

ENGINEERING AND OPERATOR TRAINING SIMULATOR OF COAL-FIRED STEAM BOILER

Petr NEUMAN, Marek POKORNÝ, Ludvík VARCOP, Willy WEIGLHOFER
Výcvikové středisko energetiky VSE Tušimice a.s., Cihlářská 4132, 430 03 Chomutov

Abstract: The process model is developed on the base of mathematical-physical analysis (so called "first principles" method) of the separate technological subsystems of the drum steam boiler. The process model describes the standard and abnormal operation regimes in the range of 60 % - 100 % of Maximum Continuous Rate, with implementation of individual disturbances by the instructor of Operator Training Simulator.

This Training Simulator is based on technology object oriented model library called "EnergySIM" developed in the simulation packages MATLAB-SIMULINK. The "distributed control system", which is implemented in the real boilers, is also emulated in packages MATLAB-SIMULINK. The Human Machine Interface is realized in standard software package InTouch and the real desks and panels MOZAIC are also connected through the PCI slots and I/O cards. The communication between MATLAB-SIMULINK and InTouch is based on standard DDE protocol. This Operator Training Simulator belongs to "replica - partially stimulation types", because Human Machine Interface is realized in the InTouch package and MOZAIC equipments as in the real control room of power plant. The OTS is fully acceptable for engineering tasks, learning and training of engineers, students and operators.

Keywords: modeling, simulation, engineering and training simulator, thermal power plants, operation staff.

1. INTRODUCTION

The Operator Training Simulators (OTS) can be divided in three categories. First type is called full stimulation where the process is emulated. Control system and human machine interface (HMI) are used as in real plant. Second type is called partially stimulation where the process and control system is emulated and HMI is kept as real. The third type is called full emulation where all the three parts; process, control system and HMI are emulated. In the case of the presented ways of modeling, the second type of simulator, i.e. partially stimulated operator training simulator has been developed.

The models of power plant boilers may serve as a component of the Operator Training Simulators which can be used for training in staff operations in special situations. Such boiler model had to perform some behaviour:

The static and the dynamic responses within the simulation agree with the real processes in a such degree, that the experienced operator does not observe considerable difference between them.

Simulation time of specified processes must not exceed real time in corresponding situations.

The model must not limit the extent of variations in the respective variables below the required bounds.

The dynamic behaviour of the model has to be adapted in a easy way to the changes in construction or changes in operation behaviour of the equipment which may be a consequence of pollutions etc.

2. OPERATOR TRAINING SIMULATOR CONFIGURATION

The details of the simulator layout can be seen in Fig. 1. The process and the control system are modeled in Matlab/Simulink. The InTouch mimics and the operator control panels (Mosaic) are used as such in real plant. Two PCs are used, one for the operator, who is in training on the simulator and the second PC is used for the instructor who produces some disturbances and who monitors the performance of the operator. MATLAB models and all the InTouch mimics are placed on instructor PC and are coupled together via DDE protocol.

DDE is one of several mechanisms of inter process communication supported by Windows. It is an extension of

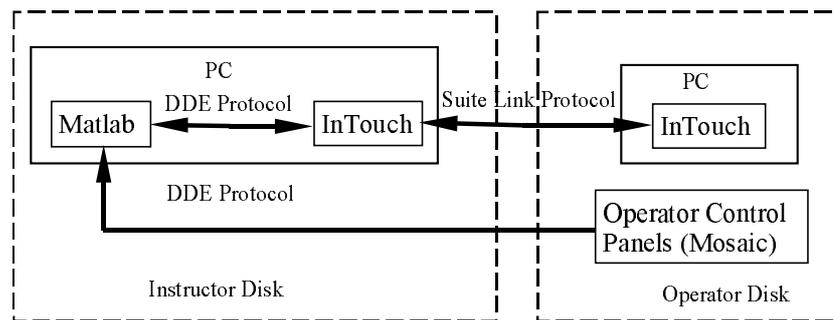


Fig. 1 Layout of Instructor and Operator Stations of Training Simulator

the messaging scheme around which Windows is designed. Of the two applications involved in the data exchange, one is known as the server and the other as the client. The client application is the consumer of the data and the server is the provider. The data communication via DDE is possible only between Matlab and InTouch. The model has been created in Simulink so it was necessary to program special S-functions in order to establish DDE communication between Simulink model and InTouch mimics.

