Modeling, simulation, and control of multi-fuel once-through boilers

MODELING, SIMULATION, AND CONTROL OF MULTI-FUEL ONCE-THROUGH BOILERS

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Abstract. Starting with an overview of the present situation and future developments in the electricity production in the Netherlands, the problem of fast and accurate control of large coal-fired power stations is posed. The origin of this problem is the unavoidable and increasing participation of coal-fired boilers in the short term load frequency control of the national grid. From this problem formulation stems the desire for an accurate and detailed dynamic model of a complete coal-fired electricity generating plant, targeted at evaluation of the performance of control schemes. Such a simulation model is not freely available and has therefore been developed. An overview of this model is presented and several details, *e.g.*, the modeling of the water/steam flow in the steam generator and the temperature and heat flux modeling in the furnace, are highlighted. The model is used to verify whether a proposed control concept meets (1) the specifications set forth by the Dutch electricity generating board and (2) additional technological considerations. It appears that the simulation model can fulfill its intended role and that the proposed control scheme is suitable for its task.

Key Words. Boilers; power plants; modeling; simulation; control system synthesis; control evaluation

1. INTRODUCTION

For the generation of electricity in the Netherlands large and medium scale installations, *e.g.*, power stations and cogeneration plants, are in operation. The share of the power stations in the national electricity production is diminishing, in favor of imports and of decentrally generated electricity. Today, there are many cogeneration plants and only a few large power stations. Several problems are associated with this shift from large scale and centralized to medium scale and decentralized.

In condensed form, the following problems are to be considered

- a tendency to use more natural gas firing is observed, countering the policy for fuel diversification
- an increasing part of the production capacity does not participate in the load frequency control of the national grid
- an overcapacity on the production side.

In view of these considerations, the building and operation of new cogeneration plants are now (temporarily) discouraged by the Dutch electricity generating board and the Dutch government does not issue permits for construction and operation at the moment. Several initiatives have been delayed or have been canceled. Currently, the conditions for allowances for decentrally generated electricity fed to the national grid are renegotiated. This discourages new initiatives for decentrally generated electricity. This is a pity, because the specific energy consumption per product is lower with cogeneration than with separate generation of power and heat.

Several measures could be taken to maintain grid reliability while allowing cogeneration plants to have a larger share of the total production. We will not discuss all possible measures, but focus on one of them: the improvement of coal-fired power station's rate of response. This should make it possible to follow load variations faster.

Coal is the main fuel for large power stations. This is a result of the policy for fuel diversification. Furthermore, the price of coal is attractive so coal-fired power stations, with the lowest variable costs, are constructed as base load units, but this is no longer acceptable. Large coal fired power stations increasingly have to contribute to the load frequency control, acting on load disturbances. So, these power stations do not have a privileged position as base-load unit but are stopped and started daily and have to comply with control speed requirements. These developments can be observed in many countries, not exclusively in the Netherlands.

To improve the capability of these plants to handle faster transients without endangering the lifetime of the boiler or turbine, due to rapid and large temperature changes, an assessment of the current control system capabilities and possible ways to improve these is necessary. In the last three decades European boiler manufacturers have put much work into researching the dynamics and control of boilers. Attention is focused on once-through boilers, because for these type of boilers better efficiency can be obtained by increasing the steam pressure. In addition, reliability, availability, and controllability are important issues for current research.

Several industrial firms and research centers have developed mathematical models or sub-models to describe dynamic phenomena of the boiler. The models vary between simple linear ones (Gebhardt *et al.*, 1988; Rettemeier, 1982) and complex nonlinear ones (Dupont and Sarlos, 1979; Bruens, 1981). A comprehensive set of rather simple models for cogeneration plants is presented in (Ordys *et al.*, 1994). Some models are based on first principles and others are validated by experiments. A complete model, describing the relevant dynamic phenomena in a wide range of operational modes, that is useful for process simulation and control strategy studies, and that avoids excessive computational costs, is not easy to come by.

The main contribution of this paper is the presentation of a mathematical model for coal-fired once-through boilers, valid and validated over a large range of loads, and that is quite efficient. It can be used to evaluate measures proposed to solve the problems mentioned above.

