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Modelling, simulation, identification, and model-based control of integrated fuel-cell-based power plants

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Abstract: In this contribution, a fuel cell-based power plant which uses water and methane to produce electrical power is considered. While earlier publications deal with the fuel cell only, this contribution takes the whole plant into account. The distributed modelling of the hydrogen producing reformer unit is presented. Methods are developed which allow for a fast and efficient simulation of the model equations. As the other parts of the power plant are of similar dynamical structure, the simulation methods are easily transferable. The identification of parameters for the power plant is performed on the basis of measurements and dynamic simulation. Sophisticated control concepts for the optimal operation of the power plant are proposed. They consider the whole plant and couplings between the various elements to maximise the plant's efficiency.

Keywords: Modeling, operation and control of power systems; Control system design; Intelligent control of power systems

1. INTRODUCTION

In recent years the interest in fuel cell systems (FCS) has grown, for they are environmentally friendly and effective resources of electricity and are widely regarded as a potential alternative power source for both stationary power plants and automotive applications Laboratory [2002], Pad [2000]. A Proton Exchange Membrane (PEM) fuel cell converts the chemical energy of hydrogen into electrical power with water as the only byproduct. The hydrogen is provided by a reformer unit which uses a catalytic reaction to split up water into its basic substances, hydrogen and oxygen. This chemical reaction is powered by gaseous fuels, such as methane and ethane, which are re-newable resources. Thus, the use of fuell cell-based power plants decreases the dependence on fossil fuels.

Fuel cell-based power plants comprise a large variety of different components, including electrical, mechanical, thermal, and chemical systems. The dynamics of all these components has to be incoprorated into a system description in order to develop control concepts for the optimal plant operation.

In literature, there are a number of publications available which deal with the topic of fuel cells, their modelling, simulation, and control. One of the first publications dealing with the dynamic properties of PEM fuel cells is P. Argyropoulos and Taama [2000], who applied loading cycles on a direct methane fuel cell (DMFC) in order to evaluate the effect of the loading pattern and operating conditions on the response behaviour of the fuell cell. Eborn et al. [2003] presents a model for a PEM fuel cell based on numerical modelling tools, such as Modelica. However, equation-based models are not presented as they cannot be extracted from the modelling tools. Boccaletti et al. [2006] present and compare models for fuel cells using PEM and Solid Oxide Fuel Cell (SOFC). The models are veryfied by experimental results. Pukrushpan et al. [2004] present a fuel cell model for automomtive fuel cells which is suitable for the development of controllers and show the observability of the linearised model. However, the design of controllers is not performed.

The publications mentioned above deal only with the fuel cell itself. The hydrogen which is needed for the production of electricity is provided by a tank. The present contribution, however, takes the whole plant, consisting of reforming unit, shifting unit, and the fuel cell, into account. This allows the development of system-wide control strategies which consider every part of the plant and couplings to ensure the optimisation of the overall efficiency of the plant.

This contribution is organised as follows. After stating the task in Section 2, a model for the FCS is presented in Section 3. As the resulting distributed model is higly complex and thus hard to simulate, a modal transformation is applied in Section 4. Subsequently, Section 5 shows the identification of model parameters. Having a complete model, Section 6 points out various control approaches which can be used to optimise the efficiency of the plant. Section 7 concludes the contribution.

2. TASK AND PROBLEM FORMULATION

The task of this contribution is to provide a framework for the simulation, identification, and control of fuell cell-based power plants which are powered by re-newable energy resources, such as methane, ethane, and dimethyl ether (DME).
While earlier publications (cf. Section 1) often deal with the fuel cell only, here the whole power plant is considered and a program package is provided which allows for the automated simulation and identification of fuel cell-based power plants. This prepares the ground for the development of sophisticated control algorithms which optimise the overall efficiency of the power plant.
Figure 1 shows the general layout of an FCS consisting of three basic units: the reformer unit, the shifting unit, and the fuel cell stack. The task of the reformer unit is to produce hydrogen which is used by the fuel cell stack to produce electrical power. The hydrogen is produced through chemical reactions of water and fuel. The task of the shifting unit is to reduce CO, which emerges from the fuel burning, to CO_2. Here, the functionality of the fuel cell is not discussed in detail. The reader is referred to literature, e. g. Laboratory [2002] and Zenith [2007].

