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PROCESS INSTRUMENTATION MODULAR MODELS OF THERMAL POWER PLANT FOR OPERATOR TRAINING SIMULATORS

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Abstract. The increasing use of operator training simulators means that there is a need for models of industrial plants which are at the same time detailed but also simple enough to provide a credible (but not necessarily precise) simulation for both small and large changes of operating point. These conflicting requirements are often complicated by the desire to carry out operator training using the control and monitoring system with which the respective device or process is equipped. This paper shows how in the modelling of a thermal power unit a non-linear model based on „ first principle“ analysis is used for building up operator training simulators. This process instrumentation model, which can be called a reality-oriented model, was developed as a purpose-built user block library in the MATLAB-SIMULINK standard simulation package. This process instrumentation model represents the water feeding subsystem of a steam boiler with 250 t/h power capacity of a 55 MW power unit, as a part of the operator training simulator developed for Opatovice Power Plants in the Czech Republic. *Copyright © 2002 IFAC*

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1. INTRODUCTION

One of the most efficient ways of training operators is with the use of Operator Training Simulators. Such training has formed an integral part of the comprehensive training courses provided by specialized centres for a long time, but nowadays, it is gradually becoming a part of in-house personnel education. This has created a growing demand for low cost, modular models of a generic character. These models and their simulation software must, in particular, provide support for easy modelling of instrumentation and for its manipulation by the operators.

This development can be observed nowadays in power plants, where the energy business under liberalized conditions requires extremely reliable operation of power plants and especially a high level of technical operator skills and operators who can deal effectively with operation stresses. On the other hand, advanced distributed computer control systems enable a very high level of process automation, which means that the operator plays only a small part in the control process. With the use of advanced distributed control systems, abnormal situations and breakdowns conditions are eliminated or decreased, so that operators are becoming less and less skillful specially under these conditions. Operators are gradually losing the experience and skills that are necessary for plant operation in abnormal situations or breakdowns. These skills now need to be developed by simulator training.

An undoubted advantage of operator training simulators is their fully identical operator interface; i.e., an operator using these operator training simulators has the same screens and control devices (keyboard, mouse, operator desk and panel).

There are many commercially available industrial monitoring and control systems. The Wonderware InTouch package is widely used in the power industry, so we also used it for process vizualization.

We tested the link between the MATLAB – Simulink and InTouch packages.

2. THEORETICAL BACKGROUNDS OF NON-LINEAR MODELLING WITH LUMPED PARAMETERS

There are several possible ways to model a boiler system; we can describe the system behaviour using the physical properties of water and steam with there different mass and energy balance equations. These kinds of models can differ greatly because of the complexity of the balance equations. The most exact theoretical models have specific coefficients that are difficult to define. A simple so-called „global model“ can also provide results, (Astrom and Bell, 2000). The assumptions of the process behaviour can also simplify the model, e.g., if only the main events are modelled. The main advantage is that this kind of model contains all the cross-connections between the different inputs and outputs, and thus helps the trainee to understand the boiler behaviour. One of these approches is the so-called „modular“ approach.

Another approach, sometimes called dynamic modelling, considers dynamic system of the steam generation (F.P. de Mello, 1991). This kind of model describes the dynamic connections by the transfer functions (Neuman, 1997), (Neuman, Šulc and Jarolímek 1999), (Neuman, Šulc and Dlouhý, 2000) – between the inputs and outputs – and various identification methods are used to get the parameters of these functions (Keviczky et al., 1979). Its simplicity is an advantage, and it provides good mathematical bases for control design.

This paper describes the „modular“ approach. The principal feature of any „modular“ approach in energy process modelling is the reuse of modelling software for different power units. There are many ways to model power units. One is the „micromodule“ approach (Maffezzoni, 1992), where the volumes, junctions and heat conductors are the general basic building blocks to fit any real process steam boilers or power plants. The main drawback of this approach is fact the model requires equations to be written, since the modules are essentially a thermodynamic elementary system to which a certain set of standard partial non-linear differential equations correspond.

For these reasons a second „macromodule“ approach is most effective for engineering applications, where the modelling modules correspond to the plant components, so that defining the modular structure of a plant amounts to drawing its process instrumentation diagram. This „macromodule“ approach is used in this paper.

The paper deals with modelling and solving heat exchangers, because this is a central problem in simulating any thermal power plant. Segmentation is a general concept in the simulation of heat exchangers. We divide a (long) heat exchanger into several sections, for which the equations of the heat exchanger can be written in a simplified form suitable for numerical solution. In fact, segmentation is very often a way to transform the original thermohydraulics equations, which are in the form of partial differential equations (PDE), into ordinary differential equations (ODE). In this respect, segmentation just defines the spatial discretization in the application of finite-difference or finite-elements methods to solve the above-mentioned PDE´s.

When segmentation is equivalent to spatial discretization or lumping, its application should be based on accuracy criteria, taking into account both the steady-state and the dynamic accuracy of the resulting ODE model. However, it is not possible to identify the best method, because many different factors are involved; in general, it may be said that most methods yield satisfactory results when the power unit operates above its technical minimum (usually fixed at about 30 % of the Maximum Continue Rate – MCR), while unsatisfactory results may arise at very low loads, e.g., during start-up, if finite-difference spatial discretization is applied. A simulator model of a steam boiler with a capacity of 250 t/h, operated in the range of 60 % - 100 % of MCR, is described and the original „compartment model“ method is used in this paper (Šulc and Zítek, 1977).

2.1. Complex nonlinear models with lumped parameters

The first principle models of technological equipment (based on energy, mass and momentum storage) are described by partial differential equations. Ordinary differential equations are obtained when we suggest the principle of lumped parameters of subsystems and the second type of the model is available. The double Laplace transformation and an approximation of transcendent equations need not be used, as in (Neuman, Šulc and Dlouhý, 2000).

The principle of these models is based on the energy and mass balances in the separate control modules of the boiler. The numerical simulation is based on the attainment of a balance between the heat removed from the flue gases and that transferred into the water and steam with respect to particular heat transfer conditions on individual heating surfaces.

2.2. Opatovice Power Plants units

In the Opatovice Power Plants six uniform G-230 steam boilers (6 x 250 t/h) and six turboalternators (2 x 55 MWe, 4 x 60 MWe) have been installed, and they are now equipped with the ZAT Series E modular Czech Distributed Control System. The InTouch Instrumentation and Monitoring Systém, provided by the Wonderware Company, was used.

The G-230 steam boilers are fired by pulverized brown coal, granulating dry bottom, producing 250 t/h of superheated steam.
The operating conditions at Maximum Continue Rate (MCR) are as follows:
Evaporation rate 250 t/h
Outlet temperature 535 °C
Outlet pressure 9,6 MPa
Feeding temperature 215 °C
Coal heating value 14,5 MJ/kg

The required outputs of the operator training simulator are in the operation range 150 – 250 t/h, i.e., 60 – 100 % of the MCR.

The basic ideas and methods, together with the ordinary differential equations and block schemes in the SIMULINK package are described in the following papers - (Varcop, 1967), (Čermák, et al., 1968), (Doležal and Varcop, 1970), (Karták, et al., 1981), (Neuman, Šulc, Zítek and Vyhlídal, 2001).

Process Instrumentation Models (PID) are developed on the basis of the „first principles“ method, and are verified with the use of real parameters (technical, design and construction), and, especially, with the real data measurements for „model calibration“ and verification. This model and other similar models can be called „reality-oriented simulation models“. Good coincidence is ensured through model calibration in which the values of the parameters are determined on the baseis of a comparison with measurements from the real device.

2.3. Modelling steam units with the of IEEE models

The IEEE boiler model, described in (F.P. de Mello, 1991) and (IEEE Working Group Report, 1991), is depicted in Fig. 1.

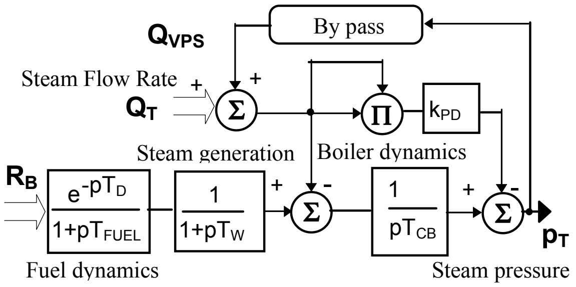

Fig. 1 Block scheme of the IEEE boiler model

The IEEE unit model (boiler and turbine) was verified by comparing a simulation and a field test of the 220 MW unit with the once through boiler, but the results were not very satisfactory. The process instrumentation model was therefore developed and used to compare the simulation characteristics with a real field test of the 55 MW unit with the Opatovice Power Plants drum boiler.

The advantage of using of these reality-oriented nonlinear models is described in Chapter 2.1, a) in comparison with the IEEE model, and b) yields from the simulation results.

3. MULTI-POLE MODULES

A possible concept in building process instrumentation models, which was used in the model developed for the Opatovice Power Plants operator training simulator, is demonstrated by the model of the feeding water subsystem. The process instrumentation diagram of this part is depicted in Fig. 2. The diagram generally serves as a basis for the design of the blocks and it also helps in interconnecting them.

3.1. Process Instrumentation Diagrams and Software Modules

The design elements depicted in Fig. 2 correspond to the plant elements, so that a definition of the modular structure of a real power plant amounts to drawing its process instrumentation diagram.
The same elements are also realized by the software, and corresponding software modules are depicted in Fig. 3.

In these figures we use the following technology elements and measured real variables, respectively software modules and simulation variables:
Modules (Elements):
- EN …...electro water feeding pump
- VTO …high pressure heat exchanger
- S ……..valve
- DV …..differential pressure valve control
- NV …..feeding control valve
- ZK …...check valve
- USS ….cold water collector
- SM …..mixing element
- EKO …economiser
- C …….controller

Variables:
- M …flow rate
- P …..pressure
- T …..temperature
- h …..enthalpy

Indices:
- P …..steam flow
- K ….flue gas flow
- V ….air flow
- W ….water flow

3.2. Multi-pole arrangement of valve and heat exchanger model modules

In the partial model of the feeding water, the models of the valves manipulated by the operator either manually or automatically by means of the installed distributed control system ("instrumentation" models) are the main element, and the "process" models represented here by the heat exchangers play a smaller role. This fact influenced the definition of the block representing these valves. Due to the need to maintain easy mutual interconnectivity, we created blocks of tripole or pentapole character, and special icons for them in SIMULINK.

The blocks strictly follow the basic idea of a block scheme - differentiation of inputs from outputs regardless of mass or energy flow orientation. This orientation is expressed either graphically by an arrow added to the square representing the whole block, or by a convention that variables supplemented by the index 1 can be found on the inlet side, whilst variables with the index 2 are on the outlet side.

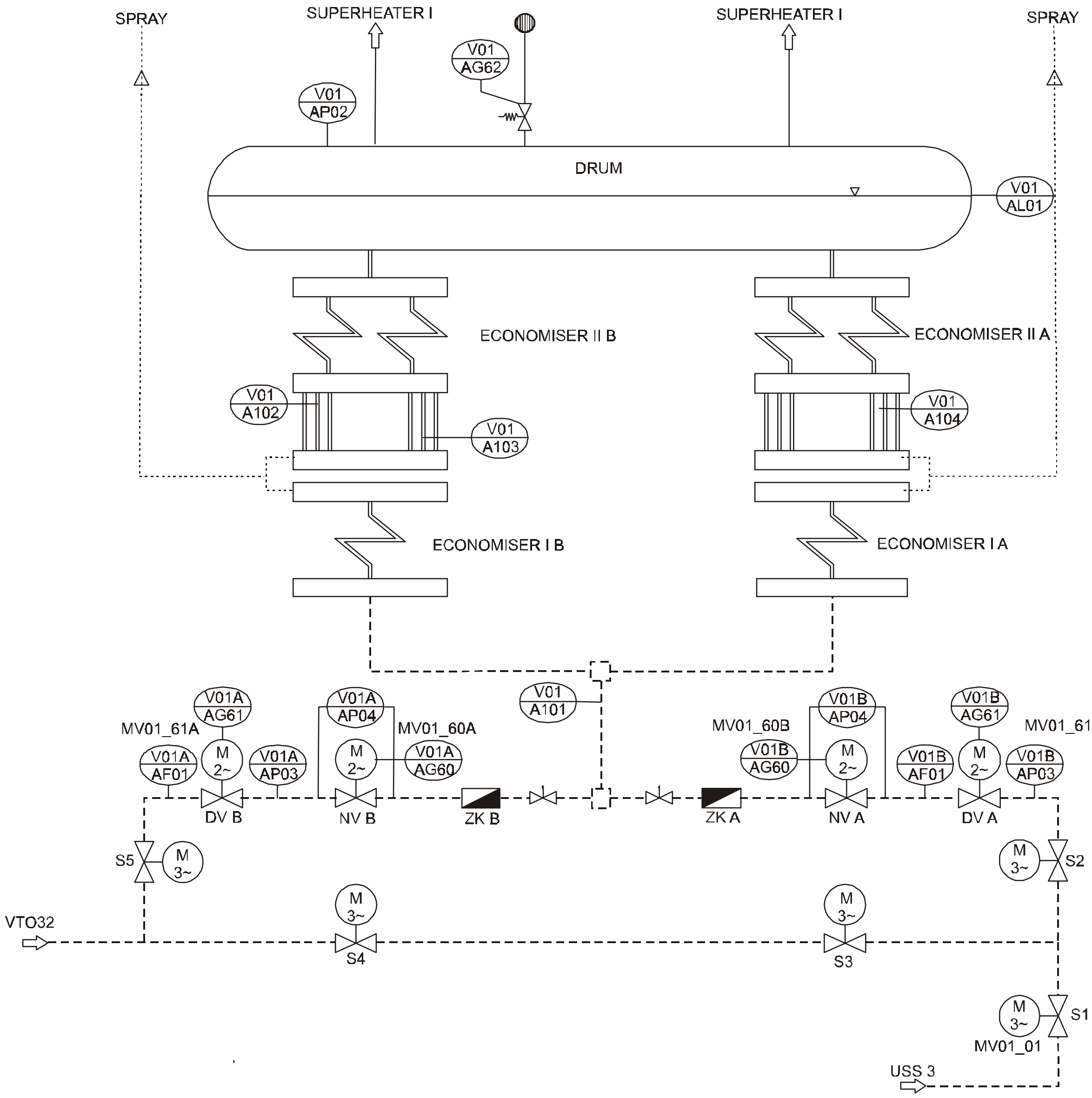

Fig. 2 Process Instrumentation Diagram of water feeding

In order to create and depict modules representing valves and heat exchangers in the Process Instrumentation Diagram in Fig. 2, there is a tripole respectively pentapole arrangement of the purpose-built SIMULINK blocks by means of which a complete model of the feeding water subsystem is composed. In order to make possible a simulation performance of the operator manipulation of each valve that is required in the operation procedures, it was necessary to model all the chains of valves. Their mutual interconnection requires two types of blocks to model the valves. In the first type both pressures, i.e., P1 at the inlet and P2 at the outlet side of a valve are considered as input variables determining the (same) flow-rate M as an output variable at both sides. The second type of block computes pressure P2 at the outlet side of a valve from flow-rate M at the outlet side (this is considered here as an input) and pressure P1 at the inlet side. The two types of modules are depicted in Fig. 4.

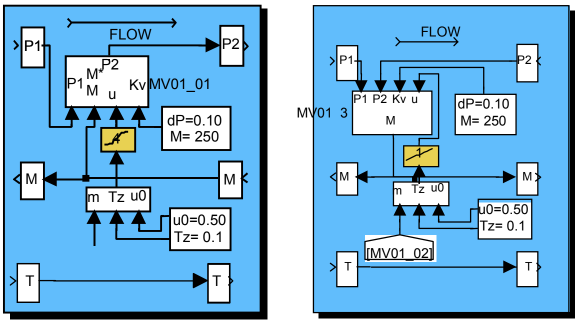

Fig. 4 Two different SIMULINK modules of valves corresponding to types S and DV (NV)

The whole model of the feeding water subsystem, built up from the described modules, is depicted in a sim : 2121plified graphic form in Fig. 3.

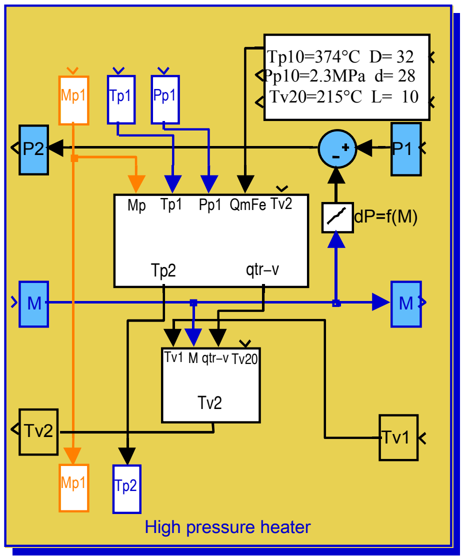

Fig 5. SIMULINK module of a heat exchanger corresponding to type VTO

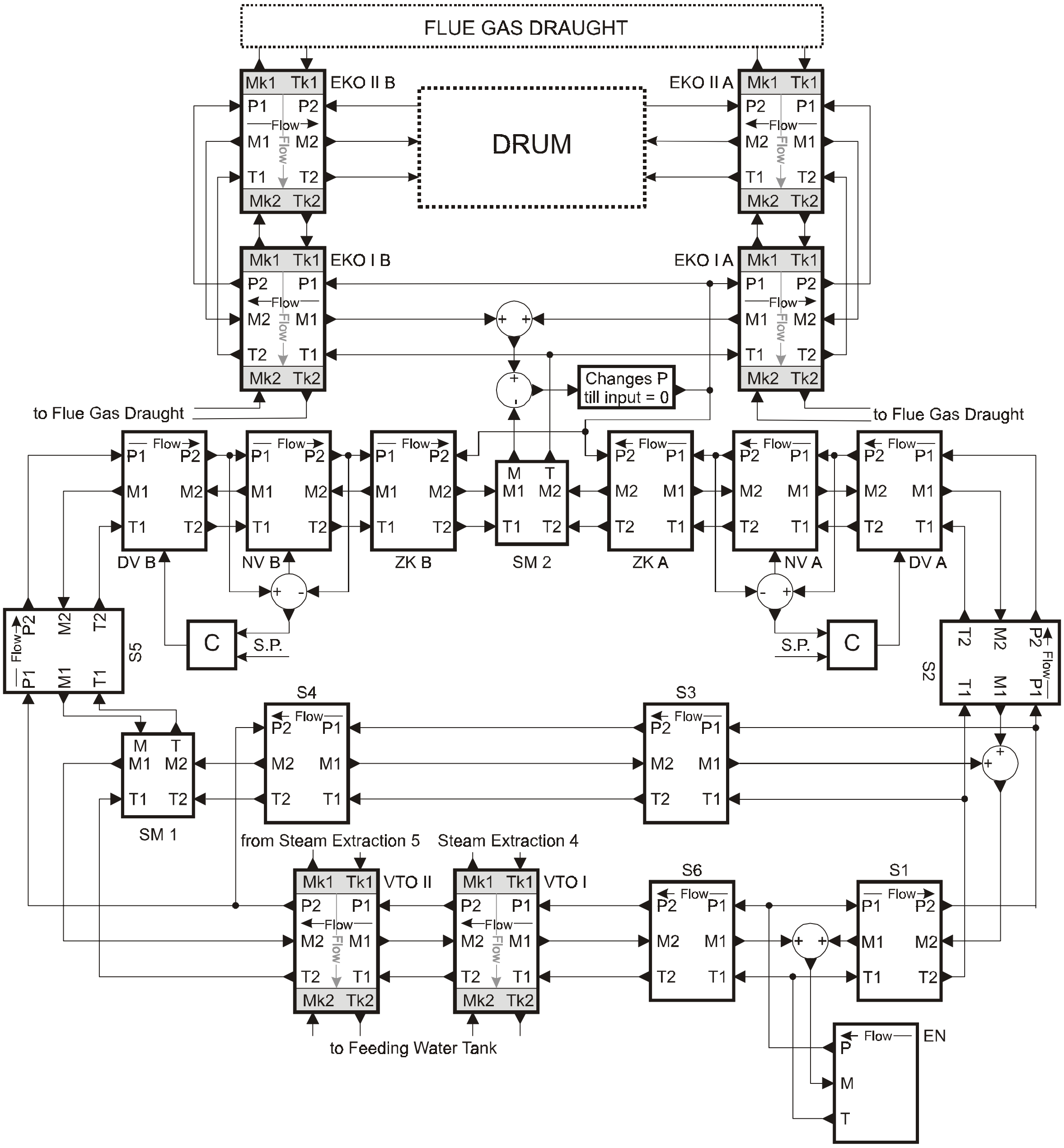

Fig. 3 Multi-pole scheme of feeding water

4. CONCLUSIONS ON REALITY-ORIENTED MODELLING OF THERMAL POWER PLANTS

Computer simulation is an important tool for investigating the dynamic behaviour of power plants and systems. It can supplement field tests (which are usually time consuming and expensive) or it may replace experiments (which are sometimes impossible). Our models should be very suitable, especially for learning and training processes. These models were succesfully applied on Operator Training Simulators.

5. ACKNOWLEDGEEMENTS

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