Also operator control panels (Mosaic) are connected to the instructor PC where the connection with MATLAB model is carried out. Only the operator can manipulate with the operator control panels (Mosaic). All the InTouch mimics can be seen on both instructor and operator PCs with the exception of disturbances windows, which are available only to the instructor. The InTouch mimics on both PCs uses in mutual communication "Suite Link" protocol. The operator training simulator is under full control of the operator by means of InTouch mimics and operator control panels (Mosaic).

3. SUBSYSTEMS MODELING IN OPERATOR TRAINING SIMULATOR

The base information for creating structure of an OTS represents a process diagram. It can be demonstrated on an example of a feeding water subsystem. This part is depicted in Fig. 2, which represents so called Process Instrumentation Diagram (P&I D). In this diagram are depicted all the objects which are either manipulated by control or were some measurement is performed. For the operator training simulator is typical that all the information, which is available in monitoring and control system, must be available also in the models used in OTS. Only in this case the operator can manipulate with all the valves, fans, switches etc. as if he would done it in the real plant. This specific requirement invokes a need to have technology object-oriented models of all such elements, which are depicted in the process diagram.

In the feeding water scheme, which is depicted in Fig. 2, such process elements are mentioned in the following description of its function. Water is supplied through a feeding pump, which has been modeled by its flow/pressure characteristics. The water is pre-heated in two high pressure heaters (VTO) in series using steam as heating media. Cold water can also be mixed in parallel with hot water from VTO. The water is then passed through series of two primary (EKO I) and four secondary economizers (EKO II). The secondary economizers are of special construction, so they must be modeled in two parts. Heated water after primary economizer is also supplied for spray to the super heaters to control the steam temperature. The pressurized water is nearly at the saturation point and it is then supplied to a drum boiler where it is evaporated to steam.

