Advances in model-based diagnosis for SOFC systems after FP7-DIAMOND (Diagnostic algorithm selection, design and testing)

M.Gallo, D. Marra, C. Pianese*, P. Polverino and M. Sorrentino
Energy and Propulsion Laboratory (EProLab)
Dept. of Industrial Engineering, University of Salerno, Fisciano (SA), ITALY
**Corresponding author e-mail address: pianese@unisa.it*

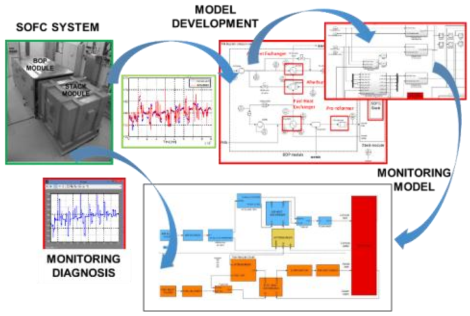
Fault diagnosis plays a significant role in improving system reliability and availability by detecting and isolating detrimental degradation phenomena and faulty conditions, which are the main cause of system performance and lifetime reduction. The result of a fault diagnosis study can support the development of adaptive control and mitigation strategies, to achieve the aforementioned improvements [1]. In this field, UNISA developed advanced and innovative diagnostic algorithm for SOFC systems, based on suitable system components modelling. Several approaches have been implemented in frame of EU-funded projects GENIUS, DESIGN and DIAMOND.

The core of the diagnostic algorithm relies on residuals generation, performed as the difference between the output signals measured on the system and the numerical ones generated by the model. When the residual goes beyond a defined level (i.e., a threshold), a symptom arises and a fault is detected in the system. For fault isolation purposes, a Fault Tree Analysis is addressed, starting from heuristic knowledge to link faults and symptoms. This leads to the formulation of a theoretical, but qualitative, Fault Signature Matrix, which is then improved via faults simulation, to account for quantitative drifts of the considered variables based on fault type and magnitude [2].

In order to achieve suitable fault detection, identification and isolation, the model supporting the diagnostic algorithm needs to be fast, robust and accurate with respect to the addressed application. Therefore, a lumped modelling approach is considered as the best compromise between computational speed and results accuracy. The main model assumption is the predominance of stack thermal dynamics with respect to other phenomena, such as mass transfer and electrochemical reactions (i.e. instantaneous); water gas shift reaction is set at the equilibrium; heat exchangers are modelled through lumped heat transfer coefficients and assumed adiabatic as well as other balance of plant components [3]. Overall, the SOFC is considered to behave as a first order system and the thermal dynamics is modelled applying the energy conservation principle to lumped control volumes. The stack voltage is modelled through an ASR approach, in which simplified parameters are identified upon experimental data [4].

The development of an accurate and robust model represents a key aspect for the design of a reliable diagnostic algorithm. A schematic representation for the development of model based for diagnostic algorithm is presented in Fig. 1a. Fault isolation can be hindered by the lack of proper measurements, due to costs (i.e., measurement device too expensive) and practical issues (i.e., unfeasibility to measure a certain variable). This induces the reduction in symptoms generation, which may lead two or more faults to have the same pattern (i.e., fault clustering issue). To overcome this problem, UNISA introduced an innovative approach based on isolated components analysis. According to the proposed technique, isolated system component models, fed with faulty inputs, are exploited to compute a set of redundant residuals reacting only if the related component is under faulty state. The accuracy of the isolation can be therefore enhanced by increasing the number of residuals through isolated sub-models. A theoretical analysis of the diagnostic improvement confirmed the capability of the proposed approach to univocally isolate faults under sensors reduction problem [5].

The developed SOFC system model and the proposed diagnostic technique have been applied to a real system in the frame of the project DIAMOND to assess their performance. The considered system is an Anode Off-gas Recycling one, composed by a 10 kW planar SOFC stack fuelled with natural gas. The unit consists of two interconnected modules, the balance of plant and the stack module. Results on stack data proved the accuracy of the model as a valid support for both control and diagnosis applications. During tests, a fault has been detected by comparing measured and simulated outlet concentrations, properly detecting, isolating and identifying a stack leakage, as sketched in Fig. 1b. The main issue related to the on-board implementation of such algorithm consists in the need for very low computational burdens associated to acceptable accuracy. Therefore, a suitable model reduction approach should be accounted.



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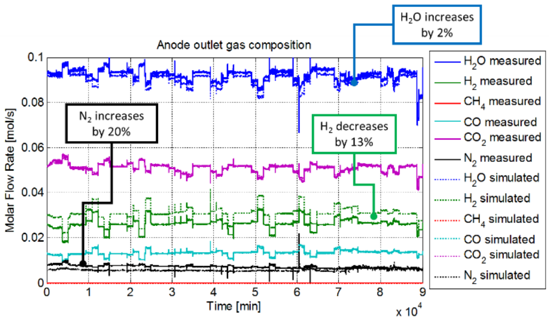

b

Fig. 1. a) schematic representation of model-based approach for the design of diagnostic tool: components identification, model development and validation on experimental data [4]. b) Stack leakage identification achieved through comparison between simulated and measured compositions for model validation [4]

Future works aim at proving the methodology effectiveness considering further symptoms and other system components, at analysing fault isolability with respect to other faults suitably modelled and at addressing the influence of model uncertainties and measurement disturbances on fault isolation results.

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