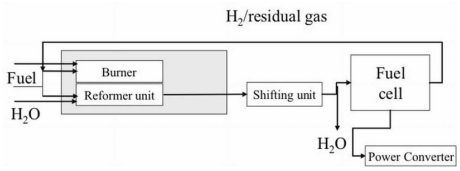

Fig. 1. Layout of a fuel cell system

Due to space restrictions of this contribution, here, the modelling and simulation is addressed for the reformer only. The models for the shifting unit and the fuel cell itself, however, are of similar structure and therefore the same simulation methods can be applied to these parts of the system. The identification of model parameters is shown for the shifting unit and control concepts are proposed for an overall plant control.
The tasks considered in this contribution are divided into four steps:

(1) Modelling all neccessary elements, such as reforming and shifting unit as well as the fuel cell itself leads to a coupled system with distributed parameters
(2) Simulation of the (nonlinear) PDEs by modal transformation to shorten simulation time
(3) Identification of unknown parameters through measurement data (stationary and transient)
(4) Sophisticated controller design for the complex structure of the FCS which takes the nonlinearities and couplings between the elements of the plant into account and guarantees robustness.

3. MODELLING

This section reviews the modelling of the reformer unit of a fuell cell-based power plant. The task of the reformer unit is to form hydrogen from water (H_2O) and heat. Thus it is the first part of a fuel cell-based power plant. The heat is provided by fuel gases like methane and ethane. If methane is used as fuel gas, the reactions taking place in the reformer are:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \quad (1)$$
$$CO + H_2O \rightleftharpoons CO_2 + H_2 \quad (2)$$
$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2 \quad (3)$$

While CH_4 and H_2O are inputs to the reformer, hydrogen, carbon dioxide, and small amounts of carbon are outputs. The hydrogen is then passed on to the fuel cell where the reactions take place which converts the chemical energy to electric power.
The processes in the reformer are complex, for the reactions take place in different phases (fluid and gaseous) and the reaction kinetics depend on many variables, such as the reactor temperature and the partial masses of the substances in the reactor. Figure 2 shows a sketch of the reformer unit including the phases as well as the input (both gaseous) and output fluxes fuel, water, hydrogen, and carbon dioxide. For model simplifications, the temperature in the reactor is assumed to be homogenous, i. e. the catalytic phase (solid phase) is not considered.

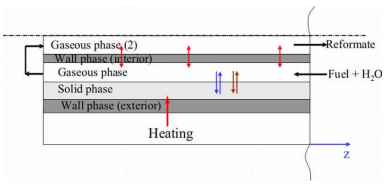

Fig. 2. Model assumption (Reformer)

The quasi-homogeneous model is written as a set of partial differential equations (PDEs). The states of this system are the gas temperature T in the reformer, the mass fractions w_j of the components, the temperature T^{W_i} on the inner wall, the temperature T^{W_e} on the outer wall of the reformer, and the temperature T^E of the educts. The following subsections show the PDE for each of these states, including the initial and boundary conditions. The derivation of the reformer model equations can be found in literature, e. g. Froment and Xu [1989].

3.1 Energy balance model of the reactor temperature

The energy balance is formulated as the following second order PDE

$$\frac{\partial T}{\partial t} = b_2^T \frac{\partial^2 T}{\partial z^2} - b_1^T \frac{\partial T}{\partial z} - b_0^T (T - T_F) + f_T(T, w_j), \quad (4)$$

with parameters b_0^T, b_1^T, and b_2^T which have to be identified. The function $f_T(T, w_j)$ describes the influence of the chemical reactions on temperature change. The initial condition and boundary conditions are

$$\left.\frac{\partial T(z,t)}{\partial t}\right|_{t=0} = T_{in} \qquad \left.\frac{\partial T(z,t)}{\partial z}\right|_{z=L} = 0$$
$$\left.\frac{\partial T(z,t)}{\partial z}\right|_{z=0} = \frac{b_1^T}{b_2^T}(T(0,t) - T_{in}). \quad (5)$$

