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Final report

EIT-FC

Development of a non-invasive method to measure spatially resolved membrane conductivity of polymer electrolyte fuel cells

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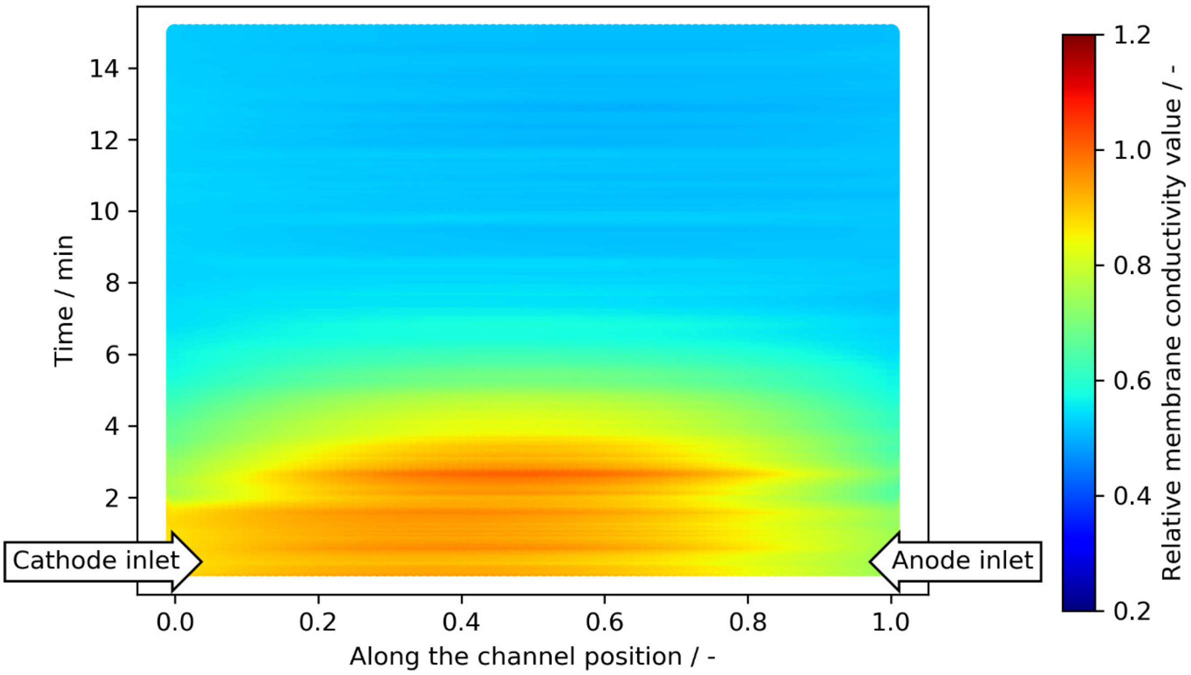

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Summary

High power density operation of polymer electrolyte fuel cells (PEFC) in mobility applications requires homogeneous cell conditions to avoid system efficiency degradation. This project aimed at developing a non-invasive and local PEFC stack-level impedance diagnostics, suited for research and development but also in actual applications based on Electrical Impedance Tomography (EIT). EIT is an already established method in different fields such as medicine, geology and different industrial processes. It is based on the relationship that exists between the conductivity inside an object and the boundary voltages existing when an AC current is supplied to the object. The reconstruction process to retrieve the conductivity distribution from the boundary voltages is however very challenging.

In order to assess the feasibility of the method on a fuel cell, a numerical feasibility study was performed in the project's first year. It showed that for the method to work, a very high level of accuracy was needed between the model and the experiments. If this accuracy is achieved, different conductivity distribution typical of fuel cell operation could be reconstructed even though the center of the active area was not probed. Based on the numerical findings, a dedicated measurement system with the best possible accuracy was then designed, purchased and programmed. Different experimental tests with samples of increasing complexity were performed to investigate if the required accuracy between the model and the experiments could indeed be reached. These tests uncovered severe challenges for fuel cell application even though the model was able to predict the boundary voltages with an accuracy of about 15%.

A different way to retrieve spatial resolved information from the local measurements was then investigated. It is based on the interpretation of local current supply and voltage measurements all around the cell. The ability to assign a zone of the active area to each stimulation, coupled with reference measurement at specific conditions allowed to study the conductivity distribution of an operating fuel cell stack. Different conditions were studied and compared well with literature. Time resolved measurements were also performed to highlight the transient capabilities of the method. Finally, multiple stimulating frequencies were used to study the local influence of oxygen concentration and current density on the low frequency features of the impedance spectrum. Equivalent circuit fitting of local spectra coupled with normalization of the values with respect to a homogeneous reference case enabled the first measurement of non invasive local electrochemical impedance spectra.

The project delivers a ready to use setup for local PEFC stack impedance measurements and results based on it are published in well recognized journals. Being able to non-invasively determine the impedance distribution in a fuel cell stack is a great asset, especially as it could also be easily and quickly adapted to different cell designs. It could be used to check the homogeneity of the conductivity distribution in a stack for research purposes but also in practical operation, to provide feedback to the control system. The methods flexibility and wide applicability created already some interest in industry and will help to improve PEFC performance, durability and cost.

