Degradation Identification for Proton Exchange Membrane Fuel Cell – VirtualFCS Project

Sofía Mendoza, Nadia Yousfi Steiner, Daniel Hissel

Plénières de la FRH2, Saint Gilles, la Réunion
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VIRTUAL-FCS

Agenda

1. Overview VirtualFCS Project
2. Degradation modelling
3. Implementation
4. Conclusion

1 – Overview VirtualFCS Project

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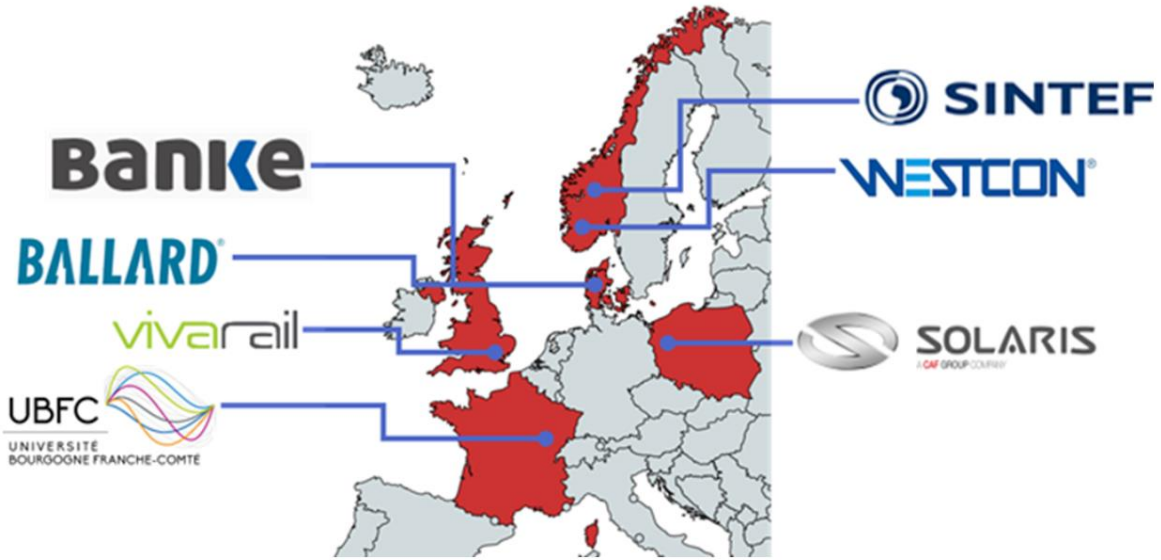
Overall objective: To make the design process of hybrid fuel cell and battery systems easier, cheaper and quicker



Geographical distribution of partners

VIRTUAL-FCS @ GitHub

GitHub: VirtualFCS is a Modelica library for fuel cell system modelling developed through the EU H2020 research project Virtual-FCS.

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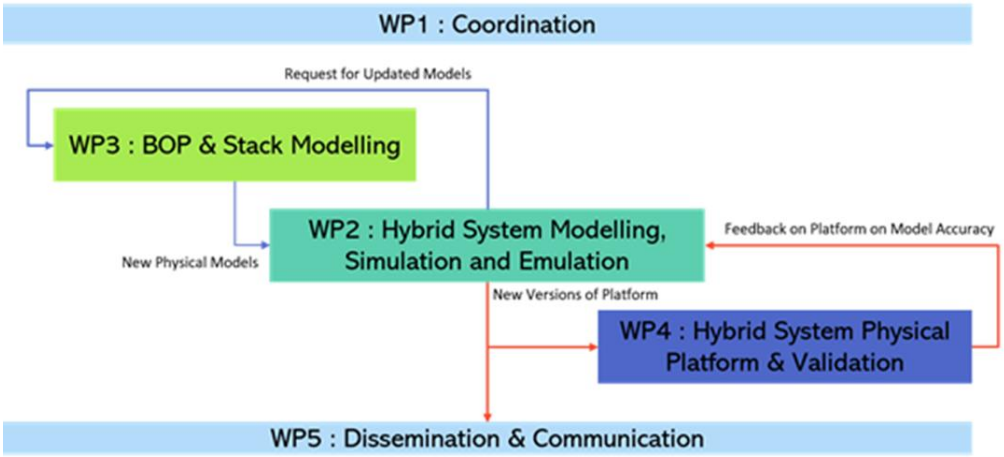
1 – Overview VirtualFCS Project