3.2 Mass balance model

The mass balance equations show the evolution of the partial masses of the substances which are involved in

the chemical reactions (cf. (1)-(3)) taking place in the reformer. PDEs are only written for two substances, the so-called key components of the reaction, namely for CH_4 and CO. The partial masses of the other substances are calculated by algebraic equations (which are not shown here).

$$\frac{\partial w_j}{\partial t} = b_2^{w_j}\frac{\partial^2 w_j}{\partial z^2} - b_1^{w_j}\frac{\partial w_j}{\partial z} + b_0^{w_j} f_{w_j}(T, w_j) \tag{6}$$

with parameters $b_0^{w_j}$, $b_1^{w_j}$, and $b_2^{w_j}$ which have to be identified. The function $f_{w_j}(T, w_j)$ describes the changes of the mass balances due to the reactions. The initial conditions and boundary conditions are

$$\begin{aligned} \left.\frac{\partial w_j(z,t)}{\partial t}\right|_{t=0} &= w_{j,in} \qquad \left.\frac{\partial w_j(z,t)}{\partial z}\right|_{z=L} = 0 \\ \left.\frac{\partial w_j(z,t)}{\partial z}\right|_{z=0} &= \frac{b_1^{w_j}}{b_2^{w_j}}(w_j(0,t) - w_{in}(0,t)). \end{aligned} \tag{7}$$

3.3 Energy balance model for the reactor wall

The energy balance model describes the behaviour of the temperature of the inner wall phase (cf. Figure 2):

$$\frac{\partial T_{W_i}}{\partial t} = b_2^{T_{W_i}}\frac{\partial^2 T^{W_i}}{\partial z^2} - b_1^{T_{W_i}}(T_{W_i} - T) + b_0^{T_{W_i}}(T - T_{W_i}), \tag{8}$$

with parameters $b_0^{T_{W_i}}$, $b_1^{T_{W_i}}$, and $b_2^{T_{W_i}}$. The initial conditions and boundary conditions are

$$\begin{aligned} T_{W_i}(z,t)|_{t=0} &= T^0_{W_i} \\ \left.\frac{\partial T_{W_i}(z,t)}{\partial z}\right|_{z=0} &= 0 \qquad \left.\frac{\partial T_{W_i}(z,t)}{\partial z}\right|_{z=L} = 0. \end{aligned} \tag{9}$$

The energy balance for the outer wall phase is similar to (8) and is derived by replacing T with T^E, T_{W_i} with T_{W_a}, and T^E with T^U.

3.4 Energy balance model for the educts

The energy balance model for the educts is an important part of the system description, for the educts form a coupling to other elements of the power plant. The PDE describing the behaviour of the temperature of the educts reads

$$\begin{aligned} \frac{\partial T^E}{\partial t} = b_2^{T^E}\frac{\partial^2 T^E}{\partial z^2} + b_1^{T^E}\frac{\partial T^E}{\partial z} \\ + b_{10}^{T^E}(T_{W_i} - T^E) + b_{11}^{T^E}(T_{W_a} - T^E). \end{aligned} \tag{10}$$

The initial conditions and boundary conditions are

$$\begin{aligned} T^E(t)\big|_{t=0} &= T^{E_0} \qquad \left.\frac{\partial T^E(z,t)}{\partial z}\right|_{z=L} = 0 \\ \left.\frac{\partial T^E(z,t)}{\partial z}\right|_{z=0} &= \frac{b_1^{T^E}}{b_2^{T^E}}(T^E(L,t) - T^{E,0})\text{..} \end{aligned} \tag{11}$$

4. MODAL ANALYSIS USING GALERKIN METHODS

As shown in Section 3, the reformer unit is described by a system of seven partial differential equations (PDE). Using this model, Monte-Carlo simulations are performed to identify its parameters and to develop control strategies. However, the simulation of PDEs (e. g. by finite element methods) is a complex task and makes high computational demands.Therefore simplifications are made which, on the one hand, reduce the computational demands and, on the other hand, preserve the accuracy of the model. In this section, a simplification is performed by transforming the system such that it is represented by a set of ordinary differential equations (ODE). Using a modal analysis based on the Galerkin method, the influence of the spacial differential operator D_z (cf. (14)) on the system dynamics is calculated off-line and the differential equations are solved with respect to time only.