Zusammenfassung

Der Betrieb von Polymerelektrolyt-Brennstoffzellen (PEFC) mit hoher Leistungsdichte in Mobilitätsanwendungen erfordert homogene Zellbedingungen, um eine Verschlechterung der Systemeffizienz zu vermeiden. Ziel dieses Projekts war die Entwicklung einer nicht-invasiven und lokalen PEFC-Stack-Impedanzdiagnose, die sich für Forschung und Entwicklung, aber auch für aktuelle Anwendungen eignet und auf der elektrischen Impedanztomographie (EIT) basiert. EIT ist eine bereits etablierte Methode in verschiedenen Bereichen wie Medizin, Geologie und verschiedenen industriellen Prozessen. Sie basiert auf der Beziehung zwischen der Leitfähigkeit im Inneren eines Objekts und den Grenzspannungen, die entstehen, wenn ein Wechselstrom an das Objekt angelegt wird. Der Rekonstruktionsprozess zur Ermittlung der Leitfähigkeitsverteilung aus den Grenzspannungen ist jedoch sehr anspruchsvoll.

Um die Durchführbarkeit der Methode an einer Brennstoffzelle zu bewerten, wurde im ersten Jahr des Projekts eine numerische Machbarkeitsstudie durchgeführt. Dabei zeigte sich, dass die Methode nur dann funktioniert, wenn eine sehr hohe Genauigkeit zwischen dem Modell und den Experimenten besteht. Wenn diese Genauigkeit erreicht wird, können verschiedene Leitfähigkeitsverteilungen, die für den Betrieb von Brennstoffzellen typisch sind, rekonstruiert werden, auch wenn das Zentrum der aktiven Fläche nicht untersucht wurde. Auf der Grundlage der numerischen Ergebnisse wurde dann ein spezielles Messsystem mit der bestmöglichen Genauigkeit entworfen, beschafft und programmiert. Es wurden verschiedene experimentelle Tests mit Proben von zunehmender Komplexität durchgeführt, um zu untersuchen, ob die erforderliche Genauigkeit zwischen dem Modell und den Experimenten tatsächlich erreicht werden kann. Diese Tests ergaben, dass die Anwendung auf Brennstoffzellen sehr schwierig ist, auch wenn das Modell die Grenzspannungen mit einer Genauigkeit von etwa 15 % vorhersagen konnte.

Anschliessend wurde ein anderer Weg untersucht, um räumlich aufgelöste Informationen aus den lokalen Messungen zu gewinnen. Sie basiert auf der Interpretation von lokalen Stromversorgungs- und Spannungsmessungen rund um die Zelle. Die Möglichkeit, jeder Stimulation eine Zone des aktiven Bereichs zuzuordnen, ermöglichte in Verbindung mit Referenzmessungen unter bestimmten Bedingungen die Untersuchung der Leitfähigkeitsverteilung eines in Betrieb befindlichen Brennstoffzellenstapels. Es wurden verschiedene Bedingungen untersucht, die gut mit der Literatur übereinstimmten. Es wurden auch zeitaufgelöste Messungen durchgeführt, um die transienten Fähigkeiten der Methode hervorzuheben. Schliesslich wurden mehrere Anregungsfrequenzen verwendet, um den lokalen Einfluss der Sauerstoffkonzentration und der Stromdichte auf die niederfrequenten Merkmale des Impedanzspektrums zu untersuchen. Die Anpassung lokaler Spektren durch Äquivalenzschaltungen und die Normalisierung der Werte in Bezug auf einen homogenen Referenzfall ermöglichten die erste nicht invasive Messung lokaler elektrochemischer Impedanzspektren.

Das Projekt liefert einen einsatzbereiten Aufbau für lokale PEFC-Stack-Impedanzmessungen und die darauf basierenden Ergebnisse wurden in anerkannten Fachzeitschriften veröffentlicht. Die Möglichkeit, die Impedanzverteilung in einem Brennstoffzellenstapel nicht-invasiv zu bestimmen, ist ein grosser Vorteil, zumal sie auch einfach und schnell an verschiedene Zellkonzepte angepasst werden kann. Sie könnte zur Überprüfung der Homogenität der Leitfähigkeitsverteilung in einem Stapel zu Forschungszwecken, aber auch im praktischen Betrieb eingesetzt werden, um dem Kontrollsystem Rückmeldung zu geben. Die Flexibilität und die breite Anwendbarkeit der Methode haben bereits ein gewisses Interesse in der Industrie geweckt und werden dazu beitragen, die Leistung, Lebensdauer und Kosten von PEFC zu verbessern.

Résumé

Le fonctionnement des piles à combustible à électrolyte polymère (PEFC) à forte densité de puissance dans les applications de mobilité nécessite des conditions de cellule homogènes afin d'éviter une dégradation de l'efficacité du système. L'objectif de ce projet était de développer un dispositif de diagnostic d'impédance de pile PEFC non invasif et local, adapté à la recherche et au développement, mais aussi aux applications courantes, basé sur la tomographie d'impédance électrique (EIT). L'EIT est une méthode déjà bien établie dans différents domaines tels que la médecine, la géologie et divers processus industriels. Elle se base sur la relation entre la conductivité à l'intérieur d'un objet et les potentiels limites qui apparaissent lorsqu'un courant alternatif est appliqué à l'objet. Le processus de reconstruction permettant de déterminer la distribution de la conductivité à partir des tensions de seuil est toutefois très exigeant.

Afin d'évaluer la faisabilité de la méthode sur une pile à combustible, une étude de faisabilité numérique a été réalisée au cours de la première année du projet. Il en est ressorti que la méthode ne fonctionne que s'il existe une très grande précision entre le modèle et les données expérimentales. Si cette précision est atteinte, il sera possible de reconstruire différentes distributions de conductivité typiques du fonctionnement des piles à combustible, même si le centre de la surface active n'a pas été étudié. Sur la base des résultats numériques, un système de mesure spécial a été conçu, acheté et programmé avec la meilleure précision possible. Plusieurs tests empiriques ont été réalisés avec des échantillons de complexité croissante afin de vérifier si la précision requise entre le modèle et les expériences pouvait effectivement être atteinte. Ces tests ont révélé que l'application aux PEFC était très difficile, même si le modèle pouvait prédire les potentiels avec une précision d'environ 15 %.

