	RUBY PROJECT Robust and reliable general management tool for performance and dUraBility improvement of fuel cell stationarY units

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v1	14/04/2020	First release
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Public Abstract
RUBY aims at developing and implementing a tool able to perform integrated Monitoring, Diagnostic, Prognostic and Control functions for µ-CHP and Backup (BUP) systems, based on SOFC and PEMFC. Regarding SOFC systems, to consider the experience obtained in the field, lessons learned in other projects will also be taken in account. Outcome from real installations will be shown and then the most important faults at Stack and Balance-of-Plant levels are reported. Also feedback from previous EU INSIGHT project is provided.

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REAL INSTALLATIONS OVERVIEW

Micro CHP (combined heat and power) unit based on fuel cells are mostly being demonstrated in private homes and small commercial buildings. By the end of December 2019, in total more than 1700 SOFC units have been installed by SOLIDpower. In the following figures the map of the installations is displayed. It is possible to see how most of the units are concentrated in Belgium and Germany, but also an increasing interest and the consequent installation for this technology has emerged in other countries.

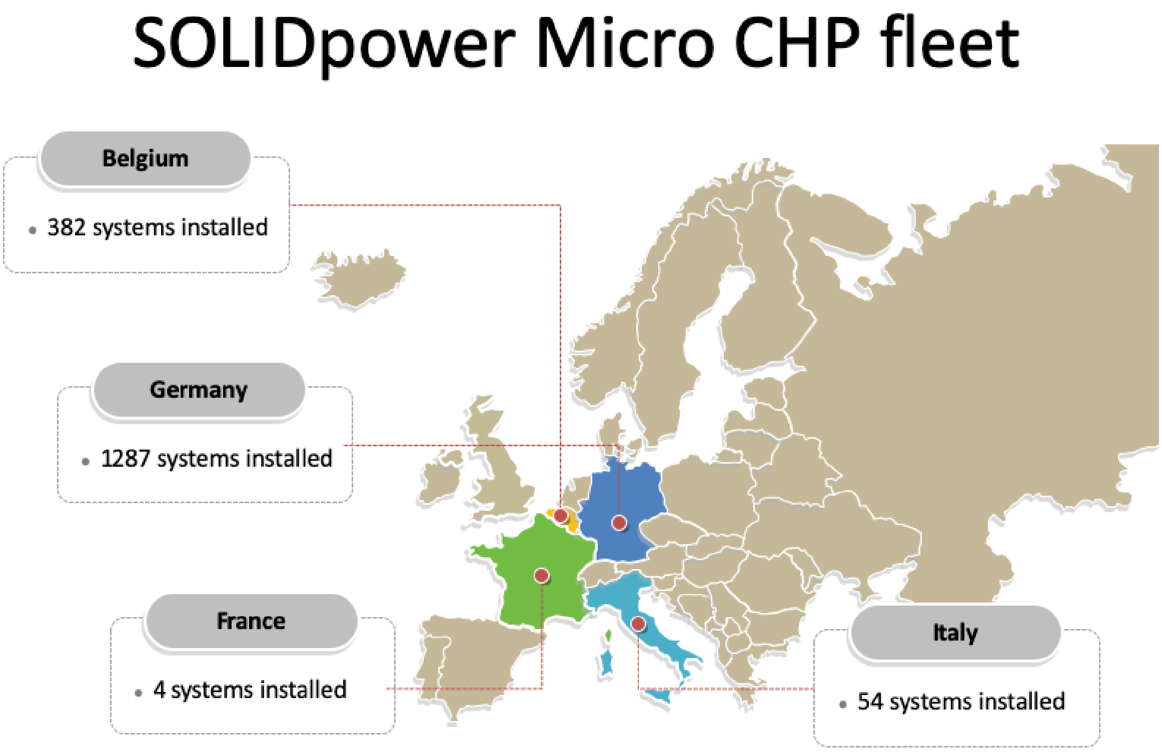

Figure 1 - Installations of BlueGEN uCHP in Europe.

An important component for the success of the technology is the amount of service required. A regular maintenance service is needed to make the uCHP able to work correctly, with the right efficiency and with the right availability. Service maintenance is not only a problem from the economical point of view, but it's also in the customer's interest that the system runs smoothly and that downtime is as low as possible. This means a system operation strategy where efficiency and uptime are maximized and service intervals are as long as possible. Here the great interest is to reduce the impact of the service on the system and prolong lifetime.

OUTCOME OF ANALYSIS AND AVAILABLE DATA

Considering the hours of operation performed by our systems the most faults of SOLIDpower's interest are grouped into two different categories:

1. Stack faults. These are faults that are triggered by malfunctioning of components in the stack. Severe faults are those that have an irreversible effect on the stack performance, and thus limit the lifetime of the stack, and that require system cool down and servicing.

2. Balance of Plant (BoP) faults. These are faults that are triggered by components in the BoP. Severe faults are those that make correct operation of the system, most importantly the stack, impossible, and thus call for system cool down and servicing.

Stack faults

The faults considered at this level are:

- Fuel starvation – Information about lack of input gas or change in gas composition would bring the most added value. In particular the knowledge of gas composition is a key factor: in the next years utilities could change the ratio of gas composition into the grid with higher margin. To have a system to detect that means to optimize fuel consumption and guarantee higher efficiency.
- Anode re-oxidation – Information about the status of SOFC stack after thermal cycles and after hours of operation could give some information about degradation and performance of systems.
- Fuel Leakage – Information about leakage of gas from stack for sealant failure.
- Low Steam/carbon – Information about a lower steam/carbon than expected would help to prolong life of system and extend period of maintenance.

