Advanced Control and Fault Detection in Steam Super-heater

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Abstract: The scope of this paper is to define the transfer function of the super-heater for the implementation of some supplementary control reactions in fault conditions of the super-heater actuator. This control structure maintains the stability of control systems and assures a faster response to a variation of the steam flow of the entrance of the turbine.

Keywords: steam temperature, fault detection, residuals, super-heater and control.

1. INTRODUCTION

The running conditions of the steam turbine impose the constant temperature and pressure of the steam at the turbine input. The steam temperature must be constant before steam hits the tips of turbine's blades (Vinatoru, 1994, 2001). For steam temperature control, the super-heater is divided in three parts, in every point of connection there are mounted the devices that allow injection of condensates for cooling steam (Iancu and Vinatoru, 1999, 2003). Control of the steam pressure is made through fuel flow command. The assembly of super-heaters 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 (Vinatoru, 2001).

In this system with distributed parameters it is necessary to introduce a complex control structure for the automatic control of the temperature (Gertler, 1998).

For a high efficiency and lead's steering, the automatic equipment is grouped depending on the charges made. Their functions are based on receiving information from the process through sensors and this actuate concerning process through actuator with continuous and discontinuous action.

The paper presents a control structure which uses the supplementary control reaction in fault conditions of the super-heater actuator. This control structure maintains the stability of control systems and assures a faster response to a variation of the steam flow of the entrance of the turbine.

The experimental results obtained by simulation using the non-linear model of the super-heater with three parts and three injections (one of this is supplementary) confirm the validity of this structure. In this case we realize an increasing of robustness of the super-heater control structure.

2. THE EQUIVALENT MODEL OF THE STEAM SUPER-HEATERS

It is difficult to verify the function of the complex control structure directly from the steam boiler (Chowchury and Aravena, 1998). It is preferred the use of mathematical models and/or physical models of electronic super-heater.

The existing literature presents a series of models for the steam super-heaters used in steam power plants (Iliescu and Fagarasan, 2005; Iliescu *et al*. 2005).

In Fig. 1 we have the block diagram of the steam super-heater in which there are presented the links between the control input (W_{inj} - the injection flow), the perturbation of the process (G_e - the gas flow, D_c - the steam flow to the turbine, T_g - the gas temperature to the input of super-heater area) and the output system (T_a - the steam temperature of the super-heater) (Vinatoru, 2001).

The detail diagram of the steam super-heaters of the boiler is presented in Fig. 2, where the heating pipe groups SA1, SA2, SA3 are placed in the correspondent zones of gas SG1, SG2, SG3 with the gas and steam flow. These modules are approximated with concentrated parameters elements (Vinatoru, 1994, 2001).

