flow rate signal behind the boiler, calculated according to a formula (1)

$$F_m = F_v \rho \quad (1)$$

where  $F_m$  is the calculated mass steam flow rate, kg/h;

$F_v$  is the volumetric steam flow rate obtained at the flow-measuring knot, m<sup>3</sup>/h;  $\rho$  is the density of overheated steam vapour calculated according to a formula;

$$\rho = \frac{73,874969\pi}{\tau Z} \quad (2)$$



where  $t = (t+273.15)/647.14$  is the reference temperature, ( $t$  - temperature, C0);  $\pi$  is the reference pressure,  $\pi = P/22,064$  ( $P$  is the absolute pressure, MPa);  $Z$  is the compression coefficient of overheated steam vapour

$$Z = 1 + \pi \left( \frac{0,4409392}{\tau} - \frac{1,386598}{\tau^2} + \frac{0,7644377}{\tau^3} - \frac{0,7644377}{\tau^4} \right) + \pi^2 \left( \frac{56,40548}{\tau} - \frac{297,0161}{\tau^2} + \frac{617,8258}{\tau^3} - \frac{634,747}{\tau^4} + \frac{322,8009}{\tau^5} - \frac{65,45004}{\tau^6} \right) + \pi^3 \left( \frac{149,3651}{\tau} - \frac{895,0375}{\tau^2} + \frac{2123,035}{\tau^3} - \frac{2488,625}{\tau^4} + \frac{1439,213}{\tau^5} - \frac{327,7709}{\tau^6} \right) + \pi^4 \left( \frac{151,1386}{\tau} - \frac{967,3387}{\tau^2} + \frac{2478,739}{\tau^3} - \frac{3178,106}{\tau^4} + \frac{2038,512}{\tau^5} - \frac{523,2041}{\tau^6} \right)$$

2. To use the signal of the rate of pressure change in the steam collection chamber of the boiler instead of the signal of the rate of steam pressure change in the boiler drum, which allows to reduce the delay in the change in pressure under external disturbances.

It can be seen from figures 9-10 that with a steam flow rate “undershoot” behind the boiler at 13 t/h, the “heat” signal deviates from the initial value by 3 t/h. This permits to get rid of or at least to reduce the effect of “false” operation of the heat load controller under external disturbances [15].

The database of the CHPP-2 model was stored on the server and all its main parameters (boiler feeding, steam pressure, turbine speed, etc.) were available through certain registers in ModBus.

“ABB Freelance” hardware and software suite allows to work with the model manually and to track changes in the entire system graphically.

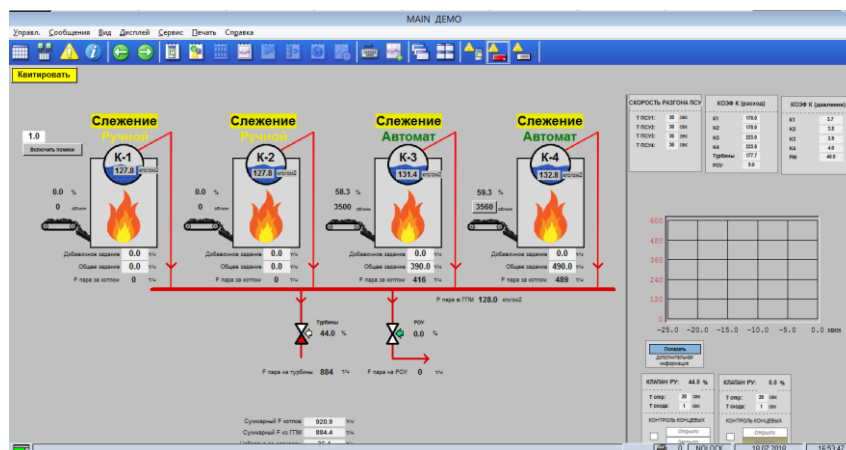


Figure 9. Appearance of the "ABB Freelance" hardware and software suite (HSS).