Here, the modal analysis and transformation is carried out exemplary for the PDE describing the reactor temperature T (cf. (13)). As the structure of the other PDEs in the system is similar, the same analysis and transformation procedure is applied. In the context of this work, the transformation is automated by using a computer algebra system to minimise the effort of model transformation.

As the PDE describing the temporal and spacial behaviour of the reactor temperature (cf. (13)) has non-homogenous boundary conditions, the first transformation step consists in splitting the temperature into a homogenous and an inhomogenous part:

$$T = T_H + T_I. \tag{12}$$

Having a constant $T_I = T_{in}$, the homogenous temperature PDE reads

$$b_t\frac{\partial T_H}{\partial t} - b_2\frac{\partial^2 T_H}{\partial z^2} + b_1\frac{\partial T_H}{\partial z} + b_0 T_H = RS(w_j, T) \tag{13}$$

with parameters b_i^T, $i = 1, 2, 3$ and

$$RS(W_j, T) = f_T(w_j, T) - a_t\dot{T}^+ - a_0 T_{in}.$$

The nonlinear function $f_T(w_j, T)$ depends on the reactor temperature and mass fractions with initial conditions and boundary conditions as stated in Section 3. By defining the temporal and spacial differential operators

$$D_t = \frac{\partial}{\partial t}\ , \quad D_z = -b_2^T\frac{\partial^2}{\partial z^2} + b_1^T\frac{\partial}{\partial z} + b_0^T, \tag{14}$$

the PDE (13) can be written in semi-linear form:

$$D_t T_H + D_z T_H = RS(w_j, T). \tag{15}$$

Similar to Gilles [1973], the solution of the PDE 15 is expressed by

$$T_H = \sum_{i=0}^{i=\infty} a_i(t)\varphi_i(z), \tag{16}$$

where $\varphi(i)_z$ are the eigenfunctions of the spacial differential operator D_z. The functions $a_i(t)$ are calculated by inserting the ansatz (16) into the PDE (15). The eigenvalues and eigenfunctions of D_z are calculated as a Sturm-Liouville-Problem (SLP) which is formulated as a boundary value problem (BVP):

$$\underbrace{-b_2\psi''(z) + b_1\psi'(z) + b_0\psi(z)}_{=D_z\psi(z)} = \lambda\psi(z) \tag{17}$$

with corresponding boundary conditions (cf. (5)) and eigenvalues λ. The eigenfunctions of D_z are the non-trivial

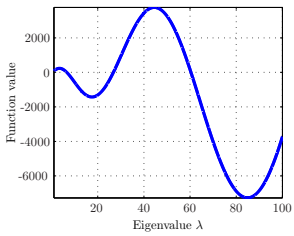

Fig. 3. Function for the determination of the eigenvalues of D_z

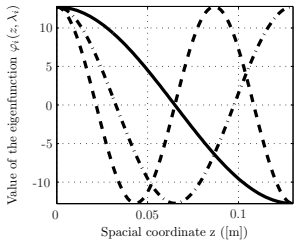

Fig. 4. Eigenfunctions φ_1 (-), φ_2 (-.-), and φ_3 (- -)

solutions of (17). The first step in solving the BVP (17) is to calculate its eigenvalues $\xi(\lambda)$ which are rendered by the characteristic polynomial:

$$\xi_{1,2}(\lambda) = \underbrace{\frac{b_1}{2b_2}}_{\alpha} \pm \sqrt{\underbrace{\frac{b_1^2}{4b_2^2} + \frac{b_0 - \lambda}{b_2}}_{\beta(\lambda)}}. \tag{18}$$