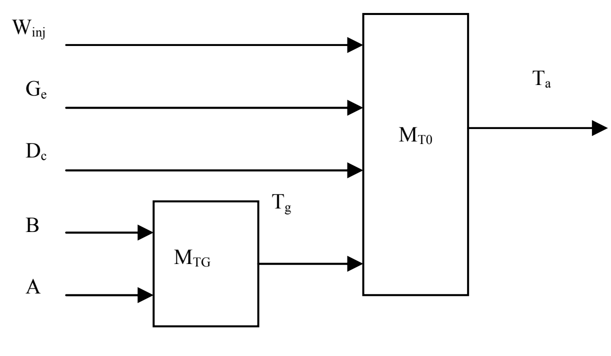

Fig. 1. The block diagram of the temperature Ta

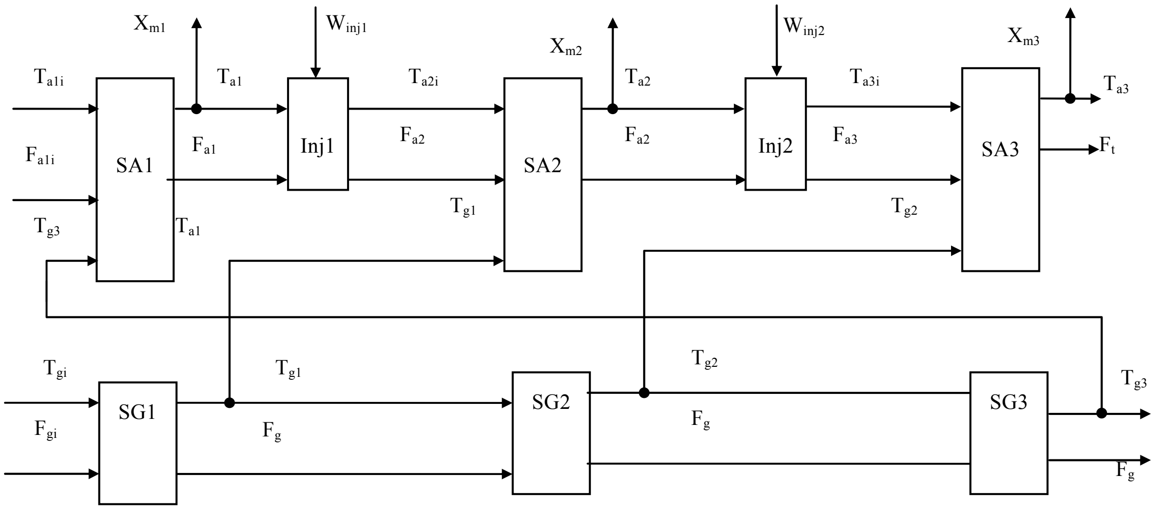

Fig. 2. Block scheme of the steam super-heater

The goal of these models is to approximate the real process running, but also to reduce the computational time for the process simulation, since these models are used for real time control and monitoring.

With the practical reasons, we consider the next data which will be used in the automated regulation structure and fault detection and localization system, (Iancu and Vinatoru 1999, 2003):

- The temperatures T_{a1}, T_{a2}, T_{a3}, at the outputs of each overheated area measured with their adequate transducer.
- The injection flow W_{inj1} and W_{inj2} used as command magnitude for the control of the temperature T_{a2} and T_{a3}.
- The steam flow at the entrance of the turbine is F_t, and it is the main measurable disturbance;
- The temperature of the burning gas T_{gi} and the gas flow F_g, at the input of the super-heaters area, which hide immeasurable disturbances but which can give information on the faults in the fuel burning process.

From the block diagram in Fig. 2 we observe that we can define the pairs with direct influences like fault measurable output magnitude: ($W_{inj} - T_{a2}$; $W_{inj2} - T_{a3}$) and we have available the pair $T_g - T_{a1}$ although T_g it may simultaneously influence T_{a2} and T_{a3}. The disturbances in the vaporization system (T_{ai} and F_{ai}) also influence T_{a1}. Under these conditions, the mathematical model is described by the equations (1)-(9). Using the mass and heat transfer balance equations for each heat exchanger and injectors it results in a set of equations, corresponding to lumped parameter model of super-heater's area, (Chow and Willsky, 1984). It can be observed that we used a system composed of 3 super-heaters of steam and 2 injectors for electronic simulator. For each super-heater, the balance equations are the following:

SA1:

$$64.4642\frac{dT_{a1}}{dt} = -T_{a1} - 0.0248F_{a1}T_{a1} + 0.0247F_{a1}T_{ai} + T_{g3} \quad (1)$$

SG3:

$$0.1731\frac{dT_{g3}}{dt} = -T_{g3} - 0.0033F_gT_{g3} + 0.0035F_gT_{g2} + T_{a1} \quad (2)$$

SA2:

$$81.4455\frac{dT_{a2}}{dt} = -T_{a2} - 0.063F_{a2}T_{a2} + 0.063F_{a2}T_{a1} - 0.138W_{inj1} + T_{g1} \quad (3)$$

SG1:

$$0.204\frac{dT_{g1}}{dt} = -T_{g1} - 0.0374F_gT_{g1} + 0.0425F_gT_{gi} + T_{a2} \quad (4)$$