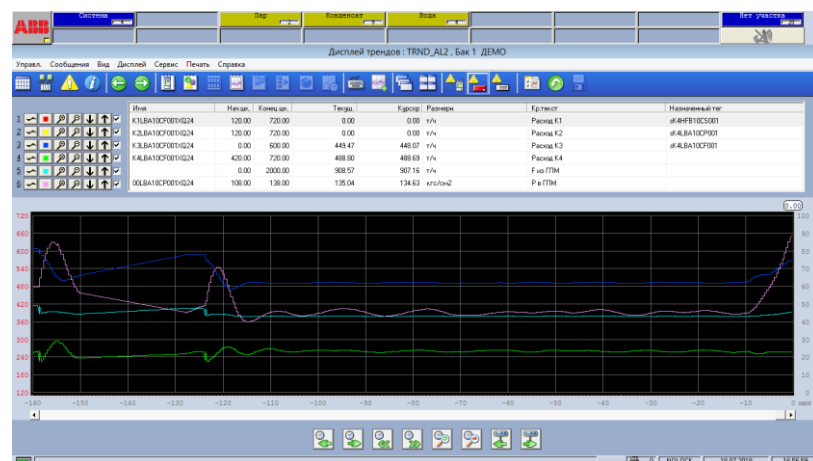


Figure 10. Graphs of changes in boiler loadings.

In addition, not all options are available through registers but at the same time they are available in ABB. The program gets access to the model and data only when connected to the enterprise network [16].

Also, it is possible to change the system coefficients there, for example, the dynamics of boilers and turbine. This allows to make the model maximally representative of a real unit.

The option that is responsible for connecting to the server:

Listing 1 - Connection options.

```
def
fit(self):
loop = asyncio.get_event_loop()
conn = OPCConnection(host='192.168.32.93', port=50200, read_interval=5, loop=loop)
conn.set_trace()
conn.start(self._read_callback)
try:
loop.run_until_complete(conn.wait())
finally:
conn.stop()
loop.close()
```

Work with the server was implemented through ModBus-server, which was the connecting link between the server and the program, since working with ModBus is much simpler than with a server. This is not a standard but convenient solution, which is quite enough to work with the model [17].

For example, in order to enable the tracking mode, it is necessary to put a value from 0 to 15 into the register 2100. When converting this number from the decimal to binary system, the unit will have those digits that you need to enable tracking [18].

In other words, if number 15 is put into register 2100 (1111 in binary form), tracking on all boilers will be obtained (figure 11).

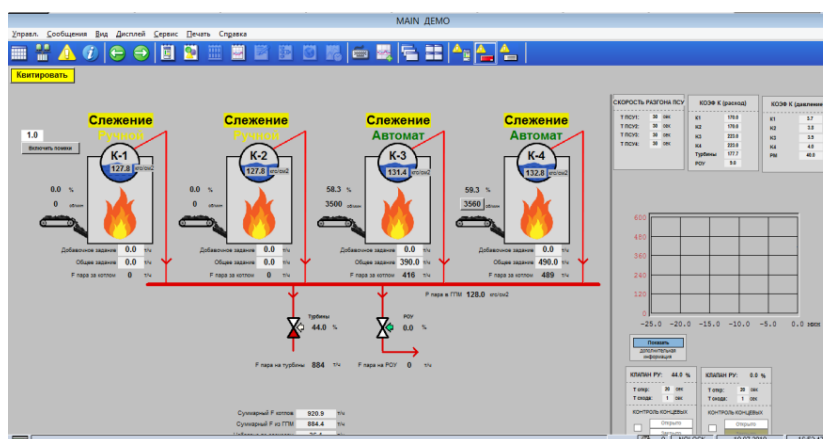


Figure 11. Launching the program.

