Robust and reliable general management tool for performance and durability improvement of fuel cell stationary unit

European Commission

First Periodic Report

Clean Hydrogen Partnership

RUBY

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

Grant Agreement n° 875047
Research and Innovation Project

Editors: Cesare Pianese, Pierpaolo Polverino, Ennio Andrea Adinolfi, Luigia Scorziello

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Duration: 60 months
Project Coordinator: Cesare Pianese – Università degli Studi di Salerno

Contact: Cesare Pianese – Università degli Studi di Salerno – pianese@unisa.it

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Clean Hydrogen Partnership

1 SUMMARY OF THE CONTEXT AND OVERALL OBJECTIVES OF THE PROJECT

Fuel Fells (FCs) are becoming more and more attractive for real world applications, their performance meet the strong constraints imposed by regulations and international policies aiming at reducing the carbon footprint of power systems. Despite the noticeable improvements attained in the last decade, still the competitiveness with respect to conventional solutions is yet to be achieved for FCs efficiency, reliability, availability and durability. The implementation on FC Systems of suitable control, diagnostic and prognostic algorithms can improve those performance, making FC cell more efficient and competitive. The RUBY project covers the areas of Proton Exchange Membrane FC (PEMFC) backup and Solid Oxide FC (SOFC) µ-CHP systems that are among the most mature stationary FC solutions available on the market today.

The project aims at developing, integrating, engineering and testing a comprehensive and generalized Monitoring, Diagnostic, Prognostic and Control (MDPC) tool capable of improving efficiency, reliability and durability of SOFC and PEMFC systems for stationary applications. The MDPC tool features Electrochemical Impedance Spectroscopy (EIS)-based stack monitoring for fault diagnosis and lifetime estimation, Balance of Plant diagnostics, supervisory Real Time Optimization (RTO) control and mitigation strategies. The tool relies on advanced dedicated hardware and will be embedded in the Fuel Cell Systems (FCSs) for on-line validation in relevant operational environment.

Therefore, the RUBY tool will reach at the end of the project a Technology Readiness Level equal to TRL 7. It is foreseen that the tool will be ready for engineering scaling up of production, together with certification for embedding within commercial FCS.

To successfully fulfil the aims of RUBY, the following four main technical objectives were set:

1. Improve FCS performance and durability by implementing an advanced and integrated algorithm that combines monitoring, diagnosis, prognosis, control and mitigation actions for both SOFC and PEMFC systems.
2. Design and engineer the hardware required for MDPC algorithms application, with attention to sensors reduction issues and the specific constraints imposed by stack technologies and systems applications towards industrial scalability.
3. Perform dedicated experimental campaigns for stacks and system characterization and MDPC tool prototype validation embedded on FCSs running in operational environment.
4. Develop an advanced FCS management strategy (supervisory level), with functionalities integrated with remote monitoring, for future smart-grid interaction and predictive maintenance application.

The Figure 1 sketches the main tasks planned for RUBY with respect to the four objectives and the logical links among them. The workflow of the project is reported in Figure 2 along with the activities described in each box of the diagram. The three arrows on the left are the main building blocks, which are linked with the main objectives, namely experiments (obj. n.3, light blue upper path), algorithms (obj. n.2, yellow middle path) and hardware (obj. n. 1, orange lower path).