SA3:

$$21.7655\frac{dT_{a3}}{dt} = -T_{a3} - 0.027F_{a3}T_{a3} + 0.0026F_{a3}T_{a2} - 0.01W_{inj2} + T_{g2} \quad (5)$$

SG2:

$$0.0295\frac{dT_{g2}}{dt} = -T_{g2} - 0.001F_gT_{g2} + 0.0015F_gT_{g1} + T_{a3} \quad (6)$$

And:

$$F_{a3} = F_{ai} + W_{inj1} + W_{inj2} \quad (7)$$

$$69.6\frac{dF_{a2}}{dt} = -F_{a2} + F_{a3} - W_{inj2} \quad (8)$$

$$11.13\frac{dF_{a1}}{dt} = -F_{a1} + F_{a3} - W_{inj1} - W_{inj2} \quad (9)$$

We can attach a transfer matrix for the linearization of the equation of the mathematical model in round of the point of the steady-state regime, for constant entrances (F_g=ct., F_{ai}=ct., T_{gi}=ct., T_{ai}=ct.):

$$\begin{bmatrix} T_{a2}(s) \\ T_{a3}(s) \end{bmatrix} = \begin{bmatrix} H_{11}(s) & H_{12}(s) \\ H_{21}(s) & H_{22}(s) \end{bmatrix} \cdot \begin{bmatrix} W_{inj1}(s) \\ W_{inj2}(s) \end{bmatrix} \quad (10)$$

In steady-state regime results:

$$T^{*}_{a20} = k_{11}W^{*}_{inj10} + k_{12}W^{*}_{inj20} \quad (11)$$

$$T^{*}_{a30} = k_{21}W^{*}_{inj10} + k_{22}W^{*}_{inj20} \quad (12)$$

The variation of the injection flow vector vs. the value in steady-state regime is:

$$W_{inj0} = \begin{bmatrix} -1.9536 \\ 0.0529 \end{bmatrix} \quad (13)$$

3. THE CONTROL IN FAULT CONDITION

From the analysis of the exploitation logs of the steam boilers at different plants in the area, the following faults may be known to have occurred (Iliescu and Fagarasan, 2005; Iliescu *et al.* 2005):

- Blocking or working with hysteresis of the regulation valves on the injection flows W_{inj1} and W_{inj2}.
- Unusual burning of the fuels or incorrect working of the depression regulation in the focus which acts out as gas temperatures variations or variations of the gas flow F_g.
- Modifications of the steam flow sent to the turbine.
- Modifications of the heat transfer coefficients due to residues on the exterior or interior of over heater pipes.

It is necessary to establish the action channels of these possible faults and the output magnitudes of the process which are influenced as fast and directly as possible by this disturbance (Dalton, 1998; Frank, 1990; Willsky, 1976). In the scheme in Fig. 2, SA1, SA2, SA3 represent great time constants processes (tens of seconds) and SG1, SG2 and SG3 situated on the gases route represent small time constants processes (below a second). From the block scheme we observe that we can define the pairs with direct influence like fault measurable output magnitude: ($W_{inj} - T_{a2}$; $W_{inj2} - T_{a3}$).

For the control of the steam temperature T_{a2} and T_{a3} in fault condition we use the block scheme presented in Fig.3, where AC1, AC2 are the actuators corresponding to the injection flow W_{inj1} respective W_{inj2} and AC3 is a supplementary actuator which is active when one of AC1 and AC2 are faults.

According to these specifications we define the deviation vector DE as a matrix function depending on the fault vector DE.

$$DE = \begin{bmatrix} DE_1 \\ DE_2 \end{bmatrix} = \begin{bmatrix} T_{a2} - T_{a2m} \\ T_{a3} - T_{a3m} \end{bmatrix} = F\left(\begin{bmatrix} W_{inj1} \\ W_{inj2} \end{bmatrix}\right) \quad (14)$$

The residual vector $R=[Y_1\ Y_2]^T$ has the components equal to zero in normal condition and different to zero in fault condition.

