**Grant agreement number: 779730**

WP3 MSc course design and operations

D 3.1 ‘Remote Lab’ Interface

Due date: 30-06-2018

Lead participant name: POLITO

List of contributors: POLITO

Status: F (final)

Dissemination level: CO (confidential)

Last updated: 31 October 2019 (V2.0)

Document History

| Issue Date | Version | Changes Made/Comments |
|---|---|---|
| October 15th, 2019 | 1.0 | First version |
| October 18th, 2019 | 1.1 | Revision |
| October 31st, 2019 | 2.0 | Final edits for upload, acknowledgment statement |



**Disclaimer and Acknowledgment:**

The research leading to the results reported here has received funding from the European Union's H2020 programme through the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement no. 779730. Any opinions expressed in this report are solely those of the authors and neither of the FCH 2 JU, nor the European Commission or its representatives.

# Table of Contents



# Abstract

The deliverable 3.1 provides the description of the "Remote Lab" offered by Politecnico di Torino (POLITO) for remote SOC experiments. The hardware, web interface and possible experiments offered to the course are described in this document.

# 1 Introduction

The "Remote Lab" consists of a test-bench for single Solid Oxide Cells (SOC) characterisation located at Politecnico di Torino, equipped with a data acquisition and control system with a web interface. The test bench requires a phase of "hardware preparation" of the experiment that is performed locally by PoliTo personnel to bring the SOC into operative conditions. Then characterisation experiments can be performed remotely through the web interface. Local sensors and actuators, completely independent from the data acquisition and control system remotely accessible by the web interface, ensure the test-bench safety. The control architecture of the bench between the hardware and the web interface is based on a local controller exchanging data by ethernet with a control software installed in a virtual machine hosted by Politecnico di Torino servers. Data are stored on a database in the virtual machine and exchanged with the web interface following the security protocols of Politecnico di Torino. The web application allows administrators (ie., the laboratory personnel) to setup the control variables for users (i.e., students) in accordance with the experimental tasks to be performed for the course within safe limits for the tested cells.

# 2 Remote laboratory

## 2.1 Description of the infrastructure

The test bench is designed for testing single planar Solid Oxide Cells (SOCs) at ambient pressure in fuel cell operating mode. The test-rig is composed of several subsystems:

1. an oven, which the test chamber is located in which the cell is maintained at fixed test temperature in a dedicated test fixture that provides gas distribution to the cell and current collection;
2. a gas distribution system that provides mixtures of gaseous reactants from cylinders to the test fixture, with desired composition and flow rate;
3. a humidification system, in which water is added to dry gaseous streams to obtain the desired humidity level of the mixture;
4. a group of electric auxiliaries, which supply electricity to oven, measurement and control instruments;
5. an electronic load for the electrical characterisation of the cell through current-voltage measurements;
6. the data acquisition and control system.

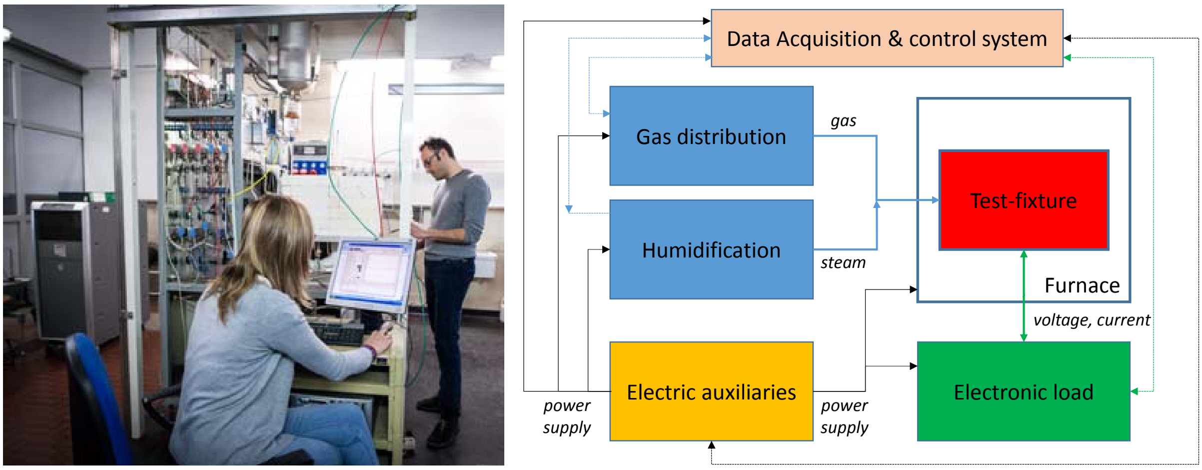


Figure 1 – General view of the test-rig and test-rig schematic.