Une autre voie a ensuite été explorée pour obtenir des informations à résolution spatiale à partir des mesures locales. Elle est basée sur l'interprétation des mesures locales d'alimentation et de tension autour de la cellule. La possibilité d'attribuer à chaque stimulation une zone de la zone active a permis, en combinaison avec des mesures de référence, d'étudier dans certaines conditions la répartition de la conductivité d'un empilement de piles à combustible en fonctionnement. Différentes conditions ont été étudiées et bien comparées à la littérature. Des mesures temporelles ont également été effectuées afin de mettre en évidence les capacités transitoires de la méthode. Enfin, plusieurs fréquences d'excitation ont été utilisées pour étudier l'influence locale de la concentration en oxygène et de la densité de courant sur les caractéristiques basse fréquence du spectre d'impédance. L'adaptation des spectres locaux par des circuits d'équivalence et la normalisation des valeurs par rapport à un cas de référence homogène ont permis la première mesure non invasive de spectres d'impédance électrochimique locaux.

Le projet fournit une structure prête à l'emploi pour les mesures d'impédance locale de la pile PEFC et les résultats obtenus ont été publiés dans des revues spécialisées reconnues. La possibilité de déterminer de manière non invasive la répartition de l'impédance dans un empilement de piles à combustible est un grand avantage, d'autant plus qu'elle peut être adaptée facilement et rapidement à différents concepts de piles. Elle pourrait être utilisée pour vérifier l'homogénéité de la répartition de la conductivité dans un empilement à des fins de recherche, mais aussi dans la pratique pour apporter un retour d'information au système de contrôle. La flexibilité et la large applicabilité de la méthode ont déjà suscité un certain intérêt dans l'industrie et contribueront à améliorer les performances, la durée de vie et les coûts des PEFC.

Contents

Abbreviations

EIT	electrical impedance tomography
PEFC	polymer electrolyte fuel cell
FF	flow field
RH	relative humidity
DAQ	data acquisition
PCB	printed circuit board

1 Introduction

1.1 Background

Polymer Electrolyte Fuel Cells (PEFC) are an essential technology for future clean, fast refill, and long-range electric mobility. For commercial success however, PEFC technology still needs improvements in performance, durability and cost. Increasing specific power will reduce cost, however, at high current density operation, the water management limits efficiency and performance. In the channels of flow field (FF) plates of technical sized cells with active areas of some hundred of square centimetres, there is an accumulation of product water from the gas inlet towards the gas outlet. These large-scale gradients cause changes in the ionic conductivity of the polymer electrolyte membrane of the cell and within the ionomer in the catalyst layer, which then give rise to current density variations, leading to lower cell efficiency and shorter lifetime.

Therefore, the understanding and measurement of operando membrane conductivity in large technical cells is of great importance. Indeed, it would provide information both on the degradation state as well as the performance. The membrane conductivity distribution is usually measured using invasive techniques such as segmented flow field plates [1] to replace the standard flow field plate or shunt resistor boards to add as an extra layer in a fuel cell stack [2]. These methods were very helpful to understand water management and design efficient flow fields but they are often quite expensive and hard to use in actual applications because of their invasive nature.

This brings the need for a non-invasive method which is able to provide localized information about the ionic conductivity in the membrane layer that could be used both in research as well as in actual application.

1.2 Purpose of the project

The goal of this project was to develop a new method to measure the spatial distribution of the conductivity in the membrane using electrical impedance tomography. This method would be non-invasive, using only surface attached electrodes and it could be easily applied to different cell design. In the scope of this project, the final aim is to demonstrate this new concept on a fuel cell stack.

2 Procedures and methodology

2.1 Electrical Impedance Tomography (EIT)

Electrical impedance tomography is based on the relationship that exists between one object's conductivity distribution and the surface potential that one can measure when an alternating current is applied to the object. This alternating current, in the range of a few mA and frequencies of up to 50 kHz, is injected between a pair of the electrodes attached to the surface of the object. The resulting surface potential fluctuation is measured with an additional pair of electrodes. The repetition with many different pairs of injecting and measuring electrodes will produce a measurement dataset that allows to determine the actual conductivity distribution in the object.

The reconstruction is based on an optimization formulation that aims to minimize the deviation between the surface potentials predicted by the finite element model and the measured surface potentials for the different stimulation patterns. In a first step, an initial conductivity profile is assumed to be a constant value. The corresponding surface potentials are then calculated with the model and compared to the experimentally determined voltages. An optimizer is used to minimize the difference between the experimental and calculated voltages by varying the conductivity distribution and recalculating the boundary voltages until a certain threshold error has been met. The final conductivity profile that is obtained after convergence of the optimizer is therefore the one corresponding to the one in the actual fuel cell. For this reconstruction process to work, the model needs to very accurately describe the real device in terms of conductivity and geometry.