The command value of the simulated process is function of the command value of the real controller and the output Y from the residual generator block. The steam temperature of the real process T_{a2} and T_{a3} are compared to the output of the simulated process T_{a2m} and T_{a3m} and the difference represents the input in the residual generator block. The output of the fault detection block indicates the value „0” in normal function and the value „1” in fault condition.

If the first actuator is fault and its adequate output, for the same command of the fault detection block, it has the value W_{injd10}, which is different from the correct value W^{*}_{inj10}, than we have:

$$T_{da2}=k_{11}W^{*}_{injd10}+k_{12}W^{*}_{inj2} \quad (15)$$

$$T_{da3}=k_{21}W^{*}_{injd10}+k_{22}W^{*}_{inj2} \quad (16)$$

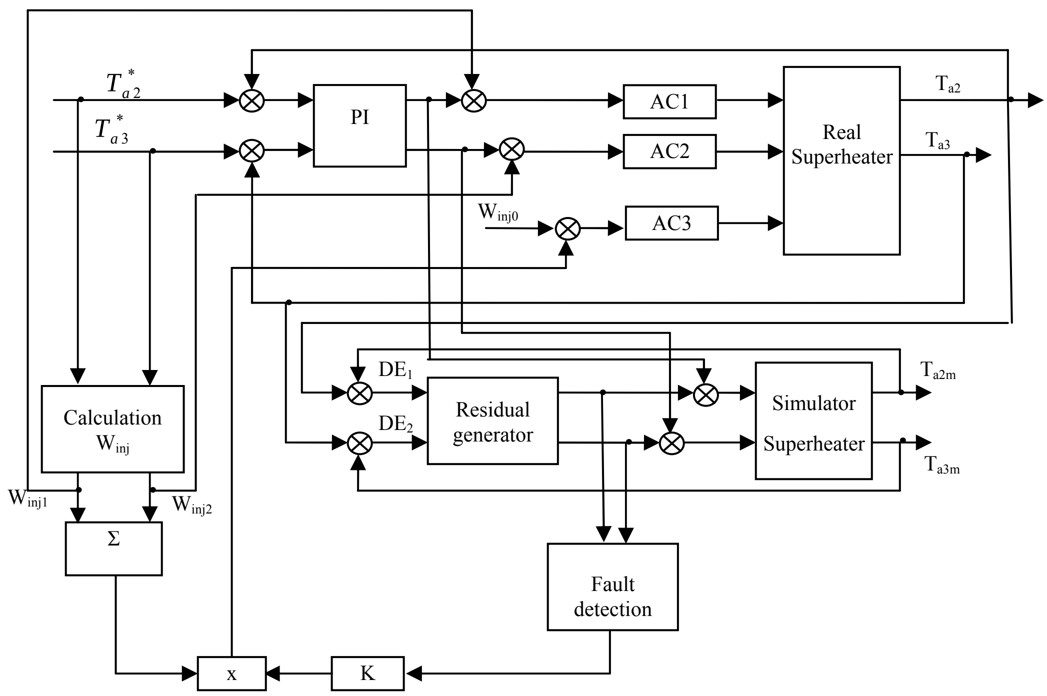

Fig. 3. The Control structure in fault conditions

4. THE EXPERIMENTAL RESULTS

Using the simulation scheme presented in Fig. 3, the following experimental results have been obtained.

For the normal performance of the actuators, the results are presented in the following figure. In Fig. 4 there are represented the steam temperature of the real process T_{a2} and T_{a3}. We can observe that in case of the modification of the prescribed value T^*_{a3} at the time moment t=200s, the steam temperature T_{a3} is stabilized to the corresponded value. The steam temperature of the real process is equal if the steam temperature of the simulated process (Fig.5), and the residual Y_1 and Y_2 indicate a value approximately equal to zero (Fig.6). In this case, at the time moment t=200s the injection flow W_{inj2} is modified as in Fig. 7.