The test chamber (dimensions 35x35x15 cm) is heated by electrical resistances (max 900°C) and insulated from the external environment by walls of removable refractory bricks. SOCs (cells) are placed in a dedicated test-fixture during experiments in the test chambers. The test-fixture provides gas distribution and electrical connection to the cell's electrodes. One test-fixture is currently available for the bench: a sealed housing for testing square cells (5x5 $cm^2$).

Figure 2 – Sealed test-fixture for single cells.

This test-fixture (FuelCellmaterials, USA) is composed of two housings (steel) with metallic meshes for current collection (silver for the cathode and nickel for the anode) and inlet/outlet pipes (steel) for providing gases to the electrodes and collect the exhaust gases. Nickel and LSM inks are used to ensure the contact between current collection meshes, test fixture and electrodes. The cell voltage is measured with two separate Platinum sensing wires contacting the cathode and anode meshes, respectively. Copper braided leads are connected to the pipes (outside the heated chamber) to act as current take-off buses and connect the cell to an external load. A thermocouple (designed for temperatures up to 1300°C) is in contact with the test-fixture providing the cell temperature. The cell is sealed with mica seals at the rim of the cell. A pressure of 5 PSI is applied by weights on the top housing to ensure the compression of seals.

A picture of the test-fixture assembled in the test chamber is shown in Figure 2.

The piping for anodic/cathodic gas distribution and spent gases collection, current and voltage wires cross the insulating walls through dedicated holes; current wires are connected to an electronic load, while the voltage ones are connected to a terminal board from which the voltage signal is collected and carried to the data acquisition system.

The gas distribution system connects the test-rig to the laboratory low-pressure gas lines and ensures that dry gas streams with specified flow rates and compositions are sent to the humidification system or directly to the SOC. This system is composed by pipes, valves and mass flow controllers (Bronkhorst). Technical gases available in the laboratory are: $H_2$, CO, $CO_2$, $CH_4$, $N_2$ and dry air. The connection of gas cylinders for feeding other gases to the SOC is also possible (e.g. for testing the effect of pollutant mixtures). The humidification system of the dry gases is constituted by a Controlled Evaporator Mixer (CEM) that produces steam from demineralised water. A gas venting system with measuring sensors for explosive and toxic gases ensures the safety operation of the test-rig. The gas distribution system is highly flexible and expandable and allows the connection and integration of new mass flow controllers and gas cylinders depending on test requirements.

The system is completely instrumented for the measurement of cell voltage, current and temperature (cell and oven). An electronic load allows performing experiments in galvanostatic (fixed current) or potentiostatic (fixed voltage) modes and measure current–voltage characteristics (i-V curves). The data acquisition and control system consists of a CompactRIO controller (National Instruments) that is the hardware interface for the input/output signals from/to the measurement and control devices (i.e. mass flow controllers and meters, thermocouples, furnace controller, voltage probes and electronic load). The CompactRIO controller is interfaced with the remote control architecture under development for the TeacHy project, which is explained in the following section.

The safety of the test-bench is ensured by a system of sensors and actuation valves connected to laboratory gas lines, which is autonomous and independent from the control system of the test-bench.

The test-rig can be also connected to gas analysis instruments (not integrated in the test bench) for the analysis of the exhaust gases collected from the test fixture of the cell. A mass spectrometer (Hiden Analytical) is already available in the laboratory for this purpose. In general, gas analysers have specific acquisition software with already developed web interfaces that could be used independently from that of the bench. A gas analysis instrument dedicated to the test bench may be added in the future and eventually integrated in the data acquisition interface of the test bench, if an independent web interface of the instrument is not available.

The hardware described in this section is already available and working; the refurbishing of some parts (mass flow controllers, piping and cabling) is ongoing and will be completed with the moving of the equipment, planned for January 2020.

## 2.2 Description of the remote control infrastructure

The remote data acquisition and control system architecture is schematically shown in Figure 3.

The CompactRIO is connected via ethernet to the data acquisition and control software, which is installed on a Linux-based virtual machine hosted on the server infrastructure of Politecnico di Torino. The software interacts with the CompactRIO by ethernet communication protocols, with the safety standards ensured by PoliTo server infrastructure. All data exchanged between software and the test bench controller are stored in a database. The database is subject to the backup policies of PoliTo that ensure to safely recover all data in case of hardware failure. The database interacts with the web interface by which the control actions are implemented and the acquired data can be visualised and exported. The communication of data between the database and the web interface is realised by an https-protocol and the access to the database is protected by the safety standards of PoliTo.