VIRTUAL-FCS

- VirtualFCS is a Modelica **library for fuel cell system modelling** developed through the EU H2020 research project Virtual-FCS.
- The objective of the complete hybrid system model is to **reproduce and simulate the dynamic behavior** of all the components according to the desired architecture.
- The model is rather dedicated to transport applications. However, it should remain reliable for other applications.



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2 – Stack degradation modelling

Hybrid-based degradation model

Physical model

Fuel cell stack Nernst voltage model

$$V_{fc\_stack}(i) = n_{cells}\left[V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss}+i}{i_0}\right) - i\,.\,R_{eq} - \frac{RT}{2F} ln\left(1-\frac{i}{i_L}\right)\right]$$

Constants

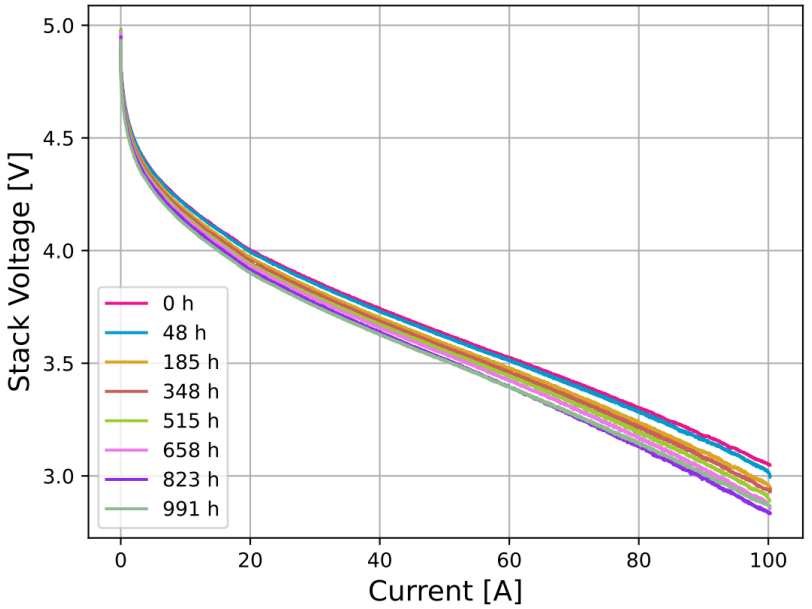
n_{cells}	Number of cells
V_0	Reversible cell voltage
R	Gas constant
T	the operating temperature
F	Faraday's constant

Parameters

a	charge transfer coefficients of the electrodes
i_{loss}	stack internal current voltage
i_0	exchange current
R_{eq}	is the equivalent ohmic resistance,
i_L	is the limiting current

Data-set with degradation

Polarization curves with different levels of degradation



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2 – Stack degradation identification

Nernst equation

$$V_{fc}(i) = V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss} + i}{i_0}\right) - i\,R_{eq} - \frac{RT}{2F} ln\left(\frac{i_L}{i_L - i}\right)$$

- Req increases
- Exchange current $i0$ decreases
- iL has remained nearly constant.

