Lab Platform for the Steam Superheater Electronic Simulator

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Abstract: - This paper present the design of the electronic simulator corresponding to the steam superheater. Using the nonlinear model of real steam superheater we realised an electronic devices and a lab platform for study the dynamic evolution of the steam superheater. The experimental applications were developed on the electronic simulator and using Multisim, data acquisition board Cassy lab and Matlab – Simulink software's.

Key-Words: - temperature, superheater, steam, control, simulator, electronic.

1 Introduction
Considering the boiler as control system object, setting the pressure and temperature’s steam becomes control system’s charge, which must be local for dynamic loads and boiler’s safety.

For steam temperature control, the superheater is divided in three parts, in every points of connection are mounted the devices that allow injection of condensate for cooling steam. Setting of pressure is made through combustible capacity command.

The steam temperature must be constant before steam hits the tips of turbine’s blades [3].

The assembly of superheaters is a distributed parameter system and the control of the output temperature is difficult because there is a transfer time delay between the points where the water is sprayed and the points where steam temperature is measured.

For the automatic control of the temperature, in this system with distributed parameters, is necessary to introduce a complex control structure.

It is difficult to verify the function of this structure directly on the steam boiler. It prefers the use of mathematical models and/or physical models of electronic superheater.

The paper proposes to design an electronic simulator to reproduce the real function of the superheater in normal condition and in fault condition.

With this electronic simulator have studied the possibility to control of the superheater at the action of the perturbation and control system structure which be implemented on the real system.

For these experiment was used:
- the data acquisition board Cassy lab;
- an electronic simulator for the three superheaters;
- Matlab – Simulink software;
- Multisim v.10 software.

2 The equivalent model of the steam superheaters
For a high efficiency and lead’s steering, the automatic’s equipment is grouped depending on charges which are made. Their function are based on receiving information from the process through sensors and gages and this actuated concerning process through actuator with continuous and discontinuous action.

In figure 1 we have the block scheme of the steam superheater in which are presented the links between the control input (W_inj - the injection flow), the perturbation of the process (G_e - the gases flow, D_c - the steam flow to the turbine, T_g - the gases temperature to the input of superheater area) and the output system (T_a - the steam temperature of the superheater) [2].

\[ W_{inj} \rightarrow G_e \rightarrow D_c \rightarrow B \rightarrow M_{TG} \rightarrow T_g \rightarrow M_{FG} \rightarrow T_a \]

Fig.1 The block scheme of temperature T_a

The existing literature presents a series of models for the steam superheaters used in steam power plants. The goal of these models is to closely reproduce the real process but also to reduce the computational time for the process simulation, since these models are used for real time control and monitoring [2].

The simplified scheme of the steam superheaters of the boiler is presented figure 2, where the heating pipes
SA1, SA2, SA3 and the respective zones of the gases SG1, SG2, SG3, are approximated with concentrated parameters elements.

Because of practical reasons we consider the next data which will be used in the automatic regulation structure and fault detection and localization system:

- The temperatures $T_{a1}$, $T_{a2}$, $T_{a3}$, at the outputs of every overheated area measured with their adequate translators.
- The injection flow $W_{\text{inj}1}$ and $W_{\text{inj}2}$ used as command magnitude for the regulation of the temperature $T_{a2}$ and $T_{a3}$.
- The steam flow at the entrance in the turbine, $F_t$, representing the main measurable disturbance;
- The temperature of the burning gases $T_{gi}$ and the gas flow $F_{gi}$, at the input of the overhears area, which hide immeasurable disturbances but which can give information on the faults in the fuel burning process.

From the block scheme we observe that we can define the pairs with the direct influences like fault measurable output magnitude: $(W_{\text{inj}}-T_{a2}; W_{\text{inj}2}-T_{a3})$ and we have available the pair $T_{gi}-T_{a1}$ although $T_{gi}$ in may simultaneously influence $T_{a2}$ and $T_{a3}$. The disturbances in the vaporization system ($T_{ai}$ and $F_{ai}$) also influence $T_{ai}$.