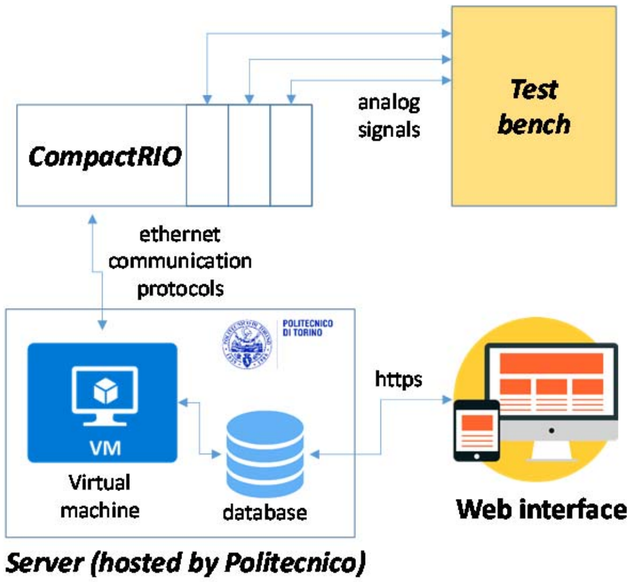


Figure 3 – Remote control system architecture.

The web user interface will be accessible by PC and smartphones. The access will be protected by a login with username and password. There will be three types of accounts: super-administrator, administrators and users. The super-administrator will be able to create all type of accounts, both administrators and users. The administrators will have the complete access to software functions, which are the followings:

- Set points input: write input values for the set points of mass flow controllers, furnace and electronic load.
- Acquired values visualisation: instantaneous values of the measured variables.
- Data visualisation and export: graphical visualisation of data from database (historical data), selection of data and exporting.

- User manager: creating user accounts and setting the time window of their authorisation to access.
- Script manager: uploader of scripts, which are series of set-point instructions, created with help of a specific software locally installed on the PC.
- Set point limits: setting limits for the set-points variables, enabling/disabling them for specific users.
- Alarms: setting alarms limits for the measured variables.

Each function will have an equivalent page in the web user interface, as shown in Figure 4.

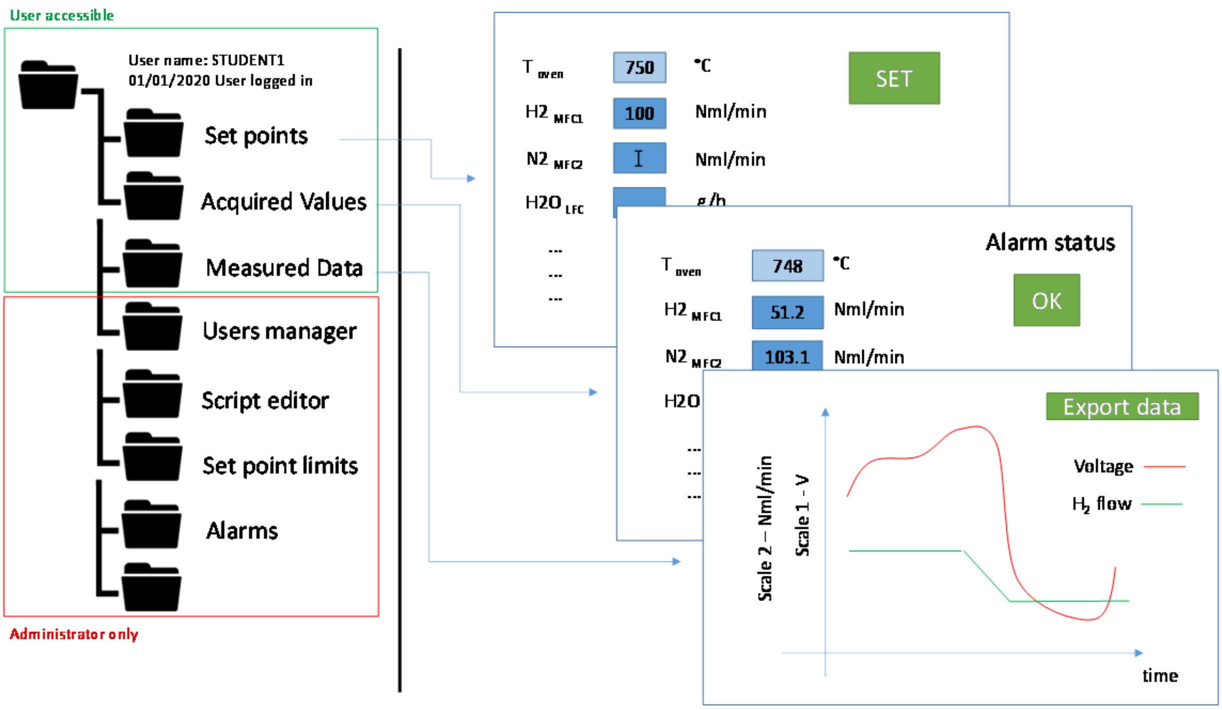


Figure 4 - Schematisation of web user interface.