Hypothesis:

- Exchange current decrease over the time through an α factor
- Equivalent resistance increase over the time through an α factor

$$R_{eq} = R_{eq,init} \cdot (1 + \alpha(t))$$

$$i_0 = i_{0,init} \cdot (1 - \alpha(t))$$

Nernst Equation

$$V_{fc}(i) = V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss} + i}{i_0}\right) - i\,R_{eq} - \frac{RT}{2F} ln\left(\frac{i_L}{i_L - i}\right)$$

Modification of the Nerst Equation

$$V_{fc}(i) = V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss} + i}{i_0(1 - \alpha)}\right) - i\,R_{eq}(1 + \alpha) - \frac{RT}{2F} ln\left(\frac{i_l}{i_L - i}\right)$$

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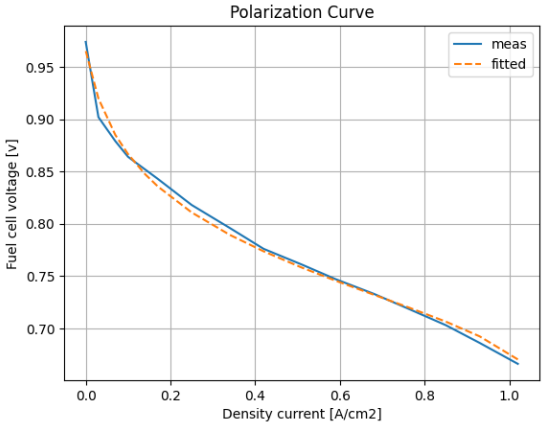
Yue, Meiling, et al. "Degradation identification and prognostics of proton exchange membrane fuel cell under dynamic load." Control Engineering Practice 118 (2022): 104959

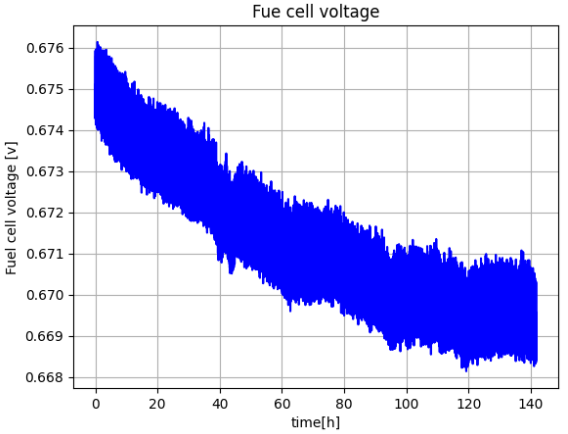
3 – Stack degradation implementation

Data-set used from

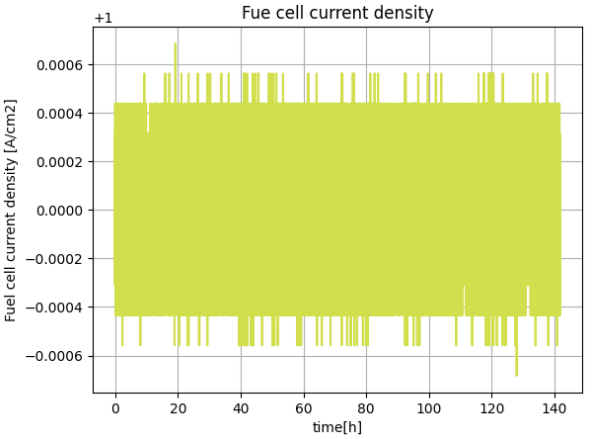
To compute the parameters of the Nernst Equation



To compute degradation coefficient



140 hours of measurements



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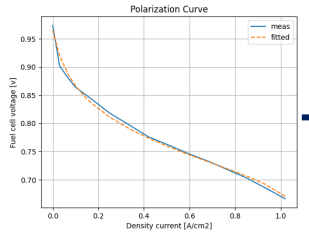
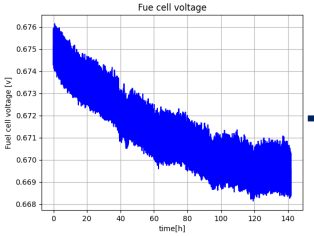
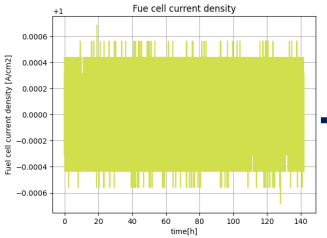
3 – Stack degradation implementation