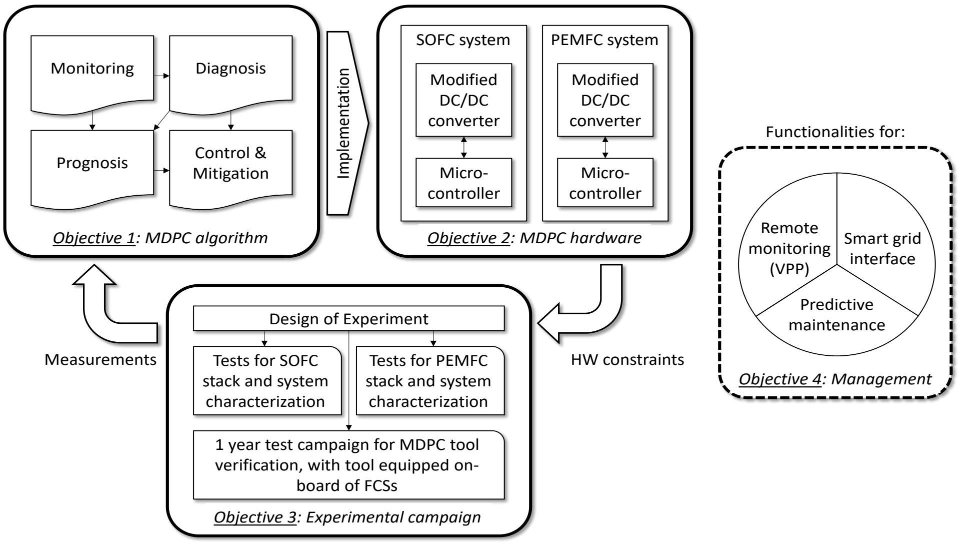

Figure 1 –RUBY project objectives and tasks.

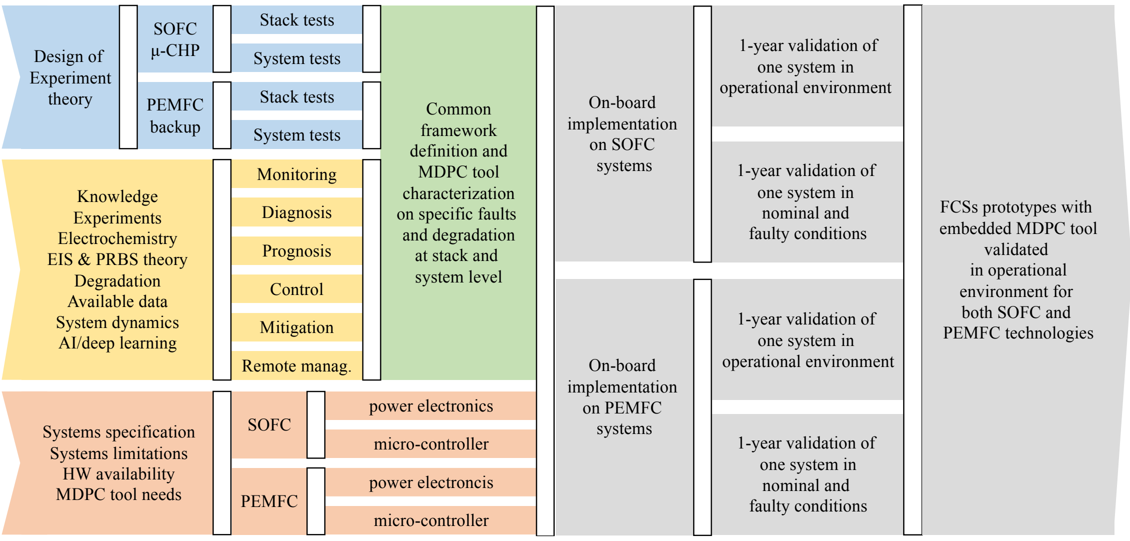

Figure 2 – Overview of RUBY project methodology and activities workflow (from left to right).

The project framework derives from the outcomes of several EU projects (e.g., GENIUS, DESIGN, DIAMOND, INSIGHT, D-CODE and HEALTH-CODE) dealing with the problem of building monitoring and diagnostic techniques for on-field applications on both PEMFC and SOFC technologies. Among them, the projects HEALTH-CODE (FCH JU H2020, G.A. No. 671486) and INSIGHT (FCH JU H2020, G.A. No. 735918) have specifically improved the know-how generated in the domain of monitoring and diagnostics, achieving successful results in testing advanced solutions for PEMFC and SOFC, respectively. The proof-of-concepts made available by these latter projects were the starting point of RUBY that aims at improving all solutions proposed within a common framework. RUBY exploits those techniques to develop prognostic and supervisory control for implementation within marketable FC systems.