By using various ansatz functions and inserting them into the boundary conditions (cf. (5)), it can be shown that solutions only exist if the eigenvalues are of complex conjugated form, i. e. for $\beta(\lambda) < 0$ and thus $\lambda > \frac{b_1^2}{4b_2} + b_0$. The ansatz for the solution then reads

$$\psi(z) = \Big[A(\lambda)\cos(\beta(\lambda)z) + B(\lambda)\sin(\beta(\lambda)z) \Big] e^{(\alpha z)}. \tag{19}$$

Inserting the ansatz into the boundary condition (cf. (5) to (5)) renders

$$\underbrace{\begin{bmatrix} \alpha - \frac{b_1}{b_2} & \beta(\lambda) \\ C_1(\lambda)\cdot e^{\alpha L} & C_2(\lambda)\cdot e^{\alpha L} \end{bmatrix}}_{M(\lambda)} \cdot \begin{bmatrix} A(\lambda) \\ B(\lambda) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{20}$$

with

$$C_1(\lambda) = [\alpha\cos(\beta(\lambda)L) - \beta(\lambda)\sin(\beta(\lambda)L)] \tag{21}$$

$$C_2(\lambda) = [\alpha\sin(\beta(\lambda)L) + \beta(\lambda)\cos(\beta(\lambda)L)]\,. \tag{22}$$

Solutions of the BVP (17) only exist for values of λ for which the boundary conditions in (20) are fulfilled, i. e. for values of λ leading to $\det M(\lambda) = 0$:

$$\left(\alpha - \frac{b_1}{b_2}\right)\cdot C_2(\lambda) - \beta(\lambda)\cdot C_1(\lambda) \stackrel{!}{=} 0. \tag{23}$$

As the only unknown parameter of this function is λ, it is used to calculate the eigenvlaues of the spacial differential operator D_z. Figure 3 shows a plot of (23). The zeros of this function, and thus the eigenvalues of D_z, are calculated numerically. With having the eigenvalues calculated, the solutions of the BVP (17) are given by the ansatz function (19). From these solutions, the eigenfunctions of D_z are calculated by normalisation:

$$\varphi_i(z,\lambda_i) = \frac{1}{||\psi(z,\lambda_i)||}\left[A\cos(\beta(\lambda_i)z) + B\sin(\beta(\lambda_i)z)\right] e^{\alpha z},$$

with $A = 1$ and $B = \frac{(\alpha - b_1/b_2)}{\beta(\lambda)}$ and

$$||\psi(z,\lambda_i)|| = \sqrt{<\psi(z,\lambda_i), \psi(z,\lambda_i)>}.$$

The first three eigenfunctions are shown in Figure 4. After solving the BVP (17) and thus calculating the eigenvalues and eigenfunctions of D_z, the PDE (15) can, by using (16) and (17), be written as

$$\sum_{i=1}^{\infty} b_t \dot{a}_i(t)\varphi(z) + \lambda \sum_{i=1}^{\infty} a_i(t)\varphi(z) = RS(w_j, T). \tag{24}$$

Applying Fourier transformation and splitting up the N^{th} order ODE renders a set of first order ODEs having the form:

$$b_t \dot{a}_i(t) + \lambda_i a_i(t) = \int_0^L RS(w_j, T)\varphi_i(z)\rho(z)dz,$$

with $i = 1, \ldots, N$, and $\rho(z)$ as a normalisation function. These ODEs describe the modal temporal behaviour of the reactor temperature. The overall solution is obtained by simulation of the ODEs and application of (16).
By applying this tranformation to all PDEs describing the states of the reformer unit and to the PDEs describing the behaviour of the shifting unit and the fuel cell, the whole system is represented by a system of ODEs.

5. IDENTIFICATION

This section presents the identification of model parameters for the shifting unit. Due to space restrictions, the equations describing the dynamical behaviour of the shifting unit are not shown here. However, the identification of model parameters is presented to give an overview of the work going on at the moment. As the shifting unit model is of similar structure as the reformer model, the modal analysis presented in Section 4 is also applied to the set of describing PDEs to reduce model complexity.
With respect to identification, there are three classes of parameters.