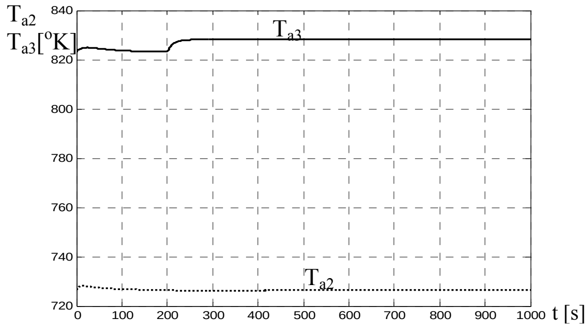

Fig. 4. The steam temperatures T_{a2} and T_{a3} in normal condition

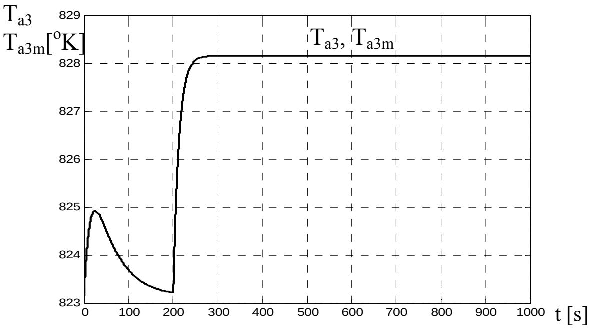

Fig. 5. The steam temperatures T_{a3} and T_{a3m} in normal conditions

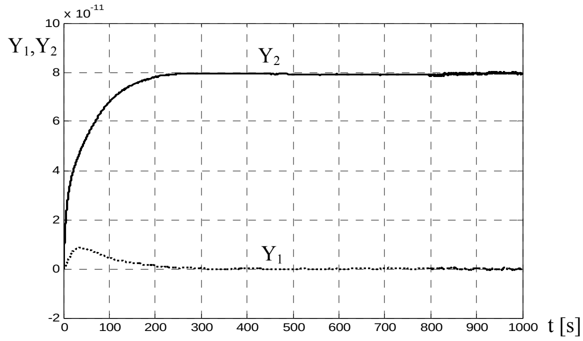

Fig. 6. The residuals Y1 and Y_2 in normal function

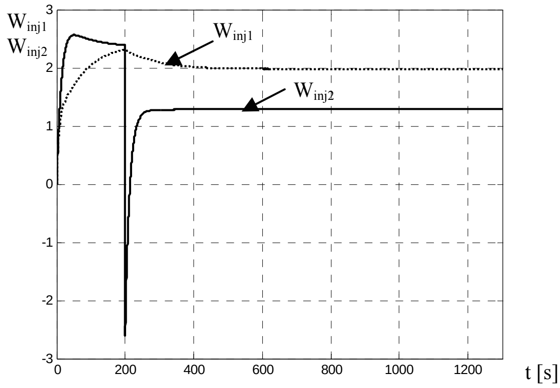

Fig. 7. The deviation of the injection flows W_{inj1} and W_{inj2} in normal condition vs. the injection flow in stationary regime W_{inj10} respectively W_{inj20}.

When the transfer factor of the actuators AC2 is modified at the time moment t=400s from the normal regime value of to an arbitrary value of $K_d=0.5 \cdot K_{AC2}$ (where K_{AC2} is the value in normal condition for AC2), the outputs Y_1 and/or Y_2 of the residual generator block vary in time as in Fig. 8. In this case the faults detection block will indicate the moment when the fault appears (Fig. 9). In this case the injection flows W_{inj1} and W_{inj2} are modified as in Fig. 10, and steam temperature of the real process T_{a3} has a deviation compared to (vs.) steam temperature value of the simulated process T_{a3m} (Fig. 11).

