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Modeling and control of the output current of a Reformed Methanol Fuel Cell system

Kristian Kjær Justesen [a,*], *Søren Juhl Andreasen* [a], *Sivakumar Pasupathi* [b], *Bruno G. Pollet* [b]

[a] *Department of Energy Technology, Aalborg University, Pontoppidanstræde 101, 9220 Aalborg East, Denmark*
[b] *HySa Systems, University of The Western Cape, Robert Sobukwe Road, Bellville, Cape Town, 7535, South Africa*

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ABSTRACT

In this work, a dynamic Matlab SIMULINK model of the relationship between the fuel cell current set point of a Reformed Methanol Fuel Cell system and the output current of the system is developed. The model contains an estimated fuel cell model, based on a polarization curve and assumed first order dynamics, as well as a battery model based on an equivalent circuit model and a balance of plant power consumption model. The models are tuned with experimental data and verified using a verification data set. The model is used to develop an output current controller which can control the charge current of the battery. The controller is a PI controller with feedforward and anti-windup. The performance of the controller is tested and verified on the physical system.

Introduction

PEM Fuel cells are receiving a lot of interest, because they provide a potentially cleaner and more efficient alternative to present energy conversion technologies [1]. They do, however, have a problem with impractical and energy consuming fuel storage when operated on pure hydrogen, either under high pressure or on liquid form cooled down to below −253 [°C] [2]. One possible solution to this problem is to use a liquid fuel as a hydrogen carrier and reform it into a hydrogen rich gas as it is needed.

One system which uses this method is the H3 350 Reformed Methanol Fuel Cell (RMFC) module from Serenergy A/S, which is the subject of this work and depicted in Fig. 1.

The module has a nominal output power of 350 [W], a rated output current of 16.5 [A] at 21 [V] and has a volume of 27 [L].

The fuel of the H3 350 module is a 60/40 vol % mixture of methanol and water, which is evaporated and steam reformed into a hydrogen rich gas which is used in a HTPEM fuel cell. A HTPEM fuel cell is used because of its high tolerance to carbon monoxide in its fuel [4] [5].

The anode waste gas of the fuel cell is used in a catalytic burner to supply process heat for the reformer, and the

* *Corresponding author*. Fax: +45 9815 1411.
E-mail addresses: kju@et.aau.dk (K.K. Justesen), sja@et.aau.dk (S.J. Andreasen), spasupathi@uwc.ac.za (S. Pasupathi), bgpollet@hysasystems.org (B.G. Pollet).
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Nomenclature

I_{bat}	battery current
V_{bat}	battery voltage
V_p	parallel voltage
R_p	parallel resistance
C_p	parallel capacitance
V_s	series voltage
R_s	series resistance
V_{OC}	open circuit voltage
V_{imp}	impedance voltage drop
P_{BOP}	balance of plant power consumption
P_{heater}	electric heater power consumption
P_{excess}	auxiliary power consumption
I_{FC}	fuel cell current
V_{FC}	fuel cell voltage
$V_{FC\ RAW}$	fuel cell voltage without dynamic component
b_{1+2} and a_1	parameters for fitting
V_{FC}	fuel cell voltage
ϑ	vector of unknown parameters for fitting
ϕ	explanatory variable, matrix of data for fitting
ε	residual error
V_{FC}	fuel cell voltage
J	objective function for optimization
$\hat{\vartheta}$	estimate of unknown parameter after fitting
K_p	controllers proportional gain
K_i	controllers integral gain
K_{AW}	controllers anti-windup gain

cathode exhaust from the fuel cell is used to supply heat for the evaporation of the fuel. The flows between the system components are passed through a heat exchanger to even out the temperatures of the flows. Fig. 2 shows a diagram of the components and flows of a Serenergy H3 350 v1.6.

A more detailed description, and a system level thermal model, of such a system can be found in Ref. [6]. A similar system is described in Ref. [7], another system with a water cooled fuel cell stack and water recovery system is described in Refs. [8], and [9] describes a system which runs on GTL

Fig. 1 – Picture of a Serenus H3 350 from Serenergy [3].

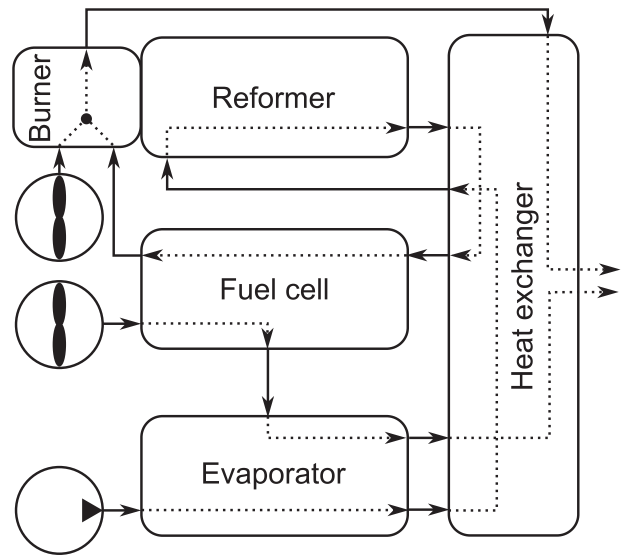

Fig. 2 – Concept drawing of the fuel flow through a H3 350 module from Serenergy.

diesel and uses a water gas shift gas cleanup stage. The addition of a fuel reformer and an evaporator means that the system complexity is increased and that changes in fuel flow migrates slowly through the system. This means that the fuel cell current and the fuel flow have to be changed synchronously at a limited rate to avoid anode starvation, which is harmful to the fuel cell as described in Refs. [10] and [11]. In addition, a sudden negative step in fuel cell current would mean that the hydrogen flow to the burner is increased suddenly, which in severe cases can lead to a thermal meltdown. For the H3 350 module the maximum rate of change of the fuel cell current is therefore set to 1 [A/min] by the manufacture. This limit will be observed throughout this work.

A DC–DC converter is therefore integrated to control the fuel cell current and the controllable parameter is the fuel cell current, which the user can set a set point for and not the output current of the module. Fig. 3 shows a plot of the fuel cell current and the output current of a H3 350 module during a series of changes in fuel cell current.

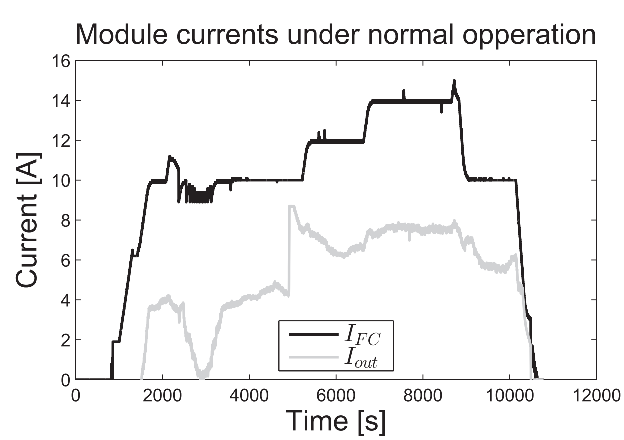

Fig. 3 – Fuel cell and battery currents during a series of changes in fuel cell current of a H3 350 module.