The paper is structured as follows. First, we provide additional background on the problem, and then introduce the control system and some simulation model specifications. Section 4 gives an outline of two components of the simulation model. Then Section 5 details some aspect of the implementation and the model validation. Section 6 presents user experiences and simulation results. Finally, Section 7 concludes the paper.

2. PROBLEM BACKGROUND

To perform economically and reliably their designated task, power stations, and ideally also cogeneration plants, have to be able to consume different types of fuel, to profit from the cheapest fuel source and to withstand disruption of a specific fuel supply. This striving is called fuel diversification. Due to this drive for diversification, coal has taken again an important role in the generation of electricity in power stations in the Netherlands, after being replaced by natural gas in the sixties. Due to technical, logistical, economical, and environmental considerations the use of fuels other than natural gas and heavy oil, *e.g.*, coal, is restricted to large power stations. The use of coal by cogeneration plants is negligible. Because the share of cogeneration plants is increasing, also the share of natural gas tends to increase, in disagreement with the fuel diversification policy. This trend is countered by the increasing use of coal by large power stations.

Cogeneration plants are mainly operated by industry, sometimes as a joint-venture with a distribution utility. They often have contracts that enable them to consume power from or to deliver power to the national grid. Normally they do not participate in the load scheduling or load frequency control because that could interfere with the normal production process. To reduce costs they apply, however, peak shaving strategies. So, the load scheduling and load frequency control has to be realized by power stations that have a diminishing share of the total production, while an increasing part of them is coal fired. This makes it necessary to participate with coal-fired boilers in the nation wide load frequency control of the national grid. So, it is no longer possible for a coal-fired plant to run at MCR (Maximum Continuous Rating) for a long time by participating in the base load scheduling only.

The government policy to reduce emissions of green house gasses, notably CO_2, has led to a covenant with industry where they agree to reduce their emissions of CO_2. The most important measure available is using cogeneration plants to generate power and heat with higher efficiency and by that reducing green house gas emissions. This has led to a stormy increase of the installed cogeneration capacity, from 11% to 21% of the electricity production in the last ten years, leading to an unanticipated surplus in the production capacity.

All these considerations lead to the problems noted in the Introduction.

3. CONTROL AND MODEL SPECIFICATIONS

It is well known that once-through boilers are well suited and capable of fulfilling the most arduous cycling duty as well as economical performance at part load. An overview and schematic arrangement of the double-pass once-through boiler (Benson type) of unit G13 of Gelderland power station are shown in Figs. 1 and 2. See (Roozendaal and Stibbe, 1981) for more information of this unit.

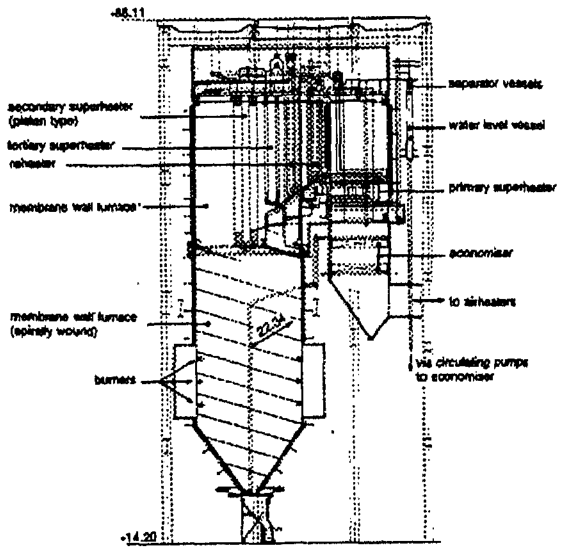

Fig. 1. Boiler of Gelderland power station unit G13

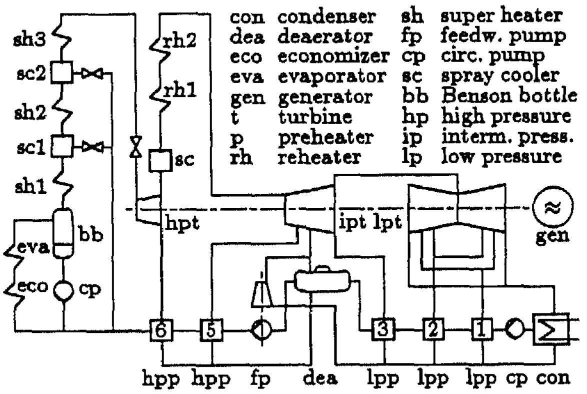

Fig. 2. Schematic of water/steam cycle of unit G13

Following a major accident, a power system may experience large disturbances in voltage and frequency and heavy loadings on the transmission system. Based on extensive simulations, the SEP (Dutch "national electricity generating board") has set out rules that the power production system should fulfill. These rules are based on a potential major disturbance, under which the grid frequency drops but is not allowed to approach the setting of safety limits for too low net frequency at intermediate points in the national grid. This all to avoid too large stresses on the system and its components that may result in cascading and tripping of certain equipment in the national grid, by that leading to the formation of electrical islands, loss of generation, and under-frequency load shedding. Using typical operating conditions for the national grid there are two standard requirements for all power generating plants connected to the grid. They should be able to

1. ramp up their production with 3%/min of MCR
2. follow a 5% step of MCR within 30 [s].

Beside the guidelines of the SEP other technological issues must be considered. If the steam temperature variations inside the boiler and at the entry of the turbine were not limited, the first SEP requirement would be no problem. Specifications set up by the association of turbine manufacturers advise to not exceed the design temperature of steam entering the turbine by 5°C or more during normal operation. Furthermore, steam temperatures inside the boiler, normally the exit temperature of the last stage super heater and reheater, but often also temperatures at intermediate points, are not allowed to exceed a certain fixed temperature. Temperature gradients in the high pressure parts of the boiler are limited. Also, the furnace exit flue gas temperature and flue gas velocities in the flue gas ducts are limited. Exceeding these limits shortens the lifetime of the boiler, possibly falling below the design lifetime, demanding an expensive preliminary overhaul with additional stop in production. So, temperature level and gradient and load increase gradient are limited.

These considerations may conflict with attaining the SEP requirements. Some solutions for this potential conflict are:

1. changes in the operating policy, *e.g.*, by setting the main turbine valves in a slightly closed position (modified pressure operation)
2. changes in the construction or changes in the control system structure or controller tuning.

The first solution, however, leads to decreased boiler efficiency, increasing the varying costs of operating the plant, and therefore increases the emissions, *e.g.*, of carbon dioxide, per unit of power generated. This is not desirable, so, the second solution seems a more promising road to solve the potential conflict.

Changes in the plant construction are only feasible in the design stage or, due to the costs of modifications, only under special circumstances in existing installations. Sometimes a redesign of the control system is appropriate. Several modifications to a basic control structure, in use nowadays at several power generating plants, have been proposed. This includes multivariable controllers. Their effectiveness can in principle be shown in practice only. Due to limitations on the modifications and experiments that are possible, a thorough verification is not feasible in general. Also, experiments on the plant are very expensive, mainly because of temporary reductions in generated power. So, the effectiveness of the proposed controllers cannot be evaluated easily in practice. The route taken therefore is to evaluate several control structure modifications with a reliable simulation model.

Once-through boilers do have a flexible end of saturation. The heat surface available for evaporation and superheating changes dependent on the steam production. The end of saturation must be limited to the end of the upper region of the combustion chamber. Below a load of 40% of MCR forced flow circulation is required to protect the evaporator from overheating. This also avoids flow instability phenomena. For this purpose a Benson bottle and circulation pump are installed. This means that pump and bottle are part of a feedback loop, the recirculation loop. When the storage capacity of this system is too low, flow and pressure oscillations can occur. The simulation model must provide for a study of the stability of the circulation mode of operation between 25% and 40% of MCR, where 25% of MCR is the lower limit of operation with coal firing.

Simulation of the start/stop mode of operation is beneficial, *e.g.*, for the dimensioning of the Benson bottles and the level control valves used to get rid of the excess water in the economizer and steam generator, and should therefore also be provided by the simulation model.

Several years ago simulation models for power stations were hard to come by and were not freely available. Commercial models were expensive and seldom sufficiently flexible to handle all types of equipment encountered in practice. Also, often problems surface using commercial codes due to bugs and inadequate documentation. The use of these models therefore requires a major investment of the buyer. To get past these problems, it was decided some years ago to develop a model in-house with substantial participation of academia.

To reliably predict the effects of potential modifications, the simulation model must have a high level of verisimilitude. To guarantee this a research program was devised, financed by the Netherlands Ministry of Economic Affairs, in the framework of the NOK (National Research Program Coal) to stimulate research that enables industry to comply with the fuel diversification policy. A part of this NOK was therefore devoted to research that aims at improving the dynamic behavior of power generating plants fueled by coal.

4. SIMULATION MODEL

The model used for simulation purposes is in part based on first principles, be it laws of physics for mass, impulse, and heat conservation, or the chemical model for the coal combustion, in part on experimentally determined correlations, *e.g.*, for the heat fluxes (Nu numbers), in part on the best available data, *e.g.*, for the properties of water, steam, flue gas, and construction materials, and partly on heuristic models of complicated equipment where a detailed model is not necessary to reliable predict the dynamic behavior of the unit.

Due to the model requirements, it was not possible to neglect the fast dynamics nor the influence of gravity and operation under atmospheric pressure. This poses severe difficulties for the simulation model that must describe effects on time scales that may differ by several orders of magnitude and of medium properties that change substantially, with additionally constraints on the computational speed that should preferably be real time for use in realistic power plant simulators. How these problems are approached is mentioned later.

Initially, only the main components in the steam generating part of the power station were included in the model, *e.g.*, the preheaters for the boiler feedwater were neglected. This made the formulation of correct boundary conditions and the computation of the generator output problematic. It was therefore decided to model all components on the thermal side that transfer at least 1% of the total heat flow, so the complete water/steam cycle is included and only a few easy to acquire boundary conditions are needed. This implies that the deaerator, steam turbine powered feedwater pump, condenser, and all preheaters, even the generator's H_2 cooling system, are included in the model. This also makes it easy to compute the steam flows through and enthalpy losses in the stages of the turbine, because all turbine bleeds are accounted for, even the steam losses through the glands.

The model constructed is too extensive to enable a complete description in this paper. Some parts of the model are considered proprietary and cannot be disclosed. Only some model components based on first principles are discussed, namely the pipe flow and furnace models.

4.1. *Boiler pipe flow model*

In this section we discuss the model for the water/steam flow in the boiler.

The modeling assumptions have to be selected with care in order to include all physical effects relevant for the particular dynamic event to be investigated. For instance, if pressure transients after a turbine trip are studied, it is essential to include the full momentum balance. Often physically unjustified simplifications have been made due to numerical stability problems, for instance quasi steady state assumptions to avoid stiffness problems. To avoid excessive computing costs it is always necessary to make some simplifying assumptions in the numerical solution, however they must not affect the required model accuracy. In this study the physical effects are modeled and solved by a very stable implicit numerical method described in (Anneveld, 1987).

The equations are derived under the following assumptions

1. a single spatial coordinate suffices to describe the relevant phenomena
2. one reference tube represents all parallel tubes
3. axial heat conduction is negligible
4. the two-phase flow is quasi-homogeneous.

The mass, momentum, and energy balances for the flow may now be written as, respectively

$$\frac{\partial \rho}{\partial t} + \frac{\partial G}{\partial z} = 0$$

$$\frac{\partial G}{\partial t} + \frac{\partial G^2/\rho}{\partial z} + \frac{\partial p}{\partial z} = -\rho g \cos\varphi - \tau_w S/A$$

$$\rho\frac{\partial h}{\partial t} + G\frac{\partial h}{\partial z} - \left(\frac{\partial p}{\partial t} + \frac{G}{\rho}\frac{\partial p}{\partial z}\right) = qS/A$$

using as state variables the mass flow density G, specific density ρ or pressure p, and specific enthalpy h. The other variables are time t, space coordinate z, acceleration of gravity g, angle to vertical φ, friction factor τ_w, heat flux q, and tube inner circumference and flow area S and A.

The constitutive equation $\rho = \rho(p, h)$ relates the thermodynamic states. In the two-phase region the states are averaged by void fractions. The fluid velocity in once-through boilers is sufficiently high to neglect slip between phases.

The spray coolers are special because they have additional source terms for the balance equations. This poses no mathematical problems, but care should be taken in discretizing the partial differential equations.

Boundary conditions are specified for mass flow and enthalpy at the entry and for the pressure at the exit of the system.

The correlations describing heat transfer and friction, needed to compute the heat flux q and friction factor τ_w, are taken partly from (VDI, 1994), are fairly complex, and are not detailed here.

4.2. *Furnace model*

In the boiler furnace the main heat transfer mechanism is radiation. Conduction and convection are less important due to the high temperatures in the furnace.

The following assumptions are used in the model

1. stationarity of the system
2. thermodynamic equilibrium
3. 1-dimensional temperature distribution
4. gas emission and absorption factors are equal
5. only isotropic scattering
6. plug flow with superimposed recirculation in the burner region.

Some additional simplifying assumptions are related to particle radiation.

Several methods are available to compute the heat transfer in the furnace. An accurate, albeit compute intensive, method is by ray tracing and Monte Carlo methods. This method is suitable for detailed furnace models, but not for a complete power plant model where the furnace is only one of many components.

A simple, but quite accurate, method is the one proposed in (Hottel and Sarofim, 1967) using a zone or diffusion type of computation for the heat transfer. This method has the advantage that computations related to the geometry of the radiating volumes and surfaces, *i.e.*, the direct exchange areas, can be computed in advance and be retrieved later from a data base for more specific computations. This enables a significant reduction in computing time.

For application of this method the furnace is divided in finite volumes and surfaces with simple geometries. In this application we only use cubes, squares and triangular shapes as basis geometric elements.

Given the finite volumes and surfaces and their relative orientation a computation of heat exchange factors is possible for clear gasses. However, real gasses, especially H_2O, CO_2 and SO_2 are not clear and absorb and emit, and do this in spectral bands. Because the spectral distribution of radiation depends on temperature, T, the emission and absorption of real gasses are also temperature dependent. It is possible to fit temperature dependent relations to spectral dependent data with sufficient accuracy to assume that all spectral dependency is captured by temperature dependency. For this at least three "gray" gasses are needed for radiation occurring in furnaces (VDI, 1994), so the emission coefficient ε_g and absorption coefficient α_g are computed by

$$\varepsilon_g = \alpha_g = \sum_{i=1}^{3} a_i(1 - e^{-k_i l})$$

where the parameters $a_i = a_i(T)$ and k_i are fitted. The value for k_i depends on the partial pressure of the radiating gasses and the "concentration" of ash, soot, and cokes particles in the flue gas and flames. The values for these parameters are taken from (VDI, 1994). The length l is characteristic for the size of the geometric elements and the value of $k_i l$ determines if the zone ($k_i l < 3$) or diffusion ($k_i l > 3$) method should be used for the computation.

The computation goes as follows: compute the mass balance, assume a temperature distribution, compute emission and absorption coefficients, find the direct exchange areas for each grey gas as functions of $k_i l$, compute the total exchange areas to account for reflections and scattering, compute the radiation and the convection energy exchange, make up the total-energy balances for each zone, finally, iterate on temperature to obtain equilibrium.

All these computations are rather standard, see (Hottel and Sarofim, 1967) and (VDI, 1994). The main problem is to figure out a suitable furnace geometry for division in finite volumes and to find the boundary conditions for the model, especially the conditions at the furnace exit, consisting of the flue gas duct entry and the platen super heater, see (Mobsby, 1979) for the approach followed by us. The smallest characteristic size considered is the height of a layer of coal burners. All other sizes are multiples of this size.

An additional problem is the geometry of the furnace boundary (wall) that is not a convex hull, making a work around to compute exchange areas necessary. The use of non-rectangular finite volumes in the furnace hopper makes a nonstandard computation necessary. These computations will not be detailed here. They merit a separate presentation.

Initially the computation made use of the exchange areas according to (Hottel and Sarofim, 1967; Figs. 7-13 to 7-17) but then the global energy balance was not correct. A further investigation showed that the lines in these figures were not very accurate, because obtained by graphical integration and because the correct values are also not exactly on a straight line in a semi-logarithmic figure. Also, some labels indexing the configuration in at least (Hottel and Sarofim, 1967; Fig. 7-14) were not correct. Therefore the exchange areas were recomputed to the desired relative accuracy of better than 1% by volume integration. The number of geometry configurations considered was extended also, covering all those needed for the furnace model. Using the adapted parameters for the exchange areas gives a correct energy balance.