BoP faults

The faults considered at this level are:

- Water treatment system - Information about the status of water treatment system would help to decrease service cost and maintenance;
- Sulphur poisoning – Information about the status of desulfurizer system would help to decrease service cost and maintenance;
- Water flow meter failure - Information about the status of water flow meter would help to decrease service cost and maintenance;

FEEDBACK FROM INSIGHT PROJECT

INSIGHT project (GA 735918), ended in December 2019, was dealing with the development of a monitoring, diagnostic and lifetime tool for SOFC microCHP unit, up to a validation on a real SOFC system (EnGen 2500).

In the frame of the project a detailed review of SOFC degradation processes was carried out, with an update from the literature and a return of experience from field and stack testing by the partners. A compiled file was circulated to partners for assessment and priority ranking of the various processes. Account was taken of the severity and frequency of the degradation phenomena, their detectability, and potential for mitigation or recovery measures.

Each process was then marked with a severity mark (1 = mild, 2 = medium 3 = severe), and an occurrence mark (1 = rare, 2 = regular, 3 = frequent), which multiplied give a risk number (between 1 x 1 = 1 (minimal risk) and 3 x 3 = 9 (maximal risk)). In addition, a qualitative mark was given to each process (A = high priority – B = medium priority – C = low priority).

Based on this overview, a final ranking was specified. The table below presents in red the 3 phenomena considered as the most important. Then the ranking continues from the most important to the less important.

Table: summary of degradation processes considered in INSIGHT. For each process, the risk quotation is provided, correpsonding the the combination of the severity and probabolity of ocurrence. Then the possibilities of recovery and of detection were provided. Finally, on the right column a qualitative ranking is provided with A, B or C, A being the most important and C the less important.for the sake of clarity a corresponding color code is provided, red corresponding to the most important and green to the less important.

Component	Process	Risk	Recovery	Detection	Σ
Anode	Reoxidation	4.5	lower UF, **OCV operation;** **current treatment**	**P5 ;** (P2, R_Ω)	**A**
Anode	C deposition	4.5	**steam/CO_2 flush,** **j↑** (electrochemical oxidation), increase H_2	**Δp(anode, reformer) reformer-T** **λ-sensors (O/C-ratio)** ; R_Ω**↓** (P2, P5)	**A**
Sealing	Leakage	4.5	**compression↑** ? **self-healing** by T **↑** ?	**OCV ↓** ; **T ↑** **cathode outlet humidity** λ-sensor **$\Delta P_{an\text{-}cath}$**, ΔP_{an}, ΔP_{cath}	**A**
MIC	Contact loss	4.5	compression? T **↑** ?	R_Ω, (P2), Δp cathode?	**B**
MIC	Corrosion + poisoning	4.38	Cr revolatilisation? (OCV or reverse polarity?)	R_Ω (scale); P3 (Cr poisoning); P2 (cathode pore blocking)	**B/C**

Anode	S poisoning	3.94	stop S-flow; T$\uparrow$; H_2-operation	S-detector at trap outlet; P5,P2	**B**
Cathode	Demixing	3.75	$T_{op}\uparrow\downarrow$?; $\eta_{cath}\uparrow$ or $\eta_{an}\uparrow$? (controversial); operation at **reduced pO_2 (e.g. 5%)?**	**P3** (R_{pol}), **P1** (O_2-dissoc), (R_Ω), P2 (when reduced porosity)	**B**
Sealing	Reactivity + Poisoning	3.38	self-healing by T $\uparrow$?	OCV $\downarrow$, T $\uparrow$, air humidity, λ-sensor, $\Delta P_{an-cath}$, ΔP_{an}, ΔP_{cath}, P3/P5 (poisoning), P2	**B/C**
Anode	Coarsening	3	Current treatment	P5, P2, R_Ω	**C**
Electrolyte	Leakage	3	none?	OCV $\downarrow$, T $\uparrow$, air humidity, λ-sensor $\Delta P_{an-cath}$, P2, R_Ω, P5, P3	**C**
Cathode	$SrZrO_3$ formation	2.81	none	R_Ω ?, P3?	**C**
Electrolyte	Conductivity loss	2.5	none	R_W	**C**

INSIGHT has considered the top 3 rows for detailed investigation and application of detection and mitigation measures in the project :

1. **Anode reoxidation**. **Detection** on the **P5** anode charge transfer signal (increase) occuring around **1 kHz**, and **recovery** study by **current treatment**.

2. **Carbon deposition**. **Detection** by **pressure drop increase** (reformer, stack anode), potentially on the **P2** gas conversion process (increase) around a **few Hz** and a temporary decrease in series resistance **R_Ω**; **recovery** study by a change in **anode gas composition** (steam / CO_2 flush, higher H_2) and **increase of operating current** to electrochemically reoxidize deposited carbon.

3. **Sealing leakage**. **Detection** by an increase in **cathode outlet humidity** and a **decrease in pressure drops** (cathode, anode, cathode vs anode, depending on where leakage may occur), and **recovery** study by temporary **temperature increase and compression increase combined with reduced gas flows** to explore self-healing of the leak(s).

This is documented in INSIGHT Deliverable D2.2. Failure analysis and critical lifetime parameters for SOFC system, which is a public deliverable, available on INSIGHT website: insight-project.eu.

RUBY project can start from this list, continue to work on faults already considered in INSIGHT or consider additional faults from above table.

CONCLUSIONS

The deliverable examined the most important faults for SOLIDpower systems and feedback from former INSIGHT project to be addressed in the frame of the project RUBY.