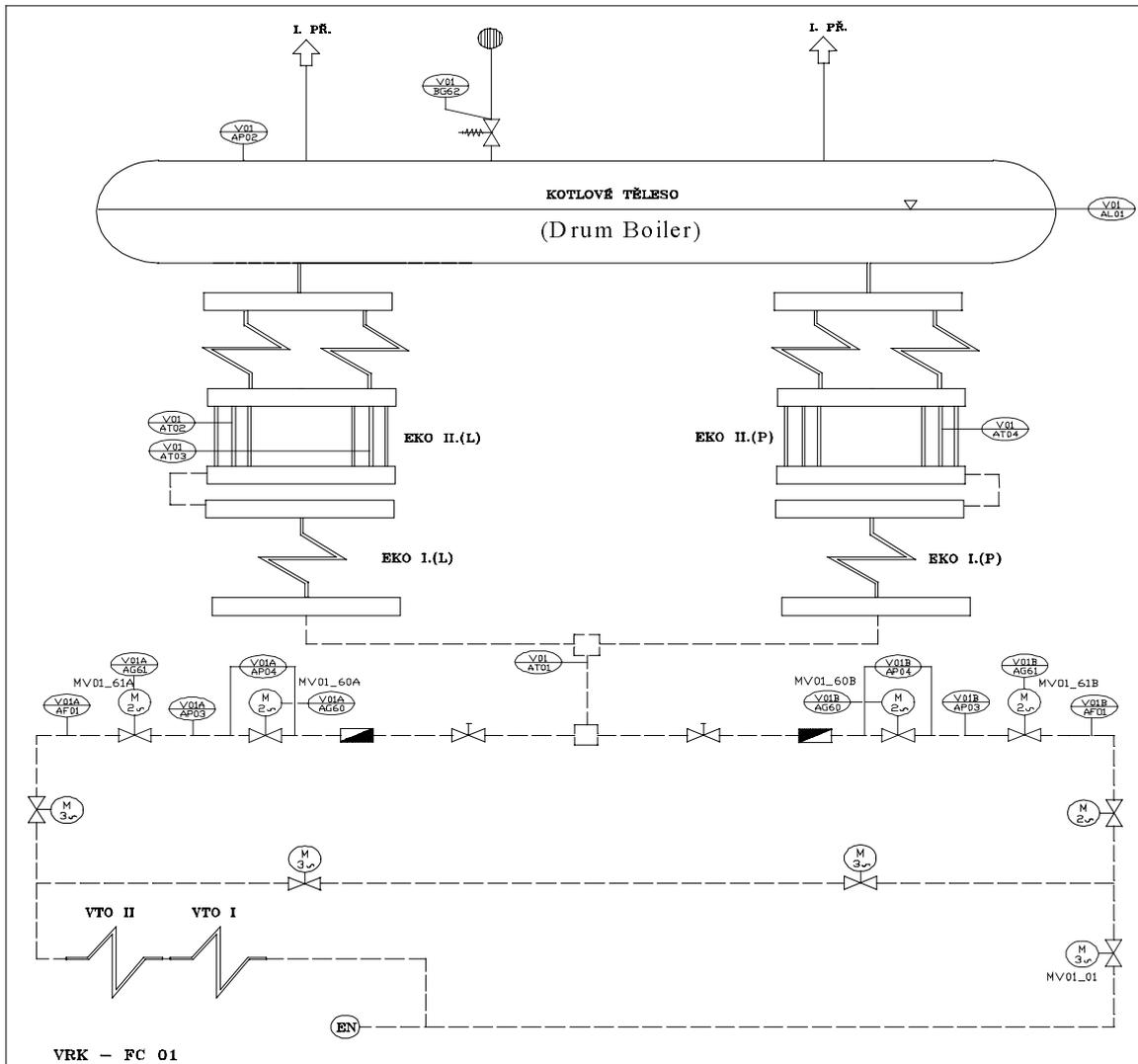


Fig. 2 Feeding Water Scheme of the Coal Fired Thermal Power Plant

The evaporating processes in the drum are difficult to describe; for Engineering Simulators (Neuman, 1997) or Operator Training Simulators can be used one of available modules, there are following its:

- a simple second order model (without “swell and shrink” phenomenon),
- a modified fourth order “Aström” model (describing the dynamic behavior of the drum boiler sufficiently simply for modeling, but enough exactly), or
- a higher order model necessary for realistic modeling of particular operating conditions, like low-loads, fast start-up, or abnormal shutdown.

In Aström model we need to respect the fact, that the time for moving the water particle from the riser-inlet to the riser-outlet at nominal steam-flow 250 t/h equals $T_{DY} = 29.65$ s. Therefore the variations of the riser hydraulic conditions have the time delay T_{DY} and we cannot neglect it.

Aström assumes the circulation system riser-downcomer as a lumped parameter system of 1st order. The time constant of that system he takes as negligible in comparison with the sampling period of $T_S = 1$ s. With these conditions the square from mass flow in the downcomer is proportional to the average volume fraction $\bar{\alpha}_v$ in the riser. As basis for the function $\bar{\alpha}_v = f(\alpha_r)$.

Aström takes the linear dependence $\alpha_r = g(y)$ in the evaporation zone in the riser, where α_r denotes the steam quality at the riser outlet and y denotes the length coordinate along the riser. This assumption is valid only in steady state.

This is the reason, for which we have decided to analyse the dynamic of the circulation loop more in detail.

The feeding water flow rate to the drum is controlled by the feeding valve (NV) according to the water level in the drum boiler, feeding water flow and steam flow from the boiler, and pressure difference across is the feeding valve is maintained by a differential valve (DV) in series with NV. All the other valves have switching functions necessary during the switching between hot and cold-water branches. They are modeled but are not mentioned in this description.

