Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

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STACKTEST

WP5: International standard status report

D5.1

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1. Introduction

Existing international standards may have substantial influence on different aspects of fuel cell testing [1; 2]. In this context, the IEC 62282-2 standard for fuel cell modules and the SAE J 2615: SURFACE VEHICLE RECOMMENDED PRACTICE: Testing Performance of Fuel Cell Systems for Automotive Applications need to be mentioned explicitly.

In this document, a collection of relevant international and national standards is established and analysed with respect to PEM fuel cell stack testing. Information gathered within this task will guide the work in the technical work packages 2-4 of the STACKTEST project. The initial draft document has been available from the internal project web page for reference.

After finalization of this document it will be updated annually during the project.

2. Definitions

Cold start: Start-up that occurs after a sufficient soak at the normal ambient temperature [3].

Fuel cell (FC): Electrochemical energy conversion device in which fuel and an oxidant react to generate electricity without any consumption, physically or chemically, of its electrodes or electrolyte [3]

Fuel cell vehicle (FCV): A vehicle that receives propulsion energy from an on board fuel cell power system [3].

Fuel cell stack(s): An assembly of membrane electrode assemblies (MEA), current collectors, separator plates, cooling plates, manifolds, and a supporting structure that electrochemically converts hydrogen rich gas and air (oxygen) reactants to DC power, heat, water and other by-products. The fuel cell stack is also known as the fuel cell stack assembly or cell stack assembly [4].

Fuel cell module: assembly incorporating one or more fuel cell stacks and other main and, if applicable, additional components, which is intended to be integrated into a power system [5].

Fuel cell power system (FCPS): The fuel cell power system consists of the fuel cell power train and the energy storage device [3].

Membrane electrode assembly (MEA): Component consisting of a proton exchange membrane with catalyst/carbon/binder layers on either face and sandwiched by two porous conductive layers which function as the gas diffusion layers and current collectors [6].

Polarisation curve: Typically a plot of the output voltage of a fuel cell [7] as a function of the current density (current by active area of one MEA).

Polymer electrolyte or Proton exchange membrane fuel cell (PEFC or PEMFC): Fuel cell that employs an ion exchange polymer as the electrolyte. The ion could be of positive or negative charge. Presently, most of the PEFCs systems developed employ cation exchange membranes as the polymer electrolyte. In this type of fuel cell, a type of acid based fuel cell, the transport of protons (H^+) from the anode to the cathode is achieved in a solid cation exchange polymer film, referred to as a 'proton exchange membrane' (PEM). This type of fuel cell typically operates at low temperatures (<100 °-C) and pressures (< 5 atm). PEMFC for operation above 100 °C are in development as well [6]

Substack: Typically a group of stacked fuel cells that makes up the base repetitive unit number of cells per full stack [3].

Stack life: The cumulative period of time that a fuel cell stack may operate berfore its output deteriorates below a specified minimum value [3].

Stack test: Experiment where an electrical load is applied to a stack of fuel cells to determine its ability to perform [3].

3. References

Procedures and program tests described in this document are extracting from:

- U.S. DRIVE Partnership Fuel Cell Technical Team [5]
- JIS C8832: performance test for stationary polymer electrolyte fuel cell stack [8]
- FCTESQA: procedures dedicated to fuel cell stack characterisations [9-14]
- IEC 62282-2: International standard providing minimum requirements for safety and performance of fuel cell modules in all applications [15]
- SAE J 2617 : SURFACE VEHICLE RECOMMENDED PRACTICE: Recommended Practice for Testing Performance of PEM Fuel Cell Stack Sub-system for Automotive Applications [4]