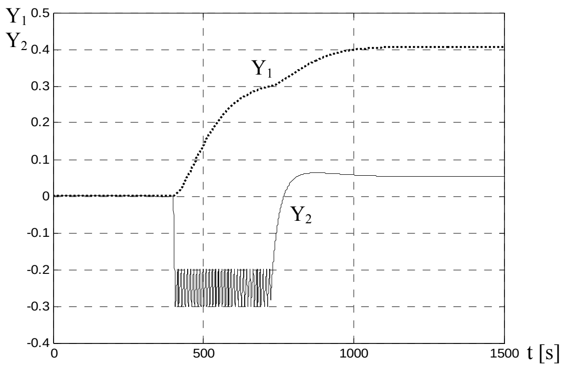

Fig. 8. The residuals Y_1 and Y_2 in fault condition at AC2

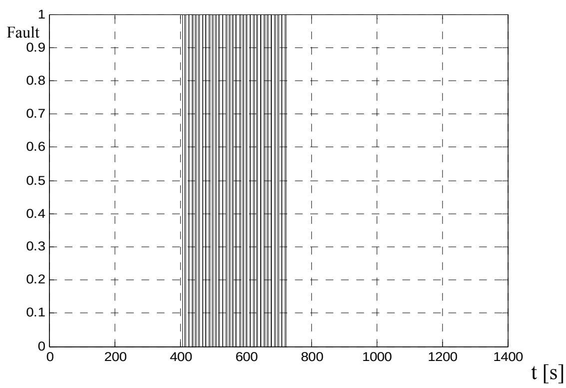

Fig. 9. The output of fault detection block in fault condition to AC2 at t=400s

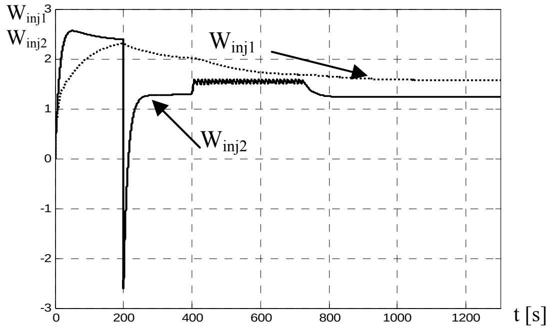

Fig. 10. The deviation of the injection flows W_{inj1} and W_{inj2} in fault condition at AC2 at t=400s vs. the injection flow in stationary fault regime t=400 at EE2 final value 0.5.

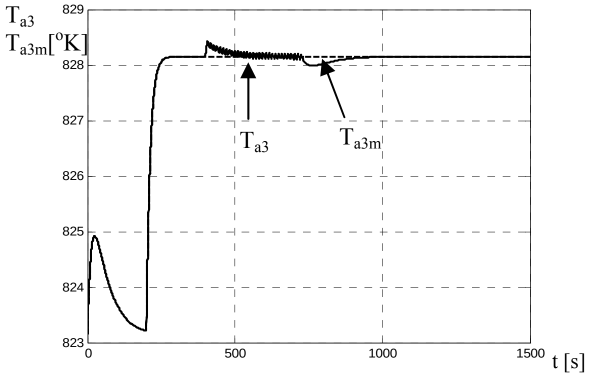

Fig. 11. The steam temperatures T_{a3} and T_{a3m} in fault condition at AC2 at t=400s.

If the supplementary actuator AC3 is activated, then the steam temperatures T_{a2} and T_{a3} not are sensitive to the fault (Fig. 12). If the actuator AC3 isn't activated, then steam temperature T_{a3} is modified by the faults to AC2 at the time moment t=400s as in Fig. 13.

When the transfer factor of the actuators AC2 is modified at the time moment t=400s from the normal regime value of to an arbitrary value of $K_d=0 \cdot K_{AC2}$ (where K_{AC2} is the value in normal condition for AC2), the outputs Y_1 and/or Y_2 of the residual generator block vary in time as in Fig. 14.

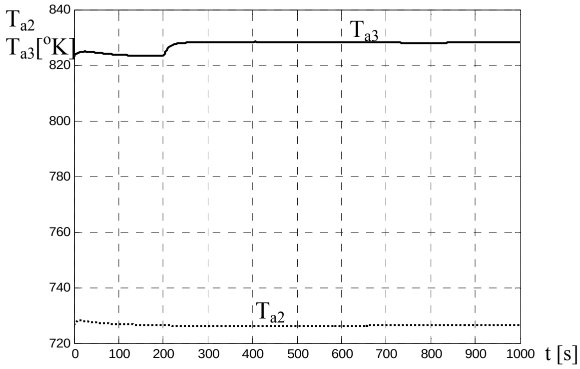

Fig. 12. The steam temperature T_{a2} and T_{a3} in fault condition at AC2, with AC3 activated