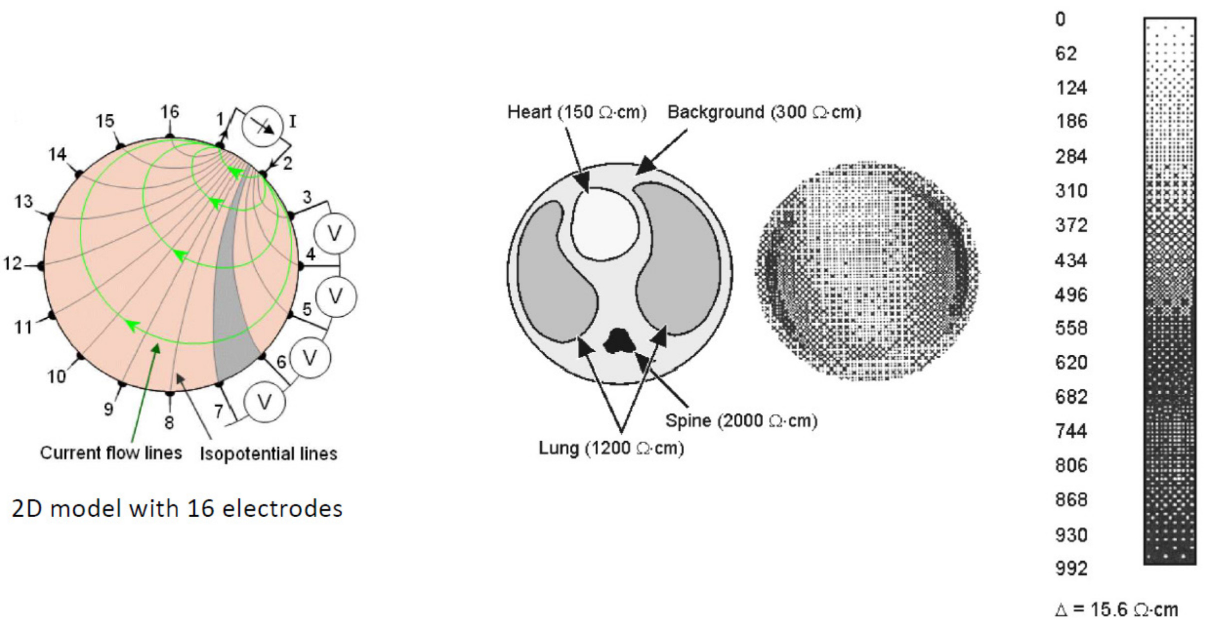

Figure 1: Working principle of Electrical Impedance Tomography (EIT): 1) successive AC current injection between two electrodes on the surface of the object to induce a voltage which will be measured by two other electrodes, 2) solve relationship between boundary voltage and inner conductivity (Source: Malmivuo, Jaakko & Plonsey, Roberet. (1995). Bioelectromagnetism. 26. Impedance Tomography. 420-427.)

3 Activities and results

3.1 Model Development

In an numerical feasibility study it could be shown that EIT is applicable to fuel cell dimensions and material conductivities and that the incorporation of a-priori knowledge of non-ionic conducting cell components into the solution process is possible (see Figure 2). In order to reduce the degrees of freedom the membrane conductivity is assumed to be constant over the membrane thickness and described by 1D or 2D parameterizations.

The reconstructed conductivity profiles showed a very good match to the assumed test scenario conductivity distributions and the method could resolve a complex 1D inlet to outlet gradient with a resolution below 3 cm. However, an analysis of the possible differences between experiments and model results showed that the model needs to be very accurate in order for the method to be precise enough. The conductivity of each component of the fuel cell needs to be precisely characterized and that information has to be fed into the model. An error well below 1% in assumed conductivity seems to be required to have a correct reconstruction. The electrodes also need to be positioned with an error of around 0.1 mm which can be achieved by a clever engineering solution. Finally, a data acquisition system has to be designed and has to meet the following basic requirements: it has to have multiple channels in order to be able to measure all around the cell at the same time and it requires a voltage fitting accuracy of about 20 dB for absolute voltage values of around 100 µV. The analysis of the current path through the membrane offered insights into challenges and opportunities of the two main flow field materials. Graphite can help EIT to provide strong local information at the expense of 2D resolution while stainless steel would help EIT to provide better 2D resolution at the expense of more smeared out weaker local information.