In these conditions, the mathematical model is described by the equations (1-6) where the coefficients were computed using the steady state for a 420 tones/hour steam boiler, working at 13.7 MPa and 823 K and using coal and oil as fuel. Using the mass and heat transfer balance equations for each heat exchanger and injectors it results a set of equations will result, corresponding to lumped parameter model of superheater’s area. It can be observed that we used a system composed by 3 superheaters of the steam and 2 injectors for electronic simulator. For each the superheater, the balance equations are the following [2]:

$$
\frac{dF_{a1}}{dt} = -F_{a1} + F_{a2} - W_{\text{inj}1}
$$

$$
\frac{dF_{a2}}{dt} = -F_{a2} + F_{a3} - W_{\text{inj}2}
$$

$$
\frac{dF_{a3}}{dt} = -F_{a3} + F_T
$$

$$
T_{a2i} = T_{a1} - 1.97034 \times K_i \times W_{\text{inj}1};
T_{a3} = T_{a2} - 1.97034 \times K_i \times W_{\text{inj}2};
T_{ai} = T_{ai} - 618,15 \times K_i;
T_{gi} = 1183,15 K;
$$

Where: $T_{ax} = \frac{P_{ax} C_{ax} V_{ax}}{F_T C_T}$; $T_{gx} = \frac{P_{gx} C_{gx} V_{gx}}{F_T P_{gx} C_{gx}}$; $x = 1, 2, 3$; and $a_{ax}$, $a_{gx}$ and $b_{gx}$ are constants determined from the boiler data.

### 3 Design of the simulator electronic circuit

It is necessary to establish a correspondence between the real temperature inside of the superheater and the voltage in equivalent point of the superheater electronic simulation.

Table 1 present the real temperature in the points of the superheater (see Fig. 2) for steam ($T_a$) and gases ($T_g$) and
the correspondence with equivalent voltage in the correspondence point of the electronic simulation. We consider the temperature variation in area 0°C-1000°C and the equivalent voltage area 0-10V of the electronic simulation modules with a conversion factor of 1/100 [V/°C].

Table 1. The temperatures of the steam and exhaust gases

<table>
<thead>
<tr>
<th>Section</th>
<th>Temp.</th>
<th>SA1</th>
<th>SA2</th>
<th>SA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>345</td>
<td>396</td>
<td>453</td>
<td>550</td>
</tr>
<tr>
<td>Tg</td>
<td>910</td>
<td>847</td>
<td>769</td>
<td>547</td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ua</td>
<td>3.45</td>
<td>3.96</td>
<td>4.53</td>
<td>5.5</td>
</tr>
<tr>
<td>Ug</td>
<td>9.1</td>
<td>8.47</td>
<td>7.69</td>
<td>5.47</td>
</tr>
</tbody>
</table>

Thus out of the drum, the steam has a temperature of 345°C, out of the first superheater 396°C, out of the second superheater 453°C and out of the third superheater and at input has into turbine has 550°C. The same thing can be said about the gases, whose temperature varies along the three sections, as seen in Table 1.

Each module of the electronic simulator corresponds for the equation 1÷6 for the steam and gas zones of the superheaters and 7÷9 for the injection blocks.

To enter the delays that occur during the overheating of the steam and gas corresponding to the equations (1-9) an RC circuit assembly was used (Fig. 3).

It is applied the first theorem of Kirchhoff and it is obtained:

\[ i = i_C + i_e \]  \hspace{1cm} (11)

Ohm’s law for this circuit is:

\[ C \frac{du_C}{dt} = i_C \]  \hspace{1cm} (12)

Applying the II theorem of Kirchhoff for an eye of the circuit and obtain:

\[ Ri + u_C = V \]  \hspace{1cm} (13)

We suppose \( i_e = 0 \), that introduce an operational amplifier. Where: \( I \) – is the intensity electric current through the circuit, \( R \) – is the electric resistance and \( C \) - is capacitor.