The furnace model is rather sensitive for variations in the furnace wall absorption coefficient that is not accurately known and depends on the fouling of the walls and temperature. In our application this parameter is used to fit the furnace exit temperature to measured data. The fitted value was within the range reported in other studies, indicating the gross correctness of the model.

5. SIMULATION PROGRAM

The equations for the model make up a set of PDEs (partial differential equations), ODEs (ordinary differential equations), and AEs (algebraic equations). Some algebraic equations are implicit and cannot be solved analytically.

Approximations are necessary to numerically solve the equations in space and time. Mass flow Φ is used as state instead of G to make the computation easier and more accurate. The reference tube has widely varying flow area A as function of the coordinate z, so while Φ is continuous the mass flow density, $G = \Phi/A$, is discontinuous, making it less attractive. First, the three coupled PDEs for the water/steam flow were rewritten, with only Φ, p, and h as state variables, using ideas of flux-splitting and characteristic methods. They are discretized in space and time by a specially developed implicit scheme, leading to upwind approximations for the space derivatives to assure a stable numerical computation, with good approximation to the exact solution. The implicit scheme assures a speedy simulation on a large time scale once the pressure waves are damped out.

Secondly, the PDE for the tube wall is discretized by a collocation type method using four state variables for the space direction. This gives a high accuracy solution, also for time varying boundary conditions.

Thirdly, the convection and radiation heat fluxes in the furnace are set up for a medium consisting of three components with different properties depending on temperature, to account for frequency dependent radiation. A polynomial represents the relation between enthalpy and temperature of the flue gas. This leads to a set of nonlinear equations, polynomials to the fifth power in the temperature, solved by Newton iteration. Typical effects associated with coal firing, like soot, ash, and cokes assisted radiation, are included, leading to an outer Picard type iteration.

Using the model for a power plant requires the use of water/steam properties. Because the medium used for transporting the energy goes through several stages (sub-cooled, saturated, superheated both subcritical and supercritical) the region for which the water/steam properties have to be valid is large. Many water/steam property routines show numerical inconsistencies, *e.g.*, when passing from subcooled to saturated, saturated to superheated or subcritical to supercritical or vice versa. The standard techniques were replaced by interpolation techniques using cubic splines to overcome these numerical problems.

The sets of implicit equations are solved in several ways. For the equations at a low level of the simulation model, *e.g.*, the relations for the steam properties and those to compute the heat fluxes, Newton or secant type iteration methods are used. Here, the derivatives are relatively easy to compute. An advantage of Newton's method is its fast convergence. At an intermediate level, for the solution of the discretized equations for the water/steam flow, a SBGS (symmetric block Gauss Seidel) method is used, exploiting the structure and properties of the relatively large set of linear equations. For the iterations at a high level, *e.g.*, the coupling between the system components, a Picard type iteration is used because now derivatives are hard to come by. A disadvantage is the slow rate of convergence for Picard iteration.

The formulae, numerical methods, *etc.*, needed to compute a time marching solution of the model equations, were programmed in a modular way and in a suitable programming language. The division in modules was partly based on the system components, partly on the type of equations, and partly on the medium flows. Using this setup and not overly stringent accuracy requirements, the simulation runs in real time or faster for smooth variations in operating conditions. Beside the time marching solution, other options, *e.g.*, trimming the model to a desired steady state, are also included.

Extensive tests validate the model. Checks performed on all modules and the complete model include

- simple test cases, *e.g.*, wave front propagation for the water/steam flow model
- global mass, impulse, and energy balances in steady state and during transients
- comparison with design data in steady state
- comparison with real plant data during steady state and transients
- comparison with black box models derived from experimental data (Aling, 1990).

From these checks it was concluded that the model was consistent but that some differences appeared with the design and experimental data, see Fig. 3 for some results of unit G13.

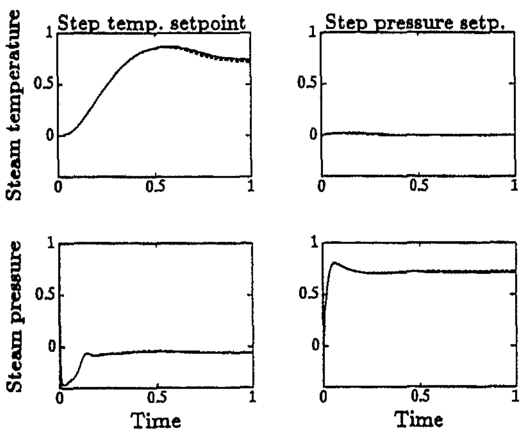

Fig. 3. Comparison of simulation (—) and filtered measurements (- -), arbitrary units

The margin of error was, however, mostly within the uncertainty of the design computations and within the natural variations in the plant. We remark that not all effects and modes of operation of a coal-fired power station are included, *e.g.*, fouling, soot attachment, or soot blowing are not modeled.