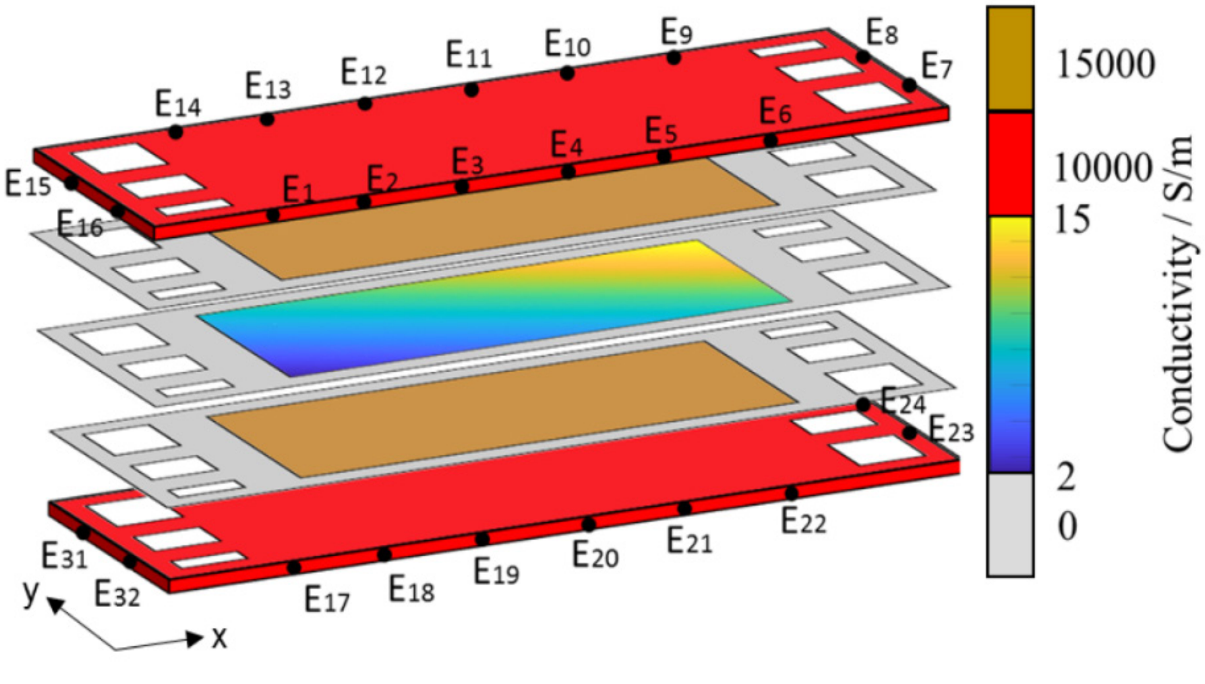

Figure 2: Simplified PEFC model with (from top to bottom) flow field plate, GDL and gasket, membrane and gasket, GDL and gasket, flow field plate and their corresponding conductivity in the color bar. Electrodes (E1 to E32) positions are marked in black dots. (Source A. Schuller, T. J. Schmidt, J. Eller, J. Electrochem. Soc., 169, 044525 (2022). CC BY, DOI 10.1149/1945-7111/ac6390):

3.2 Data acquisition system

A data acquisition system (DAQ) with components in PXI standard from National Instruments was developed for generating the AC current to be injected in to the cell and for the surface voltage measurements (see Figure 3). It includes a very high accuracy voltage measurements module (error < 1 uV at 10 kSamples/s) with 8 ADCs and a maximum of 32 channels, a current

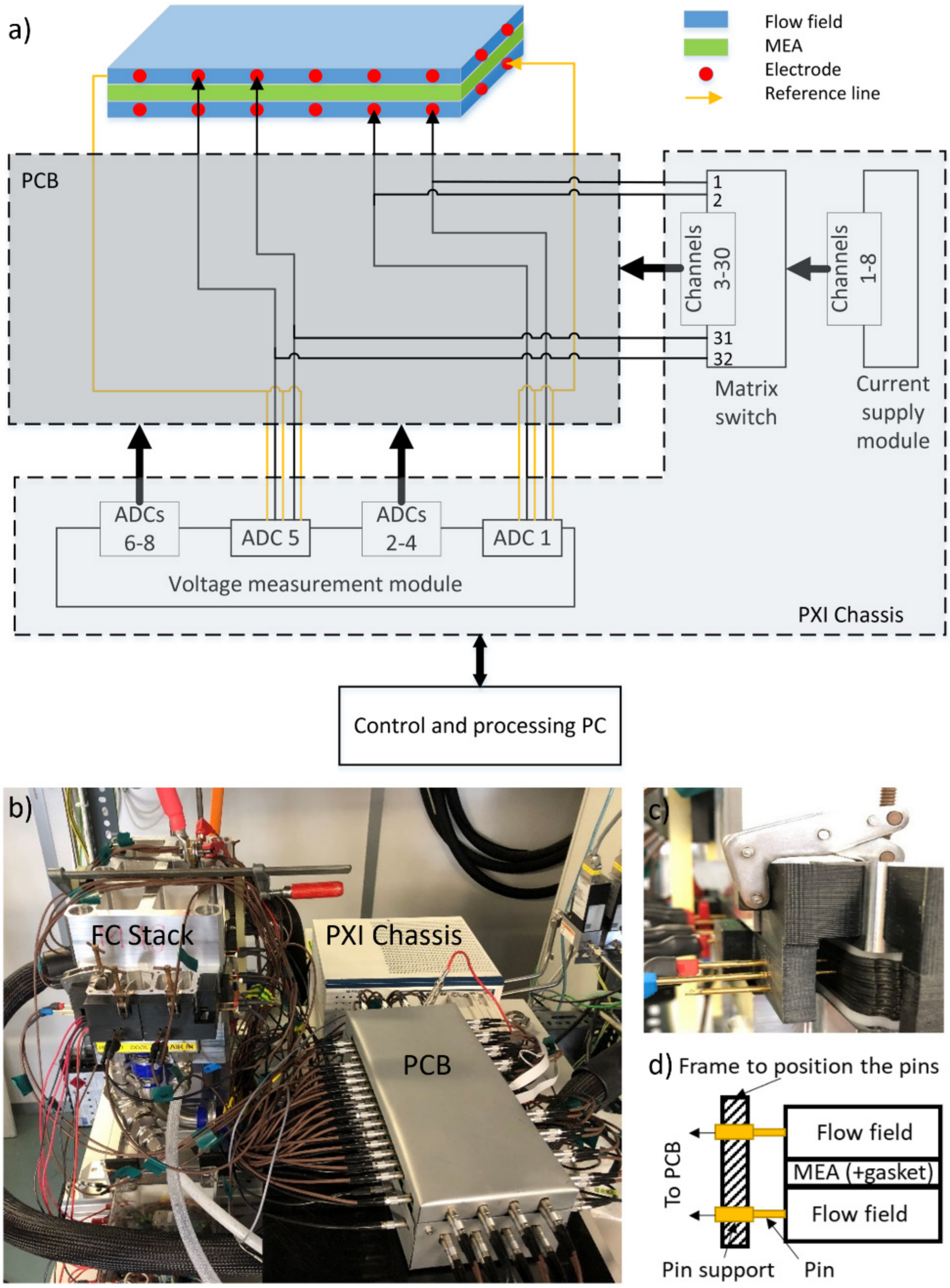

Figure 3: a) Schematic representation of the signal generation (current supply module and matrix switch) and the acquisition (voltage measurement system, the PCB for hardwired connections between the electrodes at the flow field and the modules of in the PXI chassis. b) Overview picture of the main omponents. c) Close up picture of the pins including: in gold on the left, the pin's support and the pins, in black in the middle, the frame to position the pins clamped to the compressing plate and in grey on the right, the flow fields that are contacted by the pins. d) Schematic of the pin positioning system. (Source A. Schuller, T. J. Schmidt, J. Eller, J. Electrochem. Soc., 169, 074504 (2022). CC BY, DOI 10.1149/1945-7111/ac6390)

injection module with 8 channels and up to 20 mA per channel and a matrix switch to switch the current source to all the electrodes.

