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The effect of bias in gas temperature measurements on the control of a Solid Oxide Fuel Cells system

Leonidas Tsikonis*, Joel Albrektsson, Jan Van herle, Daniel Favrat

EPFL-LENI (Industrial Energy Systems Laboratory), ME A2, Station 9, CH-1015 Lausanne, Switzerland

HIGHLIGHTS

- This is a study on Fuel Cell control including bias on temperature measurements.
- The deviation between desired and effected control due to this bias is important.
- The effect is such, that one case failed.
- We show that with simple design improvements the problem may be mitigated.

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ABSTRACT

In this paper the effect of systematic errors in gas temperature measurements on the thermal control of a Solid Oxide Fuel Cell system is demonstrated. Three control schemes were tested under two different conditions. First, the real gas temperature at the point of interest was used as input for the controller. Second, the reading of the thermocouple that takes the measurement at the same point was used as input. The second approach included the bias on the measurement due to radiation and heat conduction on the thermocouple. The results showed an overestimation of temperatures with important influence on the system control. Furthermore, in one case the system could not follow the required power demand and it failed. A successful solution to the problem was obtained by increasing the dimension of the system's heat exchanger.

1. Introduction

An efficient control system is paramount for the operability and the good performance of fuel cell systems. It allows the regulation of power output, temperatures and economic performance under a dynamic working environment where they need to operate. Several methodologies have been broadly investigated, such as Proportional-Integral-Derivative controllers (PID), Model Predictive Control (MPC), Artificial Neural Networks and Real-time Optimisation [1–5]. Similarly, different control strategies such as strategies for rapid load following, prevention of fuel starvation, optimal efficiency [7–10], etc. have been studied. Whichever the employed method, a correct feedback from the fuel cell system – voltage, current, temperatures, pressures, flow rates etc. – is mandatory for the control system to perform adequately.

This may be a subtle point for the control of high or intermediate temperature fuel cell systems. In common practice gas temperature measurements in those systems are taken with thermocouples simply dipped into the gas streams of interest. However, it was shown in previous publication [11] that an important bias may occur in such measurements on Solid Oxide Fuel Cell (SOFC) systems due to the radiation effects between the thermocouple and the surrounding solids. The discrepancy between the real and the measured gas temperature depends mainly on factors such as the temperature difference between the gas and the enclosing solids, the gas velocity, transfer factors of radiative exchange etc.

Systematic errors of this nature may have serious effects on the thermal management and generally on the control of fuel cells. To demonstrate those effects this paper studies simple cases of PID control on an SOFC system. More specifically it presents and compares three different approaches for simple thermal control of the system under two conditions. First taking for granted that the measured gas temperature is the real one,

* Corresponding author.
E-mail address: leonidas.tsikonis@a3.epfl.ch (L. Tsikonis).

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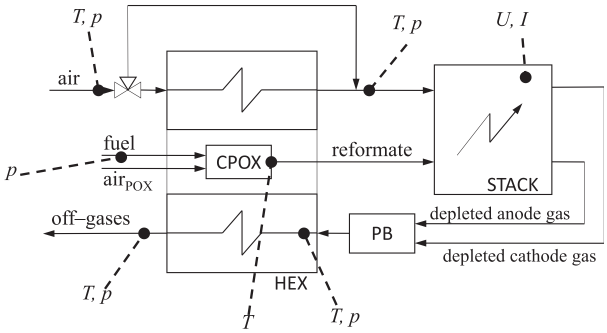

Fig. 1. Schematic flow diagram of the HoTbox™. Reproduced from Ref. [11] by permission from Whiley.

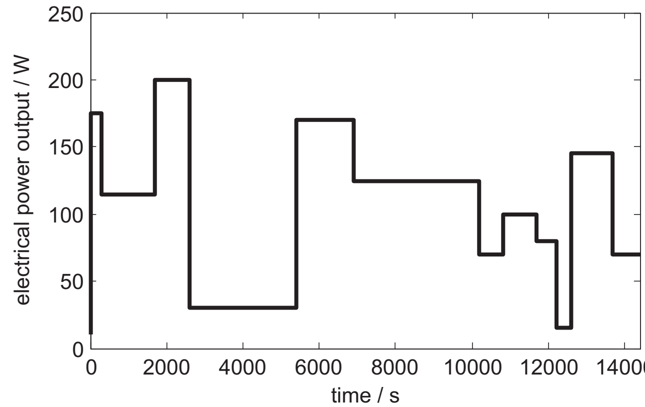

Fig. 2. Power scenario upon which different control schemes were tried.