- The first class contains the parameters which can be measured directly, such as reactor diameter or mass flux into the reactor
- The second class contains parameters which can be retrieved from literature, e. g. heat capacities.
- The third parameter class contains all unknown parameters which are difficult to measure and cannot be retrieved from literature exactly. Examples for these parameters are heat transfer coefficients.

While scale or sign of third class parameters might be known, they represent a certain degree of freedom to adapt the model to measurements from experiments. Usually, sophisticated statistic theories, such as least square fitting, are applied to calculate parameters which ensure high accuracy of the model with respect to measurements.
In the case of the shifting unit, the heat transfer coefficients of the unit's wall are unknown and have to be identified. The first identification step is carried out by measuring stationary values for the unit's temperature during experiments and adapting the heat transfer coefficients in order to reach a good estimate of the parameters in a least square sense:

$$\sum_t \left(T_m - T(t_i, w_j, a_1, a_2, \ldots, a_n)\right)^2 \rightarrow \min_{a_m} \tag{25}$$

Fig. 5. Fuel cell-based power plant at ZSW Stuttgart, Germany

Here, T_m is a set of measured temperatures at a various point in the shifting unit, $T(t_i, w_j, a_m)$ is the temperature at the corresponding point. The parameters $a_m, m = 1, \ldots, n$ are to be identified. In a second step, the transient behaviour of the reactor temperature is considered and the parameters are re-adapted.
Here, the identification results for heat transfer coefficients of the shifting unit are shown. The identification is carried out by using stationary measurements for which experiments are conducted at a $4kW_e$ plant at the Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) Stuttgart, Germany. See Figure 5 for a picture of the plant. Figure 6 and Figure 7 show the identification of the shifting unit's wall temperature and reformate temperature, respectively. One can see that the simulation produces very good results with respect to the stationary measurements (marked by dots). While the simulation differs from the measurements for some values of the heat transfer coefficient, for certain values the results are good. The results presented here have to be verified by

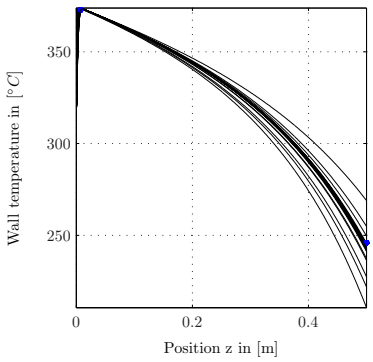

Fig. 6. Wall temperature of the shifting unit

using transient measurements. This is ongoing work at the moment.

6. CONTROL CONCEPTS

Various concepts for the control of fuel cells exist in literature. Vahidi et al. [2006] and Vahidi et al. [2007] aim at the power management and control of a fuel cell based on a linearised model. The feedforward trajectories are calculated via model predictive control (MPC) techniques. The applicability of the resulting controller structure is shown

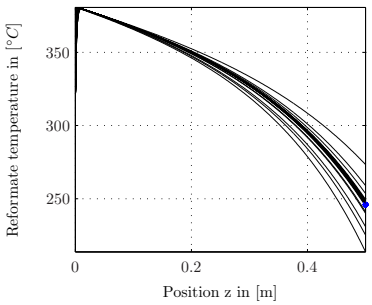

Fig. 7. Temperature of the reformate in the shifting unit

in simulation studies using a nonlinear model. Tsourapas et al. [2007] apply a control structure to the system which aims at operating the fuel cell at an optimal steady sate. The feedback controllers are designed by using linear quadratic techniques. The control structure, including a state observer, is applied to an experimental plant and its applicability is shown. Pukrushpan and Peng [2002] show a 2DOF controller structure for a PEM fuel cell. Linear feedback controllers are designed which provide robustness if the system is in steady-state. During transients, the feedback controllers are supported by nonlinear feedforward controllers. The robusteness and applicability of the proposed control structure is shown by simulations.
The goal of the control concepts discussed here, however, reaches beyond the control of the fuel cell only, for the aim is to develop control strategies which take the whole plant into account. Only a control strategy which consideres the couplings between the units of a fuell cell-based plant can provide an efficient process operation.
While taking the dynamics of the whole power plant into account, the final control concept has to make sure two basic requirements are fulfilled:

- robustness with respect to to parameter uncertainties and
- optimality with respect to a certain optimality condition.