For fuel cell application, the measurement procedure is as follows: current is injected into two the different flow fields of a cell that leads to an AC current flowing through the membrane . The resulting boundary voltage is be measured in plane on a single same flow field so that the measurement remains independent of the cell voltage and the maximum accuracy of the measurement device can be achieved. A printed circuit board (PCB) has been designed by PSI electronics division to realize the complex connections between matrix switch controlled current sources and the multi-channel voltage measurement. Figure shows the developed setup.

3.3 Local AC resistance measurement

Since the requirements for quantitative EIT measurements in terms of detailed flow field description and knowledge of conductivity of the fuel cell components besides the membrane could not been reached, an approach to interpret the local AC resistance measurements without the FEM forward model of the EIT solution procedure has been developed as an alternative approach. It is based on the finding that the current crossing through the membrane from the top and bottom flow field will spread only locally (see Figure 4).

The locally measured impedances depend on many parameters like membrane and catalyst layer hydration, the area the current crosses the membrane in through-plane direction due to in-plane conduction within the flow field plate and MEA, conductivity of the flow field plate and MEA, contact resistances between the different layers of the cells and the positioning of current injecting and sensing electrodes. In particular, the reading of the voltage probe electrodes is highly sensitive to their position on the flow field's outer surface and difficult to interpret. The local impedance values of the individual electrode combinations are therefore calibrated versus homogeneous humidity conditions and global cell high frequency measurements which allow to conclude from the local impedance on the corresponding local RH or high frequency resistance in a localized domain near the current injecting electrodes on the flow field's outer

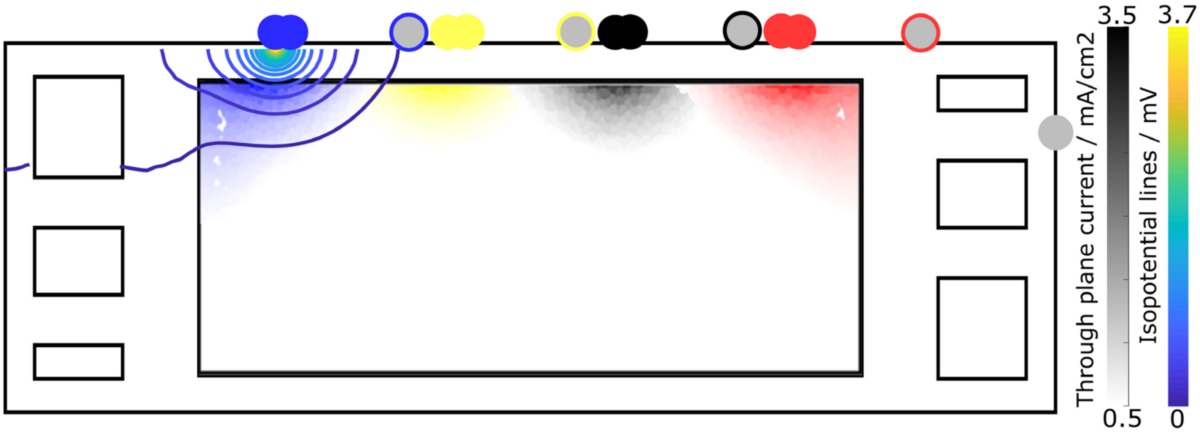

Figure 4: Simplified flow field geometry with simulatedvlocal through plane current for four different current injections (with the blue, yellow, black and red colormap) and induced potential (only for the blue current injection) displayed with equipotential lines. Current is systematically injected between the electrode on the top flow field and the one on the bottom flow field represented with the color coded circles. Voltage is measured in plane between the reference voltage probe electrode on the right (in and the nearest neighboring electrode represented with grey circles and matching edge color. (Source A. Schuller, T. J. Schmidt, J. Eller, J. Electrochem. Soc., 169, 074504 (2022). CC BY, DOI 10.1149/1945-7111/ac6390)

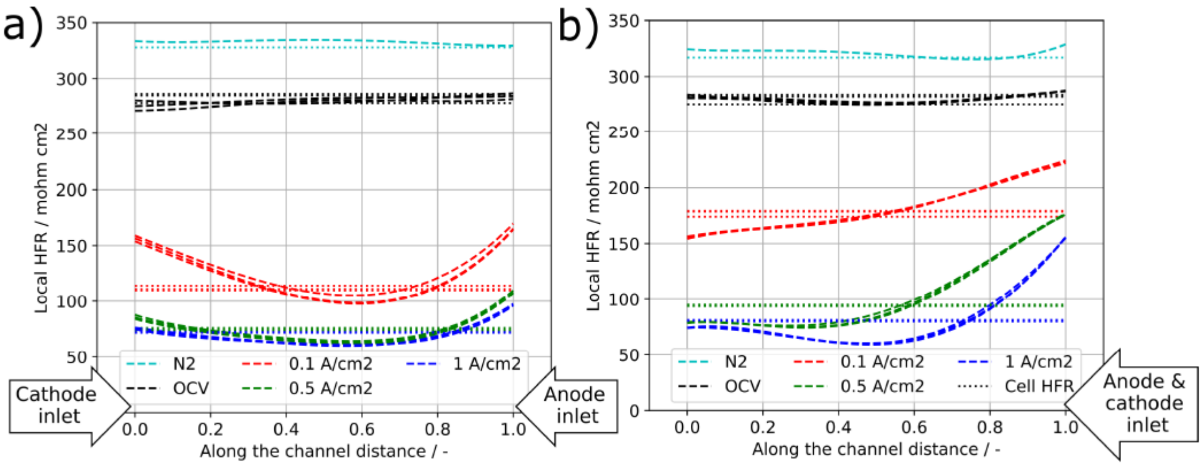

Figure 5: 1D HFR distribution of a cell operated at different current densities but constant mass flow rates a) in counter flow mode with 40% RH on both sides at different current densities b) in co flow mode with 40% RH on both sides. The multiples lines of same style correspond to repetitions of the same experiment. (Source: A. Schuller, T. J. Schmidt, J. Eller, J. Electrochem. Soc., 169, 124512 (2022). CC BY DOI 10.1149/1945-7111/aca0e3)