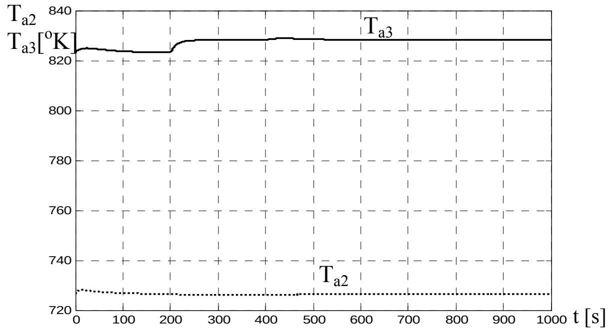

Fig. 13. The steam temperature T_{a2} and T_{a3} in fault condition at AC2, without AC3 activated.

When the transfer factor of the actuators AC2 is modified at the time moment t=400s from the normal regime value of to an arbitrary value of $K_d=0 \cdot K_{AC2}$ (where K_{AC2} is the value in normal condition for AC2), the outputs Y_1 and/or Y_2 of the residual generator block vary in time as in Fig. 14. In this case the steam temperatures of the real process T_{a2} and T_{a3} are represented in Fig. 15 and the deviation of T_{a3} vs. T_{a3m} is represented in Fig. 16.

In both cases we observe that a fault to AC2 has an influence only over the steam temperature T_{a3} (Fig. 13 and Fig. 16).

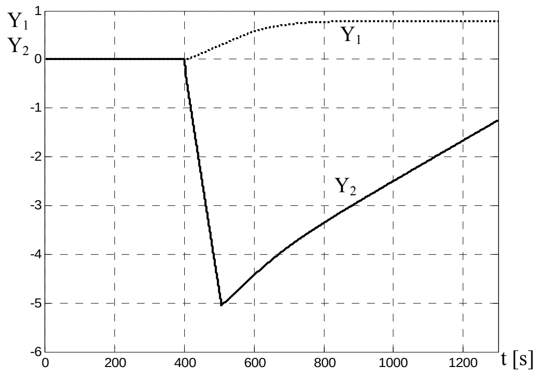

Fig. 14. The residual Y_1 and Y_2 in fault condition at AC2 Fault final value 1- completely closed

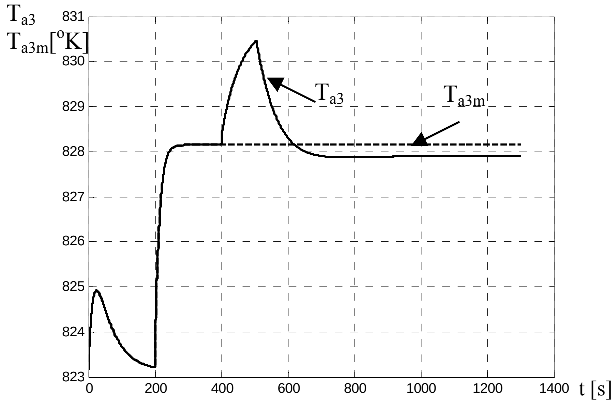

Fig. 15. The steam temperatures T_{a3} and T_{a3m} in fault condition at AC2 Fault value 1

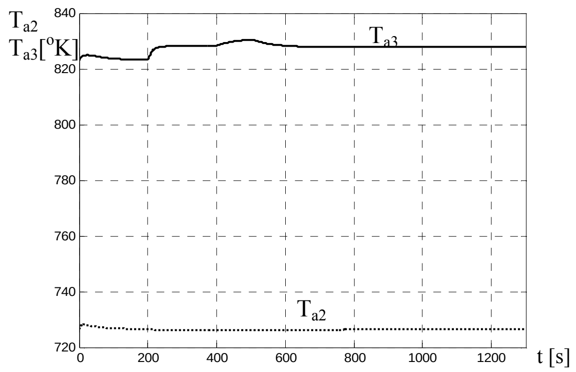

Fig. 16. The steam temperature T_{a2} and T_{a3} in fault condition at AC2 Fault value 1

When the transfer factor of the actuators AC1 is modified at the time moment t=300s from the normal regime value of to an arbitrary value of $K_d=0.5\cdot K_{AC1}$ (where K_{AC1} is the value in normal condition for AC1), the outputs Y_1 and/or Y_2 of the residual generator block vary in time as in Fig. 17. In this case the fault has an influence to both steam temperatures of the real process T_{a2} and T_{a3} as in Fig. 18. The deviation of the steam temperature T_{a3} vs. T_{a3m} is represented in Fig. 19.

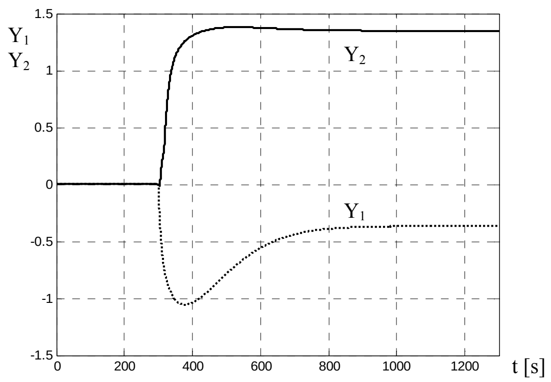

Fig. 17. The residual Y_1 and Y_2 in fault condition at AC1 fault t=300 at EE1 final value 0.5

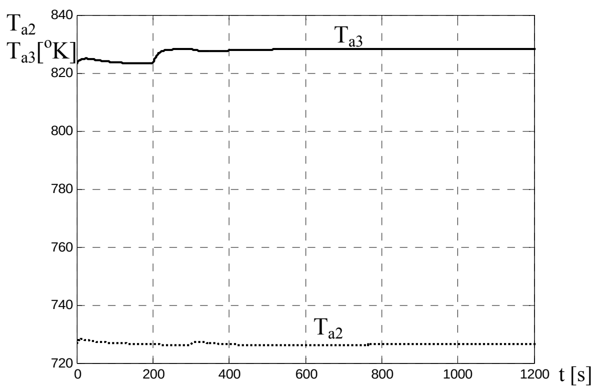

Fig. 18. The steam temperature T_{a2} and T_{a3} in fault condition at AC1 Fault t=300 at EE1 final value 0.5

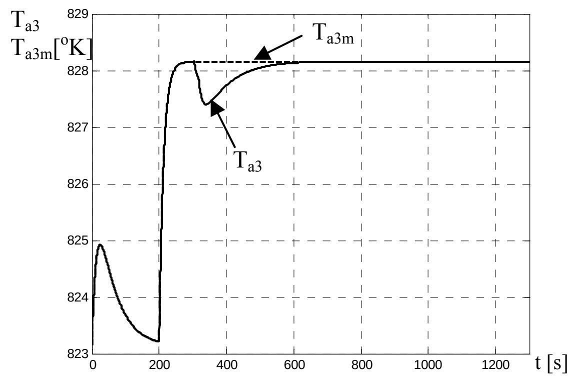

Fig. 19. The steam temperature T_{a3} and T_{a3m} in fault condition at AC1 Defect t=300 at EE1 final value 0.5

5. CONCLUSIONS

This structure allows the operators of the power plants to detect on-line the faults that can appear inside the equipment and processes that take place in the super-heater system.

This structure does not require supplementary equipments; it can be implemented as software complementary system on the existing monitoring digital control system from power plants.

We have considered the case when one or more actuators are blocked in a fixed position or are not supplied (in this case the servomechanism is either in closed or in open position). The immediate goal is to preserve the stability of process and, if possible, to control the process in a slightly degraded manner.

We propose a method to find the new values for the valid commands, in the presence of a failed actuator. To control the process with less command like usual, it is necessary to preserve the influence between the channels.

This method only offers a possibility to action in failure conditions and is not generally valid.

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