The users will have a limited access to the functions; only set-points, acquired values and measured data will be accessible. The user-level access will be provided to the students enrolled to the laboratory course, providing to each of them an access token valid only for the experimental session in which the student is booked. The administrator will set the limits of the set-point variables accordingly with the experiment the student is going to perform. The limits will ensure that the experimental apparatus is operated in conditions that avoid damage to the tested cell, and to avoid aborting the experiment during the execution of the laboratory.

## 2.3 Remote experiments offered

The test-bench allows to perform current-voltage characterisation of SOCs at different temperatures, with different anodic and cathodic gas compositions and flow rates. The option of performing gas analysis of flows at the outlet of the cell is available.

The remote experiments that the bench offers for the course are thus related to the characterisation of fuel cell performance.

Test sessions of maximum 3 hours can be performed by students. The students are expected to collect the data following a task assignment and to perform the data elaboration after the experiment to obtain required performance indicators of the SOC. The student will provide the results in the form of a report that will be used for the student evaluation.

The experimental sessions of students are recorded by the control system, thus the consistency between results presented in the report and the measured data can be checked.

### 2.3.1 Example of remote experiment

This section provides an example of an experiment that could be offered by the remote laboratory.

*Setting up the experiment*

PoliTo personnel performs the set-up of the hardware for the experiment locally in the laboratory. The set-up consists of mounting a cell in the test-fixture with the proper sealing frames, connecting gas, voltage probes and current leads, adding weights on the test-fixture, assembling the refractory insulation walls and starting the heat-up procedure. Once the cell reaches the operating conditions, the PoliTo personnel verifies the performance of the cell with a standard polarisation test. If the check is positive, the variable limits are set for the students booked for the experimental session.

The setting up takes 24 hours before the cell can be operated for the experiment. For this reason, the test sessions of students must be planned in advance in agreement with PoliTo laboratory schedules.

*Experiment*

As an example of a remote experiment, the mapping of the performance of an SOFC is provided in the following lines.

- *Goal*: drawing the performance map of an SOFC, in terms of cell power represented in the fuel flow – current space.
- *Expected duration*: 2 hours; student will have 3 hours of time window to complete the task by collecting the data. After the experiment, the student will elaborate the results and write a short report.
- *Student assignment*: the student will receive the assignment at start of the experiment, with the description of the task, for example as follows.

  Task: Given an SOC cell of 25 $cm^2$, draw the performance map for fuel cell operation with a $H_2/N_2$ mix (fixed composition: 80% $H_2$ – 20% $N_2$) in the range of 25% to 75% fuel utilisation at 800°C with a fixed air flow at the cathode (750 Nml/min). The fuel flow must be lower than 250 Nml/min and the current varied with limited steps of maximum 5 A. The performance map must show the power producible by the cell as function of the fuel flow. At least 9 operative points of the map must be determined by experiment. Collect the data and draw the graph of the performance map. Write a short report that includes the testing conditions adopted and a short comment on the graph obtained.

- *Experiment:*

  The test bench will be prepared in advance, setting the limits of the set-points in order to maintain the cell in safe conditions. The student will not have access to air flow rate and temperature and will only have access to the set points of the flow rates of $H_2$ and $N_2$ and to the cell current. The limits of the controlled variables will be imposed to maintain a safe air/fuel flow ratio and to have a maximum cell current corresponding to 90% fuel utilisation in all the conditions. A PoliTo administrator will be connected to see the experiment and intervene if necessary (the administrator intervention will remove the student access). All the commands are recorded during the session, so that it is possible to recover the complete track of the experiment if necessary.

  The student will have to calculate the correct flow of $H_2$ and $N_2$ in order to have the prescribed value of anodic gas composition and set the current to obtain experimental points between $u_F$ = 25% and 75%. The student must export the values of voltage obtained and calculate the cell power to plot the performance map.

- *Student evaluation*: the student will prepare a report due in short time after the experiment with the performance map, experimental description and comments. The student will be evaluated from the capability to: 1) follow the instructions and achieve the experimental task in the fixed time, 2) elaborate the data to obtain the map, 3) describe the experiment and results in the report.