surface. The applicability of the approach was confirmed using different symmetric inlet RH as well as asymmetrical RH conditions between anode and cathode without electrochemical cell operation.

It could be shown that the method is also applicable to operating fuel cell stacks (see Figure 5). An offset in HFR between the nitrogen reference case and OCV was observed which is likely to be caused by hydrogen crossover and reaction with oxygen in the cathode catalyst. The local HFR was decreasing with increasing current density and the shapes of the distributions for co- or counter-flow match trends reported in the literature. Limitations of the method were identified when the humidity is very high: the HFR changes very little with changes in water content after a certain threshold. Furthermore, the fast data acquisition capabilities of the measurement setup allowed to study the transient behavior during current jump and stack drying.

3.4 Local electrochemical impedance spectroscopy

Using the developed setup and approach it is also possible to measure and interpret local electrochemical impedance spectra of polymer electrolyte fuel cell stacks in a non-invasive way. The setup's signal generation and data acquisition is validated against a commercial potentiostat with convincing accuracy over a wide frequency range of 3 to 1000 Hz. The maximum AC current of 120 mA that can be provided by the setup limits currently the operation condition range, in particular for full stack measurements. In a proof of principle study this was not a limiting factor because low current density and high humidity conditions were chosen to avoid bias of the impedance spectra by an inhomogeneous current distribution.

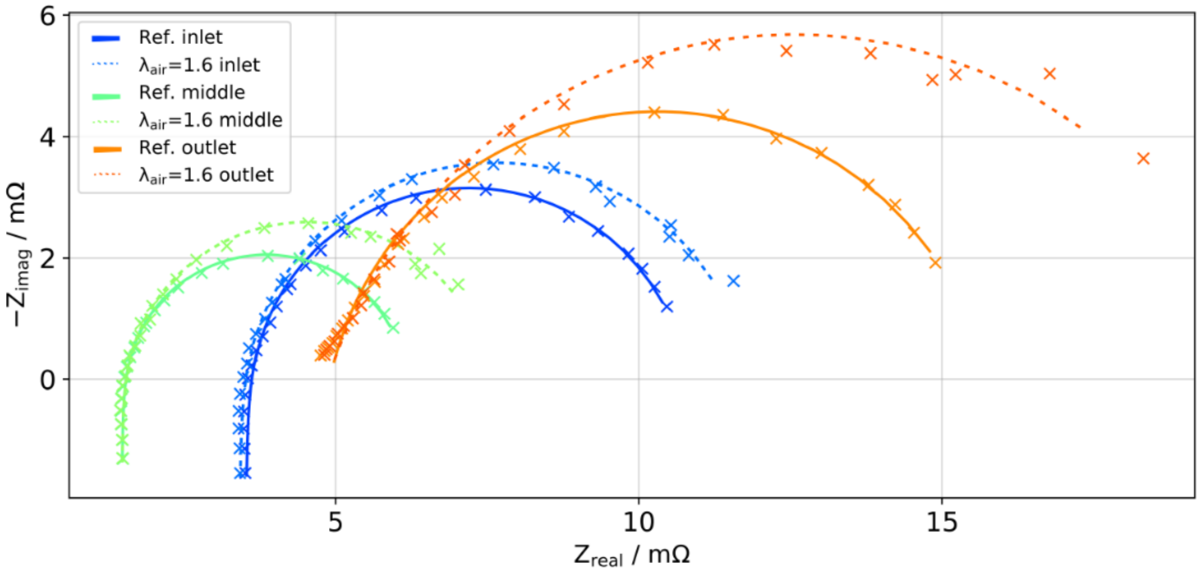

Figure 6: Local impedance spectra response to a change in cathode stoichiometry for 3 locations along the cathode channel direction in co-flow configuration. The lines correspond to fits of the individual spectra with an equivalent circuit. (Source: A. Schuller, PhD Thesis 28836, ETH Zurich, 2022.)

The local spectra exhibited different absolute impedance values and spectra shapes due to the dependency of the measured local voltages on the actual electrode positions (see Figure 6). The spectra could be fitted to a simple equivalent circuit and the membrane resistance and charge transfer resistance were extracted. These resistances were then normalized by the resistances measured in homogeneous reference conditions. The measurements at different operating conditions covering co-flow and counter-flow configurations were able to reproduce the increase of the charge transfer resistance in cathode flow direction, which is typically assigned to higher catalyst layer water saturation. The effect was found most prominent at lower cathode stoichiometry and in particular during air operation, where the reduced oxygen partial pressure towards the cathode outlet contributes additionally to the increase of the charge transfer resistance.

4 Evaluation of results

WP1: Development of PEFC stack compatible EIT electrodes

Achieved. Spring loaded pins and a mounting frame provide reliable electrodes for EIT measurements.

WP2: Implementation of data acquisition and data import into EIT solver

Achieved. A NI-PXI based data acquisition is in operation and data import into the EIT solver is implemented.