Table 1
Six control scenarios for SISO PID control. There are three options for the controller output and two options for the input.

		Controller input	
		Real gas temperature (exit cold stream HEX)	Thermocouple reading (exit cold stream HEX)
Controller output	Valve position	1A	1B
	Air ratio	2A	2B
	Fuel power	3A	3B

which, in fact, is the usual case in relevant publications. Second, simulating the behaviour of the thermocouple that makes the measurement and including the radiation bias in the control scheme. This analysis shows that depending on the control feedback, the effect of the difference between measured and real gas temperatures may vary from small to important that may even lead to failure of the system.

The paper comprises five sections. The second section that follows gives an overview of the studied SOFC system. Section three presents the six control schemes tested by simulation on the system as well as the exact configuration of the PID controller. All results are deployed in the fourth section and the effects of different approaches are discussed. For one case that failed due to the systematic error in temperature measurement a solution is given with structural changes on the system. Finally, the article concludes in Section 5.

2. The studied SOFC system, its model and validation

The employed system model is an altered version of a model simulating the HoTbox™, a product of HTceramix–SOFCpower [12,13] and a prototype of an SOFC-based generator designed for co-generation. The model is built in gPROMS® [14] and a layout of the system is given in Fig. 1. It comprises a 500 W SOFC stack

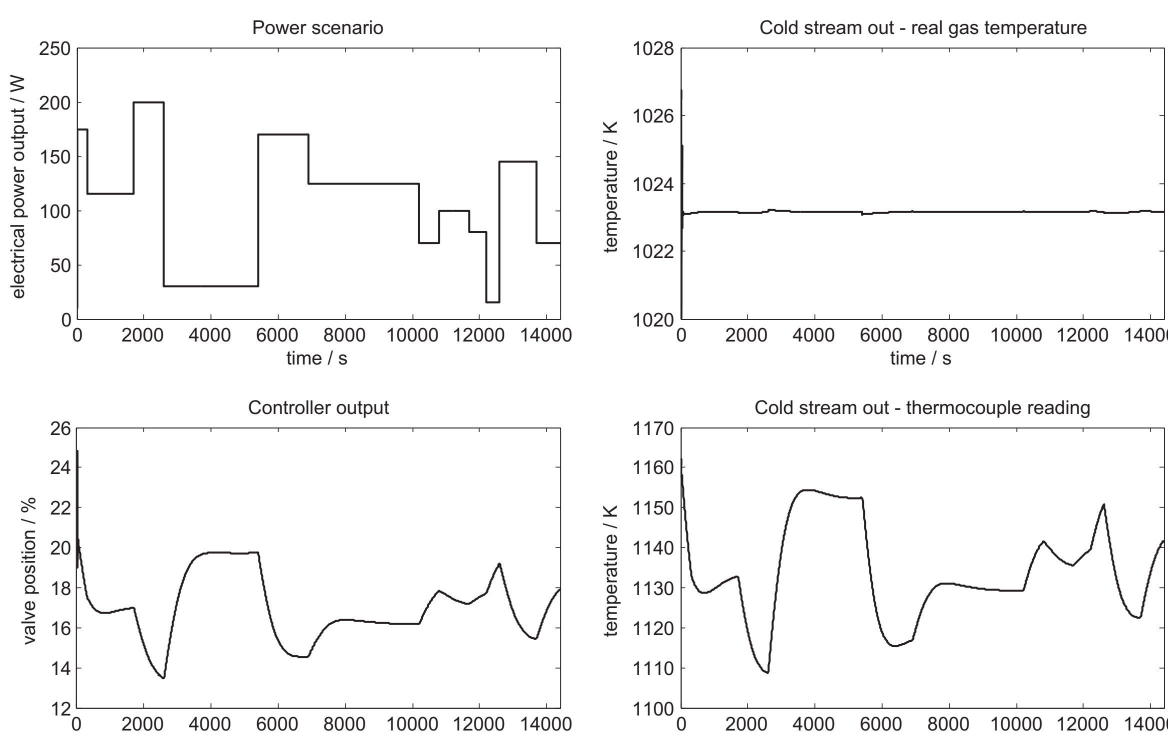

Fig. 3. Power scenario, real gas temperature, thermocouple reading and controller output (valve position) for case 1A of PID control (Table 1). Air ratio is 4 and fuel power input is 1000 W.