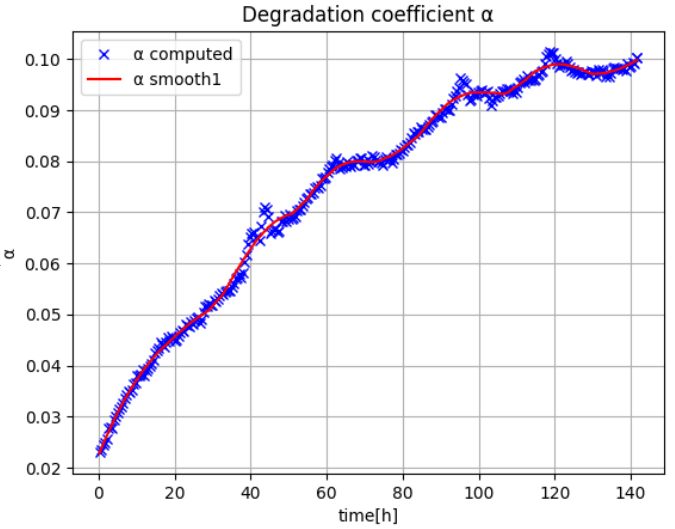
Computation of the degradation coefficient







Algorithm

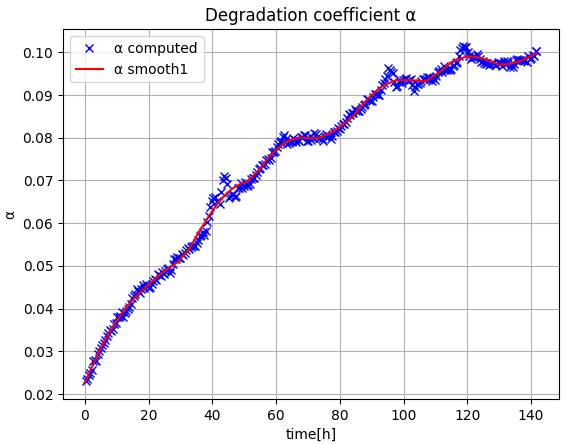


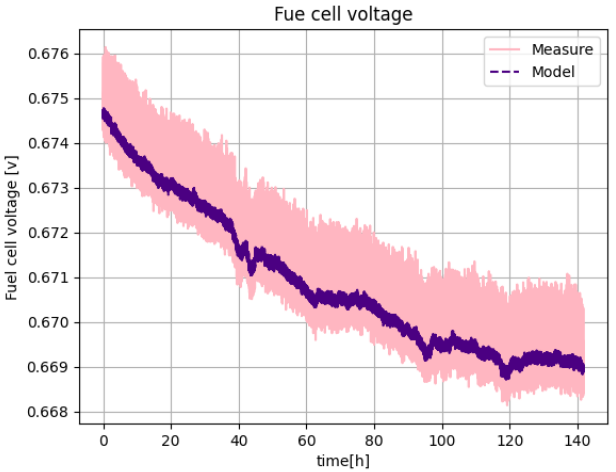
$$V_{fc}(i) = V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss} + i}{i_0(1-\alpha)}\right) - i\,R_{eq}(1+\alpha) - \frac{RT}{2F} ln\left(\frac{i_l}{i_L - i}\right)$$

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 875087. This Joint undertaking receives support from the European Union's Horizon 2020 research innovation programme and Hydrogen Europe and Hydrogen Europe Research.

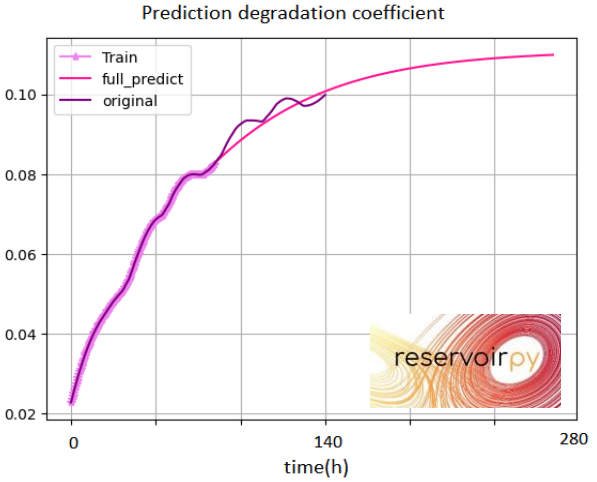
3 – Stack degradation implementation

Computation of the voltage using the Nernst equation modified including alpha and the measurements of current





The results can be used for prognostic with **ESN**



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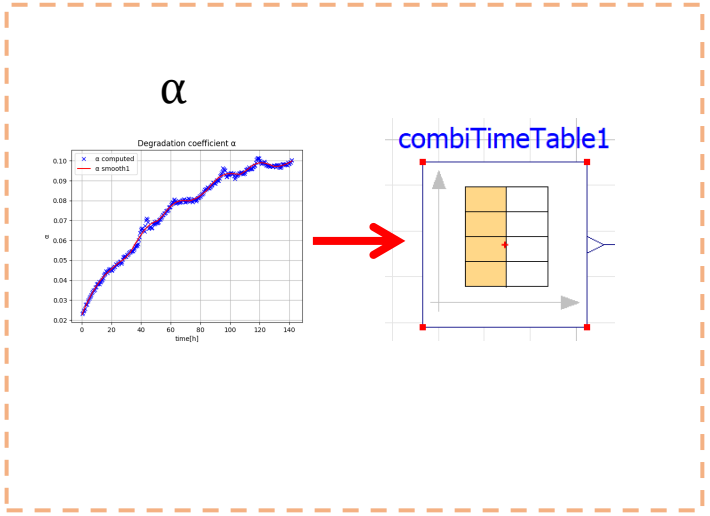
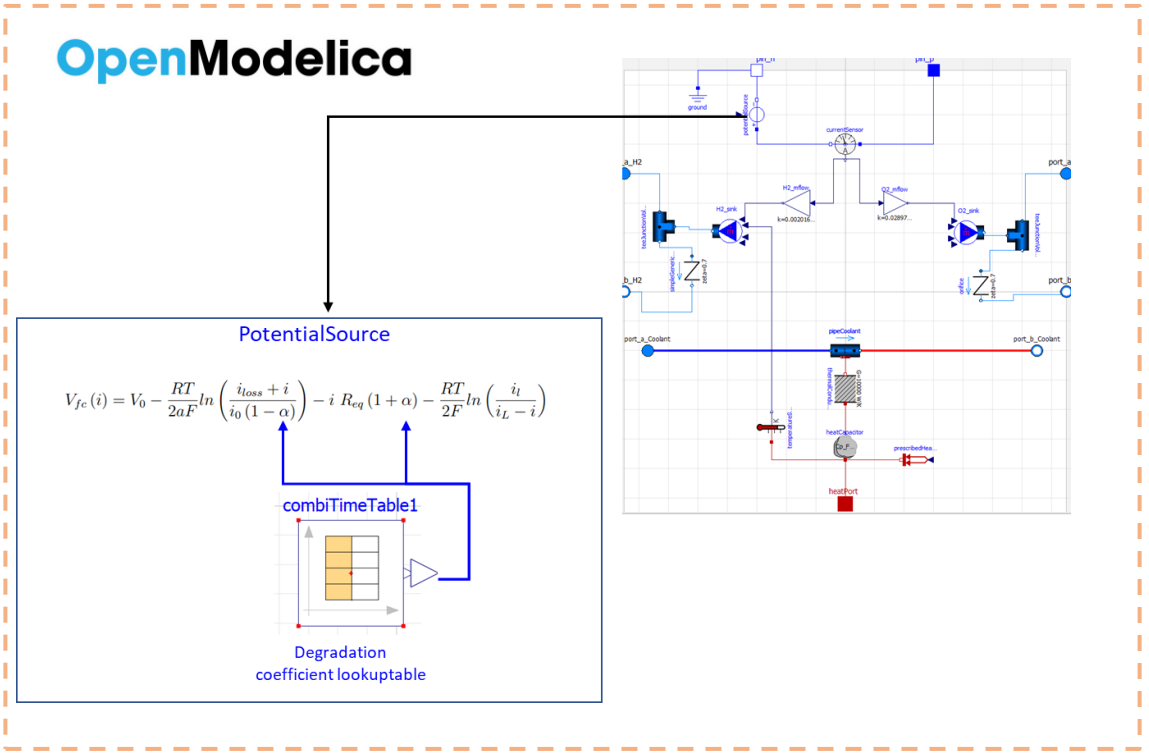
3 – Stack degradation implementation

