Validation of performance of RUBY-tool for SOFC micro-CHP

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WORKSHOP @ LUCERNE 5.7.2022

For starters a quick recap of the project

- The project develops and demonstrates a new generation of robust, general and cost-effective prognostic and control tool for both PEMFC and SOFC systems primarily for µ-CHP and energy generation (e.g. remote/backup)

- Tool detects and mitigates most common faults and optimizes the performance of fuel cell system

- RUBY-project's technical part consists roughly of the following:
  - Planning and designing what to do according to the project objectives
  - First phase testing of the fuel cell systems in normal and faulty conditions
    - to record initial performance and degradation rates of the system
    - to provide data for diagnostics algorithms and performance optimization developers
  - Algorithm and physical board development and integrating them to fuel cell system
  - Validation of the performance of the developed RUBY-tool

- Currently we are running first phase tests. Validation tests will be carried out during final year of the project (2024)

- The SOFC µ-CHP-system is Sunfire HOME system running on natural gas. Its nominal electrical output power is 750 W and thermal output is 1250 W.

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Grant Agreement Number 875047

First phase testing currently running at VTT

- Initial performance and degradation rates have been/will be recorded
- As well as reference EIS spectra
- Next we will move on to faulty condition operation
- Data will be delivered to algorithm developers
- Similar tests are run at EPFL and CEA
- These will form a basis for validation test campaign which will be carried out during the last year of the project

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Objectives and Faults? (1/2)

For SOFC µCHP-system four performance improvement targets and three faulty conditions have been set and acknowledged

- **These KPIs are**
  - System lifetime
  - Availability
  - Stack durability
  - Electrical efficiency

- **Faulty conditions which have been acknowledged as the most important ones are**
  - Sulphur poisoning
  - Carbon formation
  - Too high fuel utilization rate

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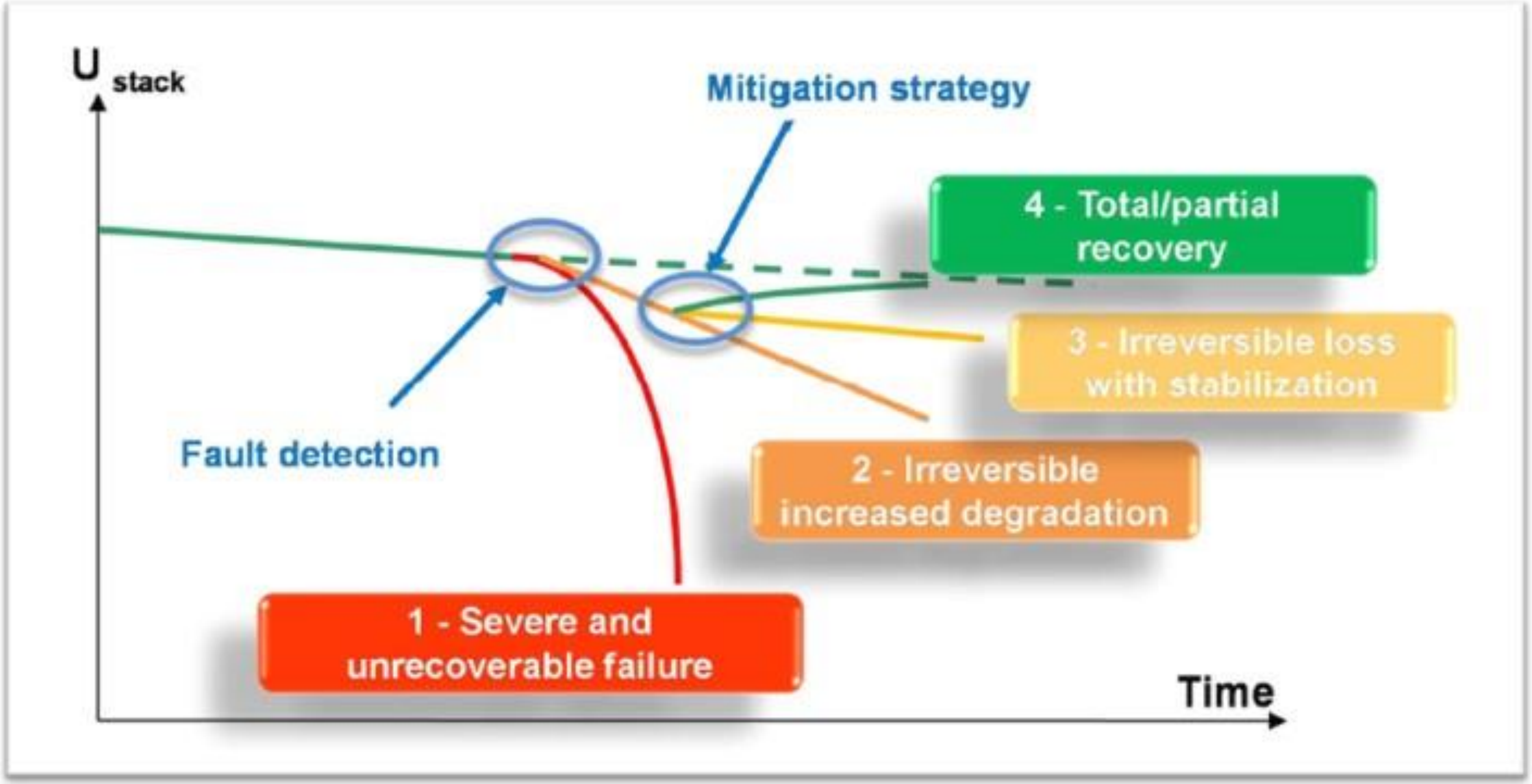
Objectives and Faults? (2/2)