Robustness is important for the operation of the plant for two reasons:

- not all parameters of the system are exactly known. While certain parameters are measured directly, others have to be identified by indirect measurements, based on a simulation model. The accuracy of the identification is directly related to the accuracy of the model. Even though the model presented in Section 3 is highly accurate, uncertainties persist.
- some parameters change over time. Aging effects in power plants are often a cause for loss of efficiency and operation safety. By taking aging effects into account in the modelling and the controller design, efficiency and safety are preserved.

The latter condition, the optimality, is formulated by the following optimisation formulation and ensures that the plant operates at maximum efficiency:

$$J = \max_{C} \int_{t_0}^{t_{end}} \left(\frac{P_{out}}{P_{in}} \right)^2 dt, \tag{26}$$

where P_{in} is the overall power input of the plant (e. g. fuel, heat) and P_{out} is the overall power output of the plant (i. e. electrical power). The maximisation argument C represents the set of available control concepts.
In the context of the work discussed here, control strategies are developed based on the model dynamics which are based on the physical process. Therefore, the controllers can be adapted to model modifications and can be transferred to other plants having a different scale. This leads to a significant decrease in time and cost for the future solution of such problems.
The development of system-wide control strategies is ongoing work at the moment. Figure 8, however, shows the two degree of freedom (2DOF) controller layout for the reformer unit which is similar to the one presented in Hagenmeyer and Zeitz [2004]. The feedback controllers are combined with feedforward controllers to optimise the reformer's behaviour and to guarantee robustness with respect to model uncertainties and disturbances. Furthermore, an observer structure is used to reconstruct unknown parameters and states of the system. The observer is also used to identifiy parameter changes which are due to deterioration effects. A challenge for the design of the

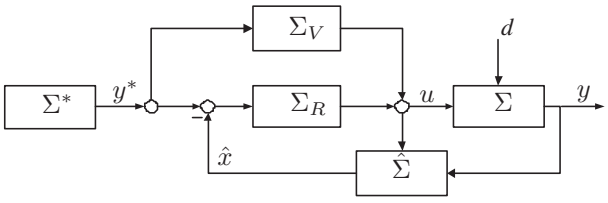

Fig. 8. 2DOF controller structure with system Σ, observer $\hat{\Sigma}$, feedback controller Σ_R, feedforward controller Σ_V, signal generator Σ^*, disturbance d, input u, and output y for tracking control $y(t) \to y^*(t)$.

controller elements is the fact that the dynamics of the system are described by a system of nonlinear PDEs (cf. Section 3) which are complex to handle. Various concepts for the control of PDE systems are discussed in literature. A very powerful tool is provided by Smyshlyaev and Krstic [2004] who present the method of backstepping. The basic idea is to transform the system such that it can be described as a system for which sophisticated control techniques already exist. Another approach for the control of parabolic PDEs is presented in Lynch and Rudolph [2002]. Here, the system is represented based on a power series and flatness-based control strategies are developed for the resulting system of ODEs. Another general method to control nonlinear systems is sliding mode control. For this topic, the reader is referred to Hanczyc and Palazoglu [1995] and Drakunov and Utkin [1992].

7. CONCLUSIONS

This contribution presents a framework for the simulation, identification, and control of fuell cell-based power plants. Due to space restrictions, only the model of the reformer unit, which provides hydrogen for the fuel cell, is shown. The distributed model is hard to handle and thus a modal transformation is applied. This method allows the PDE to be represented by a set of ODEs. The resulting model with concentrated parameters is applied for the identification of model parameters. Control concepts which allow for a optimisation-based operation of the power plant are proposed.

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