Institute for Design and Control of Mechatronical Systems

LINZ CENTER OF MECHATRONICS GMBH

Diploma Thesis:

Data Based Modeling and Optimal Control of a PEM Fuel Cell System

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Abstract

This diploma thesis includes the data based modeling of a **Proton Exchange Membrane (PEM)** fuel cell system **(FCS)** and an optimal control design for this FCS.
For data based modeling the necessary data are taken from an existing FCS which is operating in an experimental environment at the ***Fronius GmbH***.
The considered FCS consists of a PEM stack and for operating necessary facilities such as compressor, cooling circuit and an electrical load. The peak power of the stack is 5 kW and its main purpose is for a mobile use.
Throughout this thesis mainly the air path system and the cooling circuit are considered. For both systems it is shown how to identify a data based model which is suitable for control tasks. The data based modeling includes preprocessing, system structure identification and parameter estimation or identification.
It turns out that for this present application a self made definition of the system structure considering physical aspects gives the best result.
After these steps the final system identification is performed by applying the well known prediction error method (pem). Because of the different time scales two different models are identified, one for the air path and one for the cooling circuit. These models are then applied to design a controller.
Therefore for the air path system the control problem is rewritten in a **H_inf tracking set up** and solved by using standard algorithms.
For the cooling system, since of its huge delay time of 10 s, a **Smith Predictor** combination with a PID controller is performed. Both control results show a well performance in simulation.
Finally it can be summarized that not only the performance of the controllers for the air path system and for the cooling system are important to increase efficiency but mainly the set points of the operating points are important. To this end a stationary optimization is performed.

PEM Fuel Cell:

Chemical Reactions:

Anode:

$$2H_2 \rightarrow 4H^+ + 4e^-$$

Hydrogen diffuses through membrane to cathode;
Electrons runs through electrical circuit to cathode

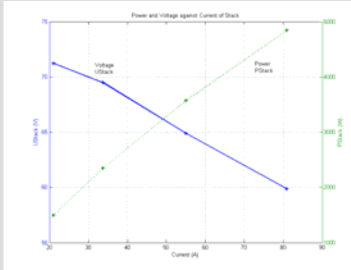
Cathode:

$$4e^- + O_2 \rightarrow 2O^{--}$$

$$4H^+ + 2O^{--} \rightarrow 2H_2O$$

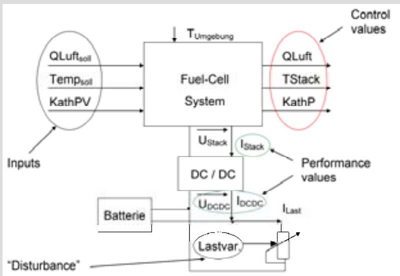
Platinum is used as catalyst at anode and cathode.
The membrane is out of a polymer (Nafion®)

FC-Stack Characteristic:



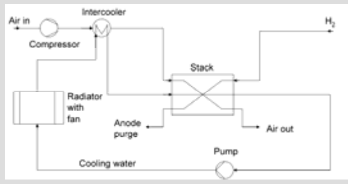
Stack out of 94 elementary fuel cells in series

Scheme of FCS:

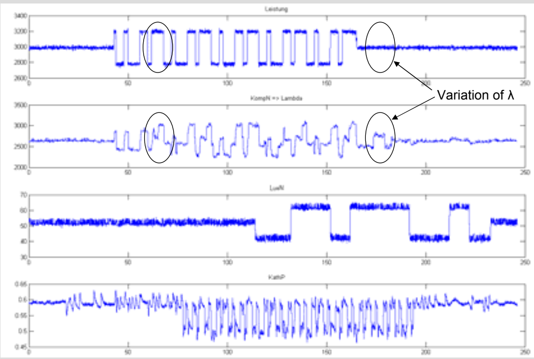


Main Paths:

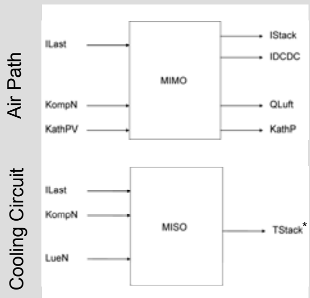
- Hydrogen Path
- Air Path
- Cooling Circuit



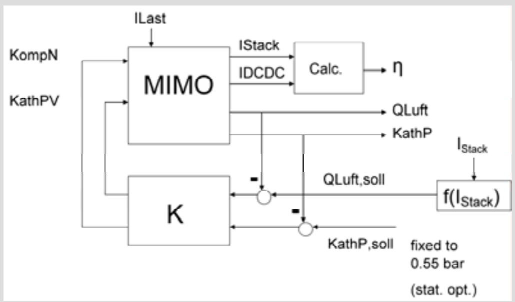
Excitation for Identification



Structure of subsystems:

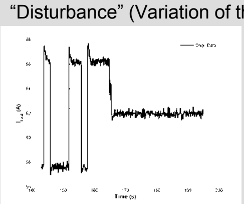


Closed Loop: Air Path Subsystem



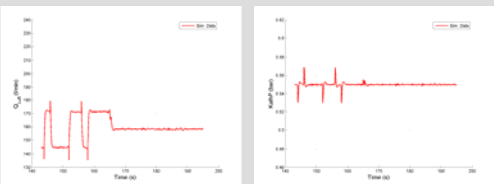
Results: Closed Loop – Air Path

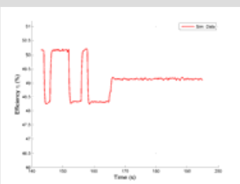
"Disturbance" (Variation of the power of the load)



Because of constant voltage at the load, the variation of power of the load is proportional to the current I_{Last}

Reaction of controlled values to the variation of I_{Last}:

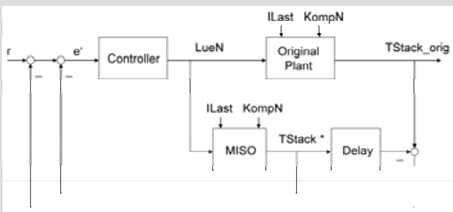




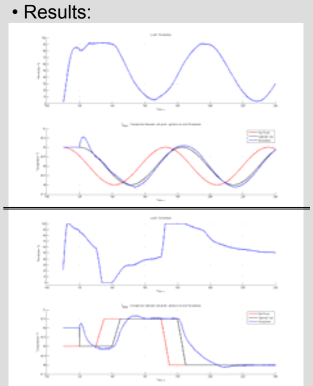
The presented efficiency of the system (left) is 1 % higher than the measured value.
This is because of stationary optimization of the set points!

Closed Loop: Cooling Circuit

- Smith Predictor



- Results:



Conclusions and Outlook

The following topics are discussed:

1. Measurement at the considered fuel cell system
2. Design of input signals to get well exciting of the fuel cell system
3. Preprocessing of measurements
4. Identification of MIMO and MISO models with different approaches
5. Control design for air path subsystem
6. Control design for cooling path (stack temperature)
7. Presentation of results

- The presented approaches show an alternative method to control the fuel cell system.
- The optimization of set points in every operating point is the key to increase the efficiency of the system.
- With the presented control of the cooling circuit, a reaction to changes is possible without delay.

Some enhancements:

- The number of measured operating points has to be increased to cover the whole range of the FCS.
- More measurements at each operating point with various excitations has to be done.
- The switching between the local models and controls has to be implemented (Gain Scheduling)
- A verification at the existing FCS has to be done.
- The variation of KathP causes negative influence to the signal Q_Luft. Hence a constant level of KathP is a good sort and slow changes are possible if necessary, steps should be omitted.
- A discussion about the thermal limits versus aging and durability has to be done with the producer of the stack and the experts of Fronius.