Target is that RUBY-tool detects and mitigates the faults. Picture below describes this and possible outcomes of the actions by the tool



At the same time the tool optimizes the performance of fuel cell system.

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How to do the validation reasonably?

Difficulties

- How to validate that RUBY tool contributes to extending system lifetime to more than 10 years in one year test campaign?
- As only two systems will be tested with the developed RUBY-tool, how to validate that results are applicable for all the systems?

Requirements

- Validation has to be connected to the faults that are dealt with in the project, otherwise testing doesn't make sense

Not the best approach…

- To run one year test keeping fingers crossed hoping that no unintentional shutdowns occur, then extrapolate the performance data up until the end-of-life conditions and hope that project targets will be met
- This doesn't sound reasonable and with only a couple of systems, what would it prove even if everything would go like a dream?

Conclusion

- To validate the targets in one-year testing campaign and to generalize the results from only two systems, the validation campaign must be based on **statistics and data** of performance of the SOFC-systems and data of likelihoods and severities of the faults

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The solution

- Acquire data of current performance and faults
  - Current performance data of the project targets meaning stack durability, system lifetime, system availability and electrical efficiency
  - Quantified data of the faults
    - How often they occur? I.e. likelihood of the fault in real life operation
    - In case of a fault, how long service breaks are required to fix the system? I.e. severity of the faults
- To carry out a validation test campaign where faults are imposed to systems like in first phase testing and real life
  - Meaning sulphur poisoning and water and/or fuel supply faults
    - These faults have been decided to be the main ones in RUBY project based on their severity and likelihood
- Then to validate that RUBY-tool detects the faults and mitigates them
  - Based on the data and detection ability of the RUBY-tool, we are able to quantify and calculate performance improvements of the RUBY-tool using current performance data as a reference
  - This is directly the case with availability but a similar approach will be used with lifetime and durability
- Electrical efficiency values in different operating points can be easily measured and validated by standard procedure
- For lifetime estimates, RUL-estimates provided by the tool will also be exploited

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RUBY

Example with availability

Clean Hydrogen Partnership

- A hypothetical example: 1000 µCHP SOFC-systems are in operation with overall average availability of 97 %. Let's assume that yearly 3 % of them face a fault which is dealt in RUBY-project and RUBY-tool detects ALL these faults and does successful mitigation actions. Due to this, one day service break is enough instead of 2 weeks of service caused by more severe damage. How much does the overall availability increase?
  - 1000 * 365 * 24 * 0,97 = 8 497 200 hours of yearly availability
  - 1*1000 * 0,03 * 13 * 24 = 9 360 hours of more availability due to the detection and mitigation measures by RUBY-tool
  - (8 497 200 + 9 360) / (1000 * 365 * 24) * 100 = 97,1 % of overall availability with the help of the tool
- So in this example with imaginative figures, RUBY-tool would have contributed to 0,1 %-unit improvement in availability.
- Depending on the detection ability (”fault hit rate”), coefficient for improvement can be calculated. E.g. if the tool will detect and mitigate 75 % of the faults without any false alarms, the increase in availability hours could simply be multiplied by 0,75.