Output α of algorithm in a lookup table



introduce the alpha/lookup table variable in the Nernst equation



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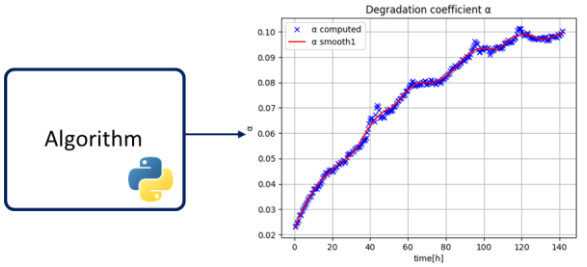
4 – Conclusion

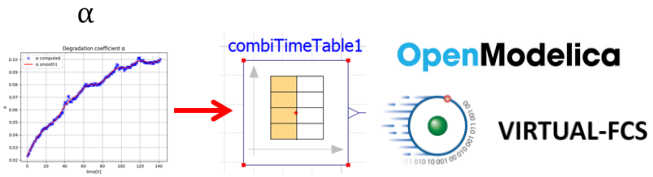
- A coefficient has been integrated into the Nerst Equation to model the voltage degradation over time.

$$V_{fc}(i) = V_0 - \frac{RT}{2aF} ln\left(\frac{i_{loss} + i}{i_0(1-\boldsymbol{\alpha})}\right) - i\,R_{eq}(1+\boldsymbol{\alpha}) - \frac{RT}{2F} ln\left(\frac{i_l}{i_L - i}\right)$$

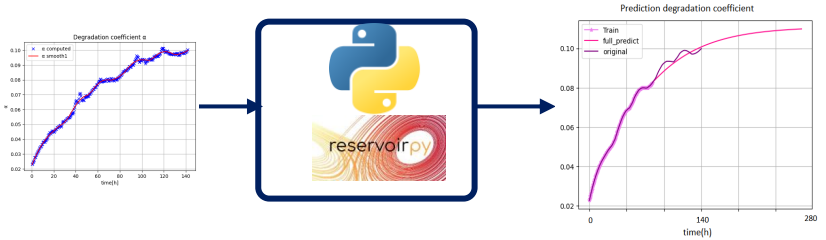
- The degradation coefficient α has been computed using a data set of measurements of experiments provided by SINTEF-Ballard and an algorithm.



- The α can be introduced as a lookuptable that modifies the Nerst Equation to model the voltage degradation of the fuel cell.



- The α can be predicted using an ESN for estimate the RUL



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