2 WORK PERFORMED AND RESULTS ACHIEVED

The achievements of the project RUBY at month 25 (January 2022) are:

- EIS board for Backup system ready.
- Experimental test protocols closed for stacks characterization.
- PEMFC stack and systems installed on test rigs under testing.
- SOFC stacks at lab premises ready for experiments to start.
- Two SOFC systems being connected to instrumentations for testing.
- Methodologies identified for MDPC functions.
- Preliminary tests for monitoring and prognostics algorithms for both PEM and SOFC.

The monitoring and diagnostic algorithms of the Balance of Plants (BpP) are being developed relying on conventional fault detection and isolation approaches making use of lumped models for monitoring; a sensors fault detection algorithm has been proposed as well. Stack monitoring and diagnostics is performed through EIS data with several approaches based on Equivalent Circuit Models and both Soft Computing and Artificial Intelligence methodologies. Prognostic algorithms are implemented via both Artificial Intelligence and Sensor Data Fusion techniques and are tested on long run field data. The RTO controller is under development for the µ-CHP system.

For the implementation of the EIS-based monitoring on-board of both FC systems the hardware has been designed to generate and superimpose on the stack current either sinusoidal or Pseudo Random Binary Signals to cause a time variation of the voltage. Two configurations (see Figure 3) have been designed; in the first one the MDPC tool controls the converter to generate the signal perturbation, whereas in the other a dedicated hardware will impose the perturbation, while keeping the inverter as it is. A compact prototype of the MDPC board has been also built.

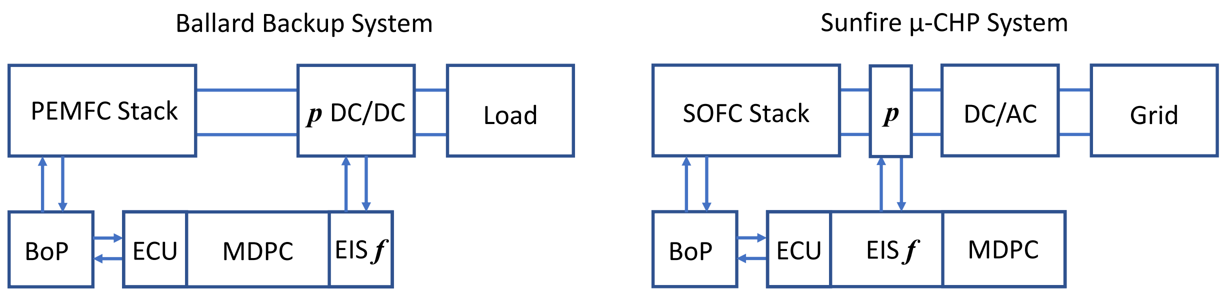

Figure 3 – Main schemes of BPSE Backup System (left) and SUN µ-CHP System (right) with the EIS perturbation (***p***) and control functions (***f***).

The experimental campaign on both FC systems has started to generate data for the validation of the algorithms. Tests are progressing for a PEM stack in nominal and faulty conditions and for two backup systems (Figure 4). For SOFC, one stack will be tested along with two µ-CHP (Figure 5), all tests will be performed in nominal and faulty operations.

Figure 4 – PEMFC backup for system and stack characterization.

Advanced functions are being developed to implement energy management systems that would help achieving the optimal use of the energy within smart grids. A hierarchical control architecture (Figure 6) has been proposed for the best exploitation of RUBY MDPC tool; it will help in managing the interactions among FCs and other energy systems within a smart grid making use of virtual power plant (VPP) concept as well.

Figure 5 – SOFC μ-CHP systems for system and stack characterization.