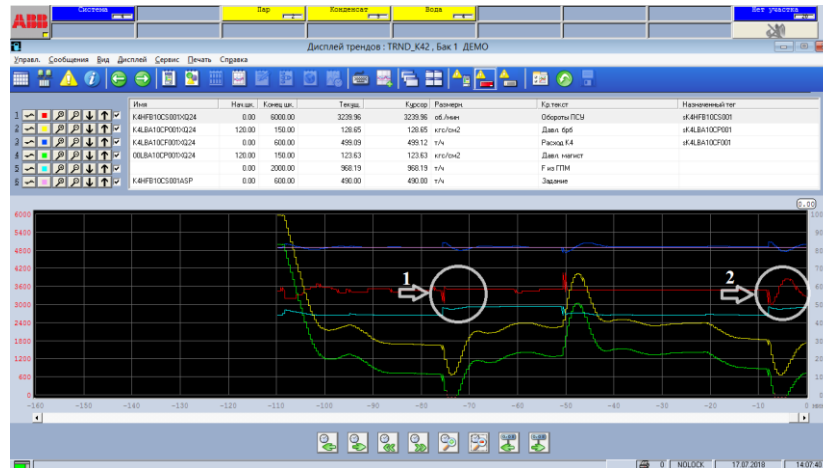
The database of the CHPP-2 model was stored on the server and all its main parameters (boiler feeding, steam pressure, turbine speed, etc.) were available through certain registers in ModBus.

A script that has been already designed at the enterprise allowed to turn on the tracking mode, in which false operation was eliminated on the boilers by recording the speed of the steam power plant (SPP) [19].

#### 4. Experimental Settings and Results

In figure 12, the readings of boiler No.4 are shown. In the second case, the “buildup” is shown, i.e. false operation and load change in SPP. In the first case, a program was launched that recorded SPP speed of

55 cycles, in response to a change in the load of the turbine and boiler [20]. This reduced the pressure differentials in the MSL by 33%.



**Figure 12.** Graphs with and without the program.

But for the timely elimination of false operation it was necessary to change the principle of its recognition by the program. Initially, the deviation of two average amounts of boiler feeding was considered. Then, it was decided to consider any deviation as a signal to eliminate false operation.

The following values were selected for the experiments:

Initial turbine mode - 44%, final mode - 49%

The maximum turbine opening to 100% is equivalent to 2000 tons of steam.

Therefore, the load change on boiler No.3, which was selected for controlling, should be 100 tons.

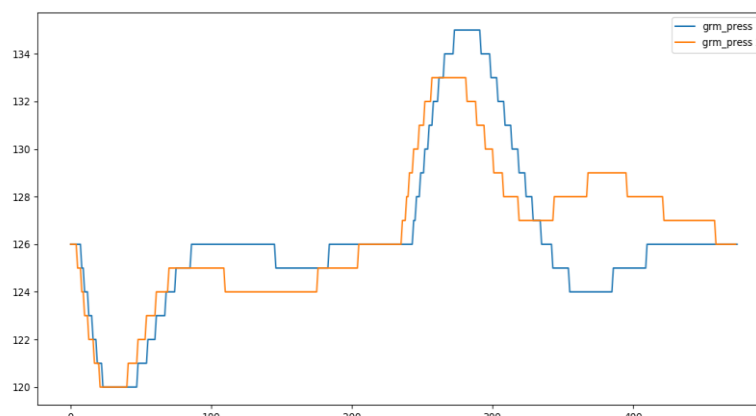
False operation will be recorded on boiler No.4, if any.

The cycle amount of the program was increased to 65 (Listing 2):

Listing 2 - Increasing the cycles.

```
if self.n > 65 or np.mean(self.outputs_K3[-5:-1]) == self.targets[-1][2]:
for i in range(4):
self.position[i] = 0
conn.set_trace()
```

The experimental findings were recorded in a text file and appeared as follows (figure 13):



**Figure 13.** Variations in pressure differentials with and without the program.

## 5. Conclusions

According to the preliminary assessment of technical and economic indicators, reducing the deviation range only for overheated steam will allow to save up to 1-2% of conditional fuel flow rate per boiler. The range of changes in the oxygen content in the final gases can be kept within 0.5% of the nominal content. The payback period for the implementation of the system for one boiler will amount to 1-1.5 years, while maintaining the existing control capabilities of operating mechanisms.

The written program allows to change the load on the boilers quickly and efficiently, i.e. to reduce or increase the coal feeding without unnecessary fluctuations.

Now the operating mode starts in 7 minutes. Without using the program, this time was 22 minutes at average. This significantly reduces the flow rate of coal and electricity. Therefore, financial costs will be significantly reduced. Such increase in the efficiency of the entire system significantly increases the operational efficiency of control. Temperature changes faster, which the system required initially.

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