The main disadvantage of the present implementation is that it is not fully parameterized, *i.e.*, to model a completely different boiler it is not sufficient to change parameter files describing the components, changes in details of the source code are necessary.

6. EXPERIENCES AND RESULTS

The model has been used in four ways.

First, during the design period of a power plant as an engineering tool to evaluate the parametric design. For instance, placement and size of super heaters, reheaters, and spray coolers were evaluated. With simulation results as a feedback, plant optimizations have been achieved.

Secondly, power plant control schemes were tested and optimized. Also, initial values for the controller parameters were determined to shorten the commissioning period. This leads to a reduction of unproductive power plant hours which means a considerable cost reduction. Also, costly tests on the actual power plant can be reduced.

Thirdly, the model including the control schemes was used to prove that the design meets the SEP requirements regulating power plants as discussed above.

Lately, a fourth benefit has been derived. Namely training and education. Using the model in a training simulator environment, operators can be taught what the dynamics of a particular power plant are and can be trained to cope with hazardous situations or exercise procedures that are seldom encountered, *e.g.*, in a stop and start situation.

Working with the model takes three steps.

First, all geometry dependent routines have to be adapted for the power plant under consideration and the control schemes have to be set up.

Secondly, a steady state has to be determined using design data sheets. This is done by entering several boundary conditions. These values can be entered using an input data file. After entering the boundary conditions the model performs an initiative computation with which the mass, energy and impulse balances are evaluated on these boundary conditions.

The third step is a dynamic simulation that uses the implemented control schemes. With this option controlled behavior is tested and evaluated.

For an evaluation of control structures several variants of a basic load control scheme were set up for the model. Extensive simulation studies, including some relevant load control scenarios, were carried out. Representative results are in Fig. 4. It shows the generated power, coal flow, and boiler exit steam pressure and temperature for a required 3%/min of MCR increase from 40% to 100% of MCR, a substantial increase of the generated power. Unit 8 of the Hemweg power station, rated at 640 MWe and commissioned in 1994, is simulated. Here, the load control requirement and boiler exit temperature specification are met.

7. CONCLUSIONS, RECOMMENDATION

The main conclusion of this study is that an extensive boiler simulation model has been developed and validated. The model can be used

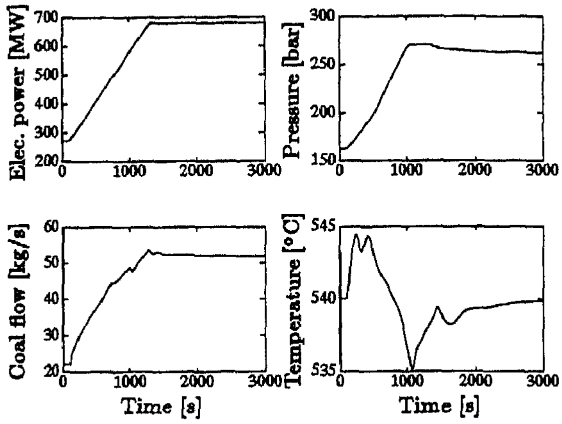

Fig. 4. Response of Hemweg unit 8 to request for increase of power of 3%/min from 40% to 100% of MCR

1. as an engineering tool during power plant design
2. to find pre-installation values for the control parameters, thus reducing unproductive power plant hours during commissioning
3. to test and evaluate new control strategies
4. as a basis for a training simulator.

It is not quite clear if the model is worth the effort to be kept up-to-date and to be made more user friendly, or if commercially available simulation codes should be used instead. This should be investigated further.

Acknowledgment

This research was partly financed by the NOK program of the Dutch Ministry of Economic Affairs, coordinated by PEO. The research was carried out with the help of several engineering departments within Stork Boilers B.V., whose contributions are gratefully acknowledged.

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