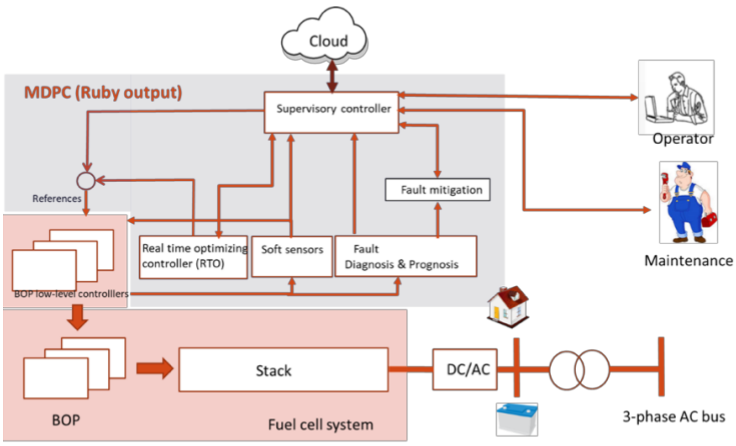

Figure 6 – Hierarchical control architecture.

3 PROGRESS BEYOND THE STATE OF THE ART AND IMPACTS

The project preliminary outcomes are confirming the potential in generating positive impacts on both technology and market fields, thus contributing to the progress of FCSs products beyond the state-of-the-art. The results achieved so far confirm the expected advancements though a complete assessment will be performed in the second part of the action. One interesting result deals with the design of two hardware configurations for EIS perturbation. In both cases the flexibility of the solutions can guarantee the implementation of EIS-based monitoring on any FC system. Furthermore, with respect to the project proposal, additional algorithms have been developed; this result will enlarge the possibility to find more appropriate and effective techniques for diagnostics, prognostics and control to enhance the lifetime while keeping the efficiency closer to that at beginning of life (BOL).

Academic research dissemination and communication is a continuous channel to enhance the spreading out of the results achieved by the project. 5 papers have been published at the current stage of the project:

- Žnidarič L.,Nusev G., Morel B., Mougin J., Juričić D., Boškoski P. Evaluating uncertainties in electrochemical impedance spectra of solid oxide fuel cells, in Applied Energy (December 2020).
- Chanal D., Steiner Yousfi N., Chamagne D., Péra M.C. Impact of standardization applied to the diagnosis of LT-PEMFC by Fuzzy C-Means clustering, in IEEE Magazines (November 2021).
- Chanal D., Steiner Yousfi N., Petrone R., Chamagne D., Péra M.C. Online Diagnosis of PEM Fuel Cell by Fuzzy C-Means Clustering, in Reference Module in Earth System and Environmental Sciences (2021).
- Moussaoui H., Nakajo A., Rinaldi G., Hubert M., Laurencin J., Van Herle J. Modeling Nickel Microstructural Evolution in Ni-YSZ Electrodes Using a Mathematical Morphology Approach, in ECS – The Electrochemical Society (June 2021).
- Da Rosa Silva E., Hubert M., Morel B., Moussaoui H., Debayle J., Laurencin J. A Dynamic Multi-Scale Model for Solid Oxide Cells Validated on Local Current Measurements: Impact of Global Cell Operation on the Electrodes Reaction Mechanisms, in ECS – The Electrochemical Society (October 2022).

Furthermore, to improve the collaboration among project partners and to foster the knowledge among the students, more than 10 students are involved in the RUBY project research activities (4 Master, 4 PhD, 6 Bachelor).

4 LIST OF PARTNERS

Name	Acronym	Type	Country
Università degli Studi di Salerno (Coordinator)	UNISA	UNI	Italy
Ballard Power System Europe A/S	BPSE	IND	Denmark
Sunfire Fuel Cells GmbH	SUN	SME	Germany
Bitron S.p.A.	BITRON	IND	Italy
Commissariat à l'énergie atomique et aux énergies alternatives	CEA	RO	France
Institute Jožef Stefan	IJS	RO	Slovenia
Teknologian tutkimuskeskus VTT Oy	VTT	RO	Finland
Europäisches Institut für Energieforschung EDF-KIT EWIV	EIFER	RO	Germany
Université Bourgogne Franche-Comté	UBFC	UNI	France
Ecole Polytechnique Fédérale de Lausanne	EPFL	UNI	Switzerland
Fondazione Bruno Kessler	FBK	RO	Italy
SOLIDpower S.p.A. (Terminated November 2021)	SP	SME	Italy

*University (UNI); Research Organization (RO); Small Medium Enterprise (SME); Industry (IND)