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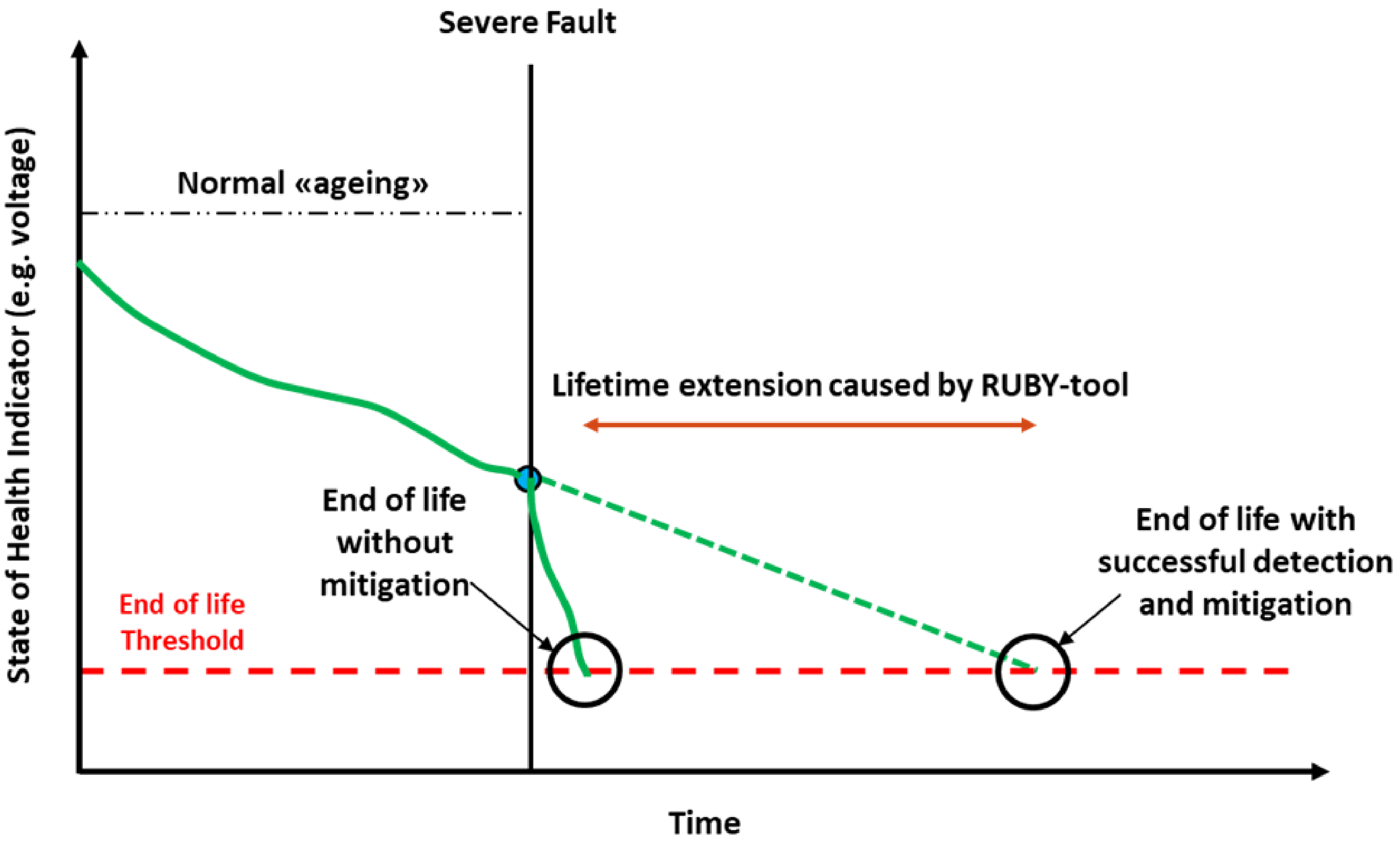
System lifetime and stack durability



Here initial/normal degradation data is used as a reference. All the faults (if not mitigated) are detrimental so lifetime extension can be extrapolated and subtracted by recording the degradation after the mitigation. Estimates for RUL by the tool are exploited too.

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Grant Agreement Number 875047

Thank you!

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 875047. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.