WP3: Determination of precision & robustness by model system experiments

Partially achieved. Numerical simulations were used to define the requirements in noise level of the DAQ-system, requirements to the knowledge of the conductivity of non-membrane layers and electrode positioning accuracy. So far, the EIT model can only provide qualitative results of the membrane conductivity distribution. For quantitativeness, the meshing of the flow field details needs to be further improved in future work, particularly in the manifold area, but then the resulting meshes become unmanageable and the conductivity of all non-membrane layers need to be known more precise. The localization of the sensitivity of the different stimulation pattern was evaluated with the FEM model to improve resolution of local AC resistance measurement approach.

WP4: Realization of 5 cell short stack EIT demonstrator

Partially achieved. The electrodes were integrated to the stack. EIT measurements are so far only qualitative. Current distribution was so far not yet determined and no invasive S++ measurements have been implemented.

Synopsis

As an intermediate step towards the intended FEM based EIT determination of the membrane conductivity distribution, the local AC resistance measurement approach was identified as an unforeseen outcome of the project and was explored in its the second part. It allows determining the local membrane conductivity without the FEM model only based on reference measurements and a look-up/interpolation approach. Using a wide frequency range, the approach even allows for non-invasive local impedance spectroscopy of operating PEFC stacks. A patent application (PCT/EP2020/054588) on the approach is pending. The project work finished with the PhD examination of Arnaud Schuller on November 30 2022.

5 Next steps

Improving the model to reach a good fit between the model calculated boundary voltages and the experimentally measured ones would enable the EIT minimization reconstruction approach to work. It would require to take into account an inhomogeneous distribution of the contact resistance and both real and imaginary parts of the impedance. Combining this approach with the neural network reconstruction method would allow to have real time quantification of local impedance changes.

Further development of the hardware, the software environment and the processing tools would be helpful, especially regarding an increase of measurement speed by improved programming and read-out as well as increased current injection range.

During the different local stimulations, offsets of the voltage sine waves could be measured. As the measurements are performed in-plane on the same flow field, the offsets correspond to DC current flowing in plane within the flow fields. When the current density distribution is not homogeneous, current will spread in the flow field to equilibrate [3]. There is therefore a link between the local offsets and the local current density which can be measured. Improving the model could also enable the analysis and interpretation of these in-plane currents and allow the direct investigation of the current density distribution.

All of the experiments in this project were performed with graphite flow fields but stainless steel is the preferred material for automotive applications. It would therefore be interesting to test the method with this new material. It is expected that the information will be more spread out because of the higher conductivity but that the center of the active area may be more accessible.

For practical applications, as in a fuel cell vehicle for example, it would be of interest to drastically decrease the complexity of the hardware and to simplify the data processing. Finding characteristic patterns to limit the total number of measurements, reducing the number of stimulation frequencies and simplifying the hardware for a quicker and less expensive method would be very beneficial – a topic to be discussed with potential industrial partners.

The local measurements interpretation approach could be improved by using the equivalent circuit fit to extract the membrane resistance. It would help to cancel out non-resistive behavior and may therefore help to reduce the differences between reference case with nitrogen and the electrochemical operation cases. Finally, it may also help to decrease the scattering of the individual measurement points.

Comparing the results obtained with the method so far with the results obtained with an established technique such as a segmented cell would help to fully validate the method and might help further the understanding of the uncertainty of certain stimulation patterns. Discussions on such a cooperation with the research division of an industrial company are ongoing.

6 Publications

6.1 Manuscripts

A. Schuller and J. Eller, Finite Element Model Based Determination of Local Membrane Conductivity of Polymer Electrolyte Fuel Cells ECS Trans., 98, 3–9 (2020).
https://iopscience.iop.org/article/10.1149/09809.0003ecst

A. Schuller, T. J. Schmidt and J. Eller, Finite Element Model Based Determination of Local Membrane Conductivity of Polymer Electrolyte Fuel Cells, J. Electrochem. Soc., 169, 044525 (2022).
https://doi.org/10.1149/1945-7111/ac6390

A. Schuller, T. J. Schmidt and J. Eller, Non-Invasive Measurement of Humidity Distribution in Polymer Electrolyte Fuel Cells (PEFCs): Part I. In Situ Proof of Concept, J. Electrochem. Soc., 169, 074504 (2022).
https://doi.org/10.1149/1945-7111/ac7a62

A. Schuller, T. J. Schmidt and J. Eller, Noninvasive Measurement of Humidity Distribution in Polymer Electrolyte Fuel Cells (PEFCs). Part II: Operando Analysis of a Fuel Cell Stack, J. Electrochem. Soc., 169, 124512 (2022).
https://doi.org/10.1149/1945-7111/aca0e3

A manuscript on the local electrochemical impedance spectroscopy approach is currently in preparation.

6.2 Presentations

A. Schuller, T.J. Schmidt, J. Eller, "Noninvasive Determination of local Membrane Conductivity in Polymer Electrolyte Fuel Cells based on a Finite Element Model", ModVal 2021, April 20 – 22 2021, Sion, Switzerland (online conference).

A. Schuller, T.J. Schmidt, J. Eller, "Noninvasive measurement of humidity distribution in Polymer Electrolyte Fuel Cells (PEFCs)", EFCF 2021, June 29 – July 2 2021, Lucerne, Switzerland (online conference).

A. Schuller, T.J. Schmidt, J. Eller, "Noninvasive measurement of conductivity distribution in Polymer Electrolyte Fuel Cells (PEFCs)", 240th ECS Meeting, October 10 – 14 2021, Florida, United States of America (online conference).

A. Schuller, T.J. Schmidt, J. Eller, "Noninvasive Determination of the local Impedance in Polymer Electrolyte Fuel Cells (PEFCs)", 32nd ISE Topological Meeting, June 20 – June 22 2022, Stockholm, Sweden.

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