The block diagram of this feeding water subsystem is depicted in Fig. 3, where each type of described elements has own object oriented block realization.

4. OBJECT ORIENTED LIBRARY “EnergySIM”

Object oriented modeling describes each part of the model as an object with certain behaviour; therefore the own-built library called “EnergySIM” was developed (“EnergySIM” is trademark of the VSE Tušimice Corp.).

“EnergySIM“ provides an solution for many of the problem currently being raised by plan builder and user:

- dynamic simulation for designing mechanical and automation systems and setting up operating procedures,
- testing by simulator of automation systems in power plant,
- real-time simulation for: full-scope training simulators, engineering simulators, plant analyzers.

The main assets of EnergySIM are the following:

- a) It is a modular system, a model is obtained by assembling instances of general-purpose models taken from libraries. The system is open, a user is free to expand the default libraries with its own models. The default libraries include the models of many typical components to be found in thermoelectric power plants. Some examples: Two Phase Units (boiler, condenser, deaerator tank), Single Phase Units (economiser, superheater), Drum Evaporator, Water Storage, Media Flow Resistance Unit, Heat Flow Resistance Unit, Burner Units, etc.

Each object is formulated from basic physical laws (first principles) and it needs few parameters. The goal is to develop moderately complex non-linear models that capture the key dynamical properties over a wide operation range. All the modelling has been performed in software package Matlab/Simulink. Building a model from this library is very easy and during modelling one can feel that he is constructing an AutoCAD drawing of the model. In this way every one is able to build a model of his own choice very easily without deep knowledge of modelling. The modelling of all the modules is based on the three-conservation laws, mass, energy and momentum balance (Dolezal, and Varcop, 1970).

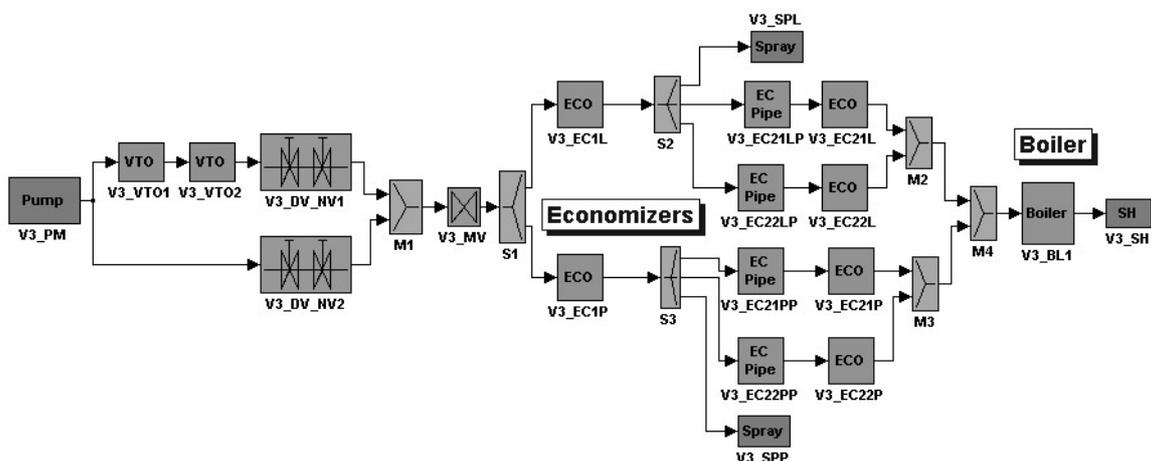


Fig. 3 MATLAB-SIMULINK diagram of feeding water of boiler

For simulation point of view and providing user-friendly dialogue, modelling has been made such that a dialogue box will appear by clicking the mouse over the model (object) as shown in Fig. 4. Initial conditions and parameters of the block can be entered through this display window. The chambers are divided mainly in two groups. One in which the water and steam flows, and other in which flue gases flows. Data in form of a vector of ten variables are obtained from each unit; in which first six (flow, enthalpy, pressure, temperature, quality, total head) are common to all chambers and other four depend on chamber (e.g. in boiler they are level, volume of water, volume of steam and steam quality at the riser exit). In case of flue gases, data in form of a vector of five variables (flow, enthalpy, pressure, temperature, heat) are obtained. The primary unit of the library is given the name unit. For example boiler chamber, valve, pump etc. are units. Units are combined in a sub-model.

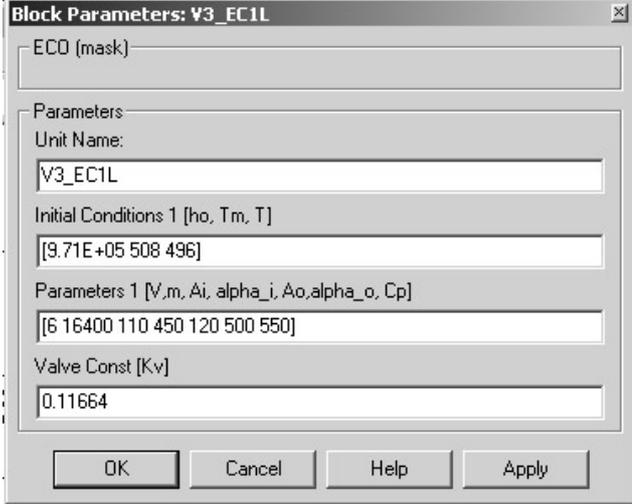


Fig. 4 Economizer menu for parameter setting

5. DISTRIBUTED CONTROL SYSTEM (DCS) EMULATION

The distributed control system consists of manual control from operator control panel (Mosaic), control from InTouch mimics and control from standard industrial PID controllers. An example of the control system can be seen in Fig. 5, where two cascade PID controllers and logic control for level control in the drum has been modelled in MATLAB-SIMULINK.

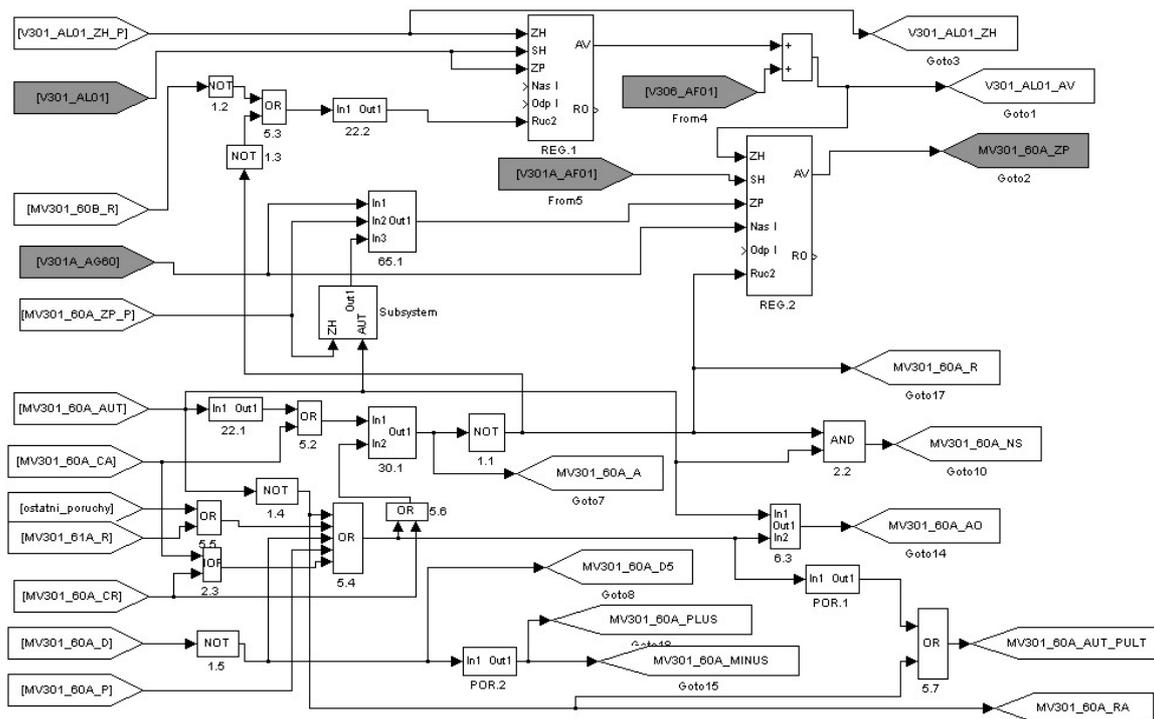


Fig. 5 Control system for level control in drum boiler

6. HUMAN MACHINE INTERFACE

As an example of a mimics in HMI, is the feeding water scheme, which is displayed in operator training simulator (OTS), in the same form, as it is available in the control room in real plant, is shown in Fig. 6. This InTouch mimics (with operator control panel, Mosaic) is available to operator and instructor, and they can manipulate different variables from the Operator Station or Instructor Station. In the bottom of this figure is shown many buttons, which can be used to display any part of the OTS e.g. steam, air, flue gas, coal mills etc. The temperatures at different sections of feeding water scheme, and water level, pressure in the drum can be seen here.

7. OPERATION PROCEDURES FOR OPERATOR TRAINING SIMULATOR

The object of one OTS are two steam boilers with nominal power 250 t/h which are working to common steam collector. It is equipped with ZAT modular Distributed Control System (DCS) and InTouch Monitoring and Control system.

As an example of some operation procedures of OTS, which are necessary to be trained for the case of operational malfunctions- disturbances, the following most important malfunctions can be listed as:

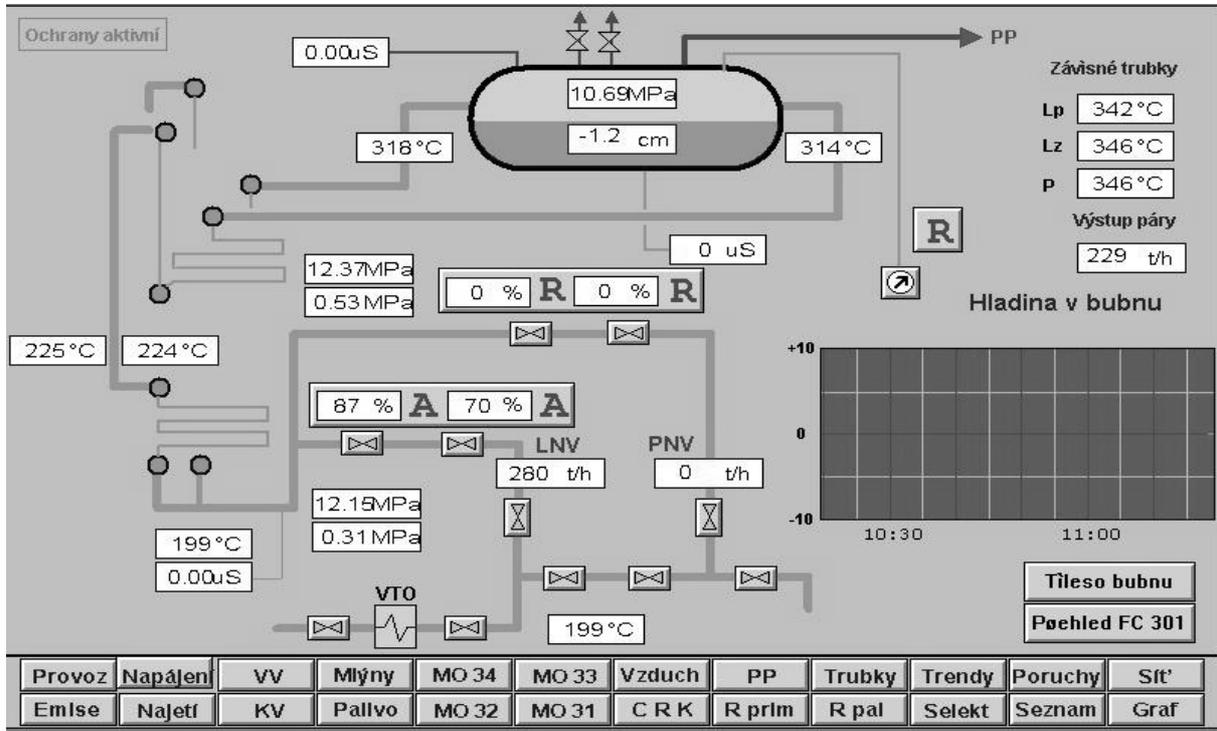


Fig. 6InTouch mimics of Feeding Water & Steam of the Thermal Power Plant

1. **Failures of boiler feeding water**, which include

- 1.1. loss of pressure in feeding system,
- 1.2. exceeding of differential pressure,
- 1.3. temperature exceeding of (inside) inclined tubes,
- 1.4. loss of boiler tightness.

2. **Breakdowns of air-duct**, represented by

- 2.1. air-fan dropout,
- 2.2. spontaneous big misbalance of air-fan control,
- 2.3. malfunction of air flaps coupling,
- 2.4. decrease of temperature behind the air heater II on one side - loss of tightness of water heater II.

3. **Flue-gas tract** is under influence of

- 3.1. dropout of flue-gas fan,
- 3.2. breakdown of flue-gas fan control,
- 3.3. malfunction of damper flaps,
- 3.4. different temperatures of flue-gases.

4. **Fuels and combustion** are concern by

- 4.1. dropout of fuel supply by one stoker,
- 4.2. dropout of fuel supply by two stokers,
- 4.3. melting of fuses, high ampere load of stoker,
- 4.4. failure of combustion control,
- 4.5. running in a mill, drop-out of stoker,
- 4.6. increase of temperature behind mill, fire of mill.

5. Other malfunctions are usually as follows:

- 5.1. dropout of voltage 220 V, 380 V and 6 kV,
- 5.2. flame extinguish,
- 5.3. dropout of "TG",
- 5.4. reasonable pressure decrease in high pressure steam collector "VT",
- 5.5. blocking of monitoring and control station InTouch, 5.6. dropout of control boxes.

6. Failures of temperature control of outlet steam, are represented by

- 6.1. temperature increase of outlet steam,
- 6.2. temperature increase of steam superheater IV,
- 6.3. breakdown of automatic control of temperature,
- 6.4. temperature misbalance of right and left boiler sides, 6.5. temperature decrease of superheated steam – overspraying.

8. CONCLUSIONS

The experiences from the operation of these operator training simulators show that there are no great problems in fidelity of the dynamics features. For the greater scope of range of energy units there are reserve in some acceleration precaution in Simulink model or by a quicker kind of communication between Matlab and InTouch (based on special S-function in C language).

On the base of our done experiences it can be said that the described type of Operator Training Simulators, based on MATLAB-SIMULINK and InTouch packages, are suitable for full scope replica type of simulators of smaller energy units (e.g. with capacity less and equal of 110 MWe) and acceptable for customers especially in Central and Eastern Europe and Underdeveloped Countries (Neuman, et al., 2002). The OTS is also fully acceptable for engineering tasks, learning, education and training of engineers, students and operators.

REFERENCES

- Neuman, P. (1997), Engineering Simulator for Fossil Power Plant. Preprint IFAC/CIGRE Symp. on Control of Power Systems and Power Plants, Beijing, China.
- Doležal, R., Varcop, L. (1970), Process Dynamics – Automatic Control of Steam Generation Plant, Elsevier, London.
- Neuman, P., Jan, J. A., Varcop, L., Weiglhofer, W. (2002). Operator Training Simulator of Coal-fired Steam Boiler. Proc. of the 5th International Conference Control of Power & Heating Systems, Zlin, Czech Republic.

Ing. Petr Neuman, CSc.
Studnická 2128
193 00 Praha – Horní Počernice
Tel: 02 / 81923547, 0606 648913
E-mail: neumanp@volny.cz