![Fig. 3 RC circuit assembly](image)

The equation (11 - 19) are equivalent with the dates obtained (1 - 9). The simulator reproduces the same dynamics of the real process. The time constants from the real process are presented in Table 2.

Table 2. The time constants for the superheaters

<table>
<thead>
<tr>
<th>Sections</th>
<th>Time Values</th>
<th>Resistances</th>
<th>Condensers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta1</td>
<td>17s 10k</td>
<td>1.7mF</td>
<td></td>
</tr>
<tr>
<td>Ta2</td>
<td>10s 10k</td>
<td>1mF</td>
<td></td>
</tr>
<tr>
<td>Ta3</td>
<td>17s 10k</td>
<td>1.7mF</td>
<td></td>
</tr>
<tr>
<td>Tg1</td>
<td>0.1s 10k</td>
<td>10 µF</td>
<td></td>
</tr>
<tr>
<td>Tg2</td>
<td>0.06s 10k</td>
<td>6 µF</td>
<td></td>
</tr>
<tr>
<td>Tg3</td>
<td>0.03s 10k</td>
<td>3 µF</td>
<td></td>
</tr>
</tbody>
</table>

We calculated the resistances and capacitor values presented in columns 3 and 4, that assume the same time constants.

Resistance of 10KΩ were chosen, in order to ensure that areas of tension out of the operational amplifier match the values of the temperatures [3]. The condensers values were chosen as to ensure the time constants for the real process using the actual relationship:

\[ R C = \tau \]  \hspace{1cm} (20)

The operational amplifiers have the advantage of performing the mathematical operations such as assembly, integrals or differentials computing, by simply changing the various components on the feedback part (resistances and condensers) [1].

Each differential equation of the mathematical model was simulated with an electronic circuit consisting of a RC group and an operational amplifier in summation assembly, with direct or reverse action according to the sign terms of the equations.

The electronically scheme was verified and adapted by using Multisim v.10 software from National Instruments (Figure 4), with the object to realise the correspondence between the temperatures and voltage conform with table 1.
From $T_{ai}$ and $T_{gi}$ potentiometers are fixed in the simulator the input parameter voltages that are equivalent of the entry temperatures. From $W_{inj1}$ and $W_{inj2}$ potentiometers are fixed in the simulator the input parameter voltages that is equivalent with the condense injectors. For the impedance adaptation U1A and U4A amplifiers were used on the receptor post to eliminate the RC circuit pregnancy influence on the potentiometers voltages. The R2, R3, C1, U1B and U1C circuit simulate the SA1 heat balance equation. The R11, R12, C2, U2A and U2B circuit simulate SA2 the heat balance equation. The circuit R20, R21, C3 and U2C1 simulate the SA3 heat balance equation. The circuits R41, R43, C4, and U4B simulate the SG1 heat balance equation. The circuit R45, R47, C5 and U4C simulate the SG2 heat balance equation. The circuit R49, R50, C6 and U4D simulate the SG3 heat balance equation. With the U3A, U3B, U3C circuits were created the equations terms corresponding to the difference temperatures $\theta_{gx} - \theta_{ax}$ that are common and of the steam.

**4 The model simulation**

In order to be able to use the electronic simulator from the heat of the steam superheaters the configuration presented in Figure 5 has been accomplished [2]. The scheme has provided a mounting number of clamps that allow the connection of the measuring instruments or the ports of entry and exit of the data acquisition to an electronic simulator. On the board of the simulator, in the right of each terminal of clamp string, process variables are passed: measurable variables; the temperature gases out of each segment analyzed namely $T_{g1}$, $T_{g2}$, $T_{g3}$ and the temperatures steam $T_{a1}$, $T_{a2}$; the command variables corresponding order flow injection $W_{inj1}$ and $W_{inj2}$; the command variables corresponding to order flow injection $W_{inj1}$ and $W_{inj2}$; the principle disturbances of the process $T_{gi}$ – the temperature gases in the area of the furnace and $T_{ai}$ – the steam temperature in the area vaporizations. These perturbations may be locally amended by of the potentiometers P1 and P2 or from computer via signals applied to the terminals $T_{ai}$ and $T_{gi}$ of the clamps string. Switch K1-K2 on the board assembly allows the selection of the two situations: C - computers, M - manually.
The possibility of the fault exists - blocking of the actuator on the flow injection of injector \( W_{\text{inj}2} \) by the switch K3. In the case of fault, the value of the flow injection \( W_2 \) is set in potentiometer P3. This command can be used to study the function in the manual regime of the simulator.

Figure 5 present the scheme of the electronic simulator of all superheaters that are simulated physically, electronically on the circuit made up of operational amplifiers and electronic components (resistors, condensators). This scheme has apparent points of measurement (temperatures) and points of order \( W_1 \) and \( W_2 \) and the link to their range of cleme to connect to devices measuring apparatus or data acquisition.

On this simulator, a final test of the stationing values voltages has been conducted in various points of the electronic circuit corresponding to scale 1/100 of the temperatures in various points of the whole real steam superheaters from Isalnita Power Station boilers. These final tests on the simulator have been achieved in parallel with tests on the simulation models used in the design phase and making of the electronic circuit. The simulations were made in stationary regime. The tests used to the layout of a stabilizing source of continue voltage with the following values: \( V_1=10 \text{V} \) - input steam + gases (green connector); \( V_2=12 \text{V} \) - supplying operational amplifier (red connector); \( V_3=5 \text{V} \) – input injectors \( W_{\text{inj}1} \) and \( W_{\text{inj}2} \).

5 Description of the data acquisition equipment

For the experimental simulations we use a PC with data acquisition equipment (see Fig.6), Profi-Cassy and data acquisition control software COM3LAB and Cassy Lab. The Profi-Cassy is the intelligent interface for all areas of the electrical engineering used for connection to the USB-port of a computer, microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements), and a benchtop, console or demonstration unit (also on CPS/TPS panel frame).

Applications: CBS 9 arrangements simulator for PLC, COM3LAB, digital technology and MFA; CASSY Lab to the admission and evaluation of the measuring data;WinFact for applications in the control engineering.

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Fig.6 Cassy lab data acquisition
Technical data: 16 digital inputs I 0 to I 15, 16 digital outputs Q 0 to Q 15, 2 analogue voltage inputs A and B, 2 analogue outputs X and Y, 1 PROFIBUS connection with 9 pin DUB-socket passive user (Slave) at the fieldbus PROFIBUS-DP, USB-Port for connection to the PC, 1 CASSY-Bus for connection to Sensor-or Power-CASSY’s. CASSY Lab supports one or more CASSY-S modules at the USB port or at the serial interface of the computer.

6 The experimental simulation
The next figures present some experimental results related to electronic simulator response at the control commands $W_{inj1}$ and $W_{inj2}$, and perturbation $T_{ai}$ and $T_{gi}$.

7 Conclusions
The paper presents the design of an electronic simulator steam superheater.
This simulator is used to study the real response to the action of the perturbations and study the possibilities compensation of the perturbation's effect to the steam temperature at the entrance of the turbine.
Also, exist the possibility to study an automatic control structure of the steam temperature.
Unlike using a software model of the superheater, the electronic simulator together with the computer system PC and the analogical input-output data acquisition system take into consideration the delays and the noises that appear on the channels of transmission of the information between process and digital control equipment.
Also, on the electronic simulator it can be create different fault events that can not be artificially created in the real process for security reasons. In this way we can determine algorithms and control models for the superheater in fault condition.
The research will be continued in the doctoral work with the implementation of control structures in normal conditions and in fault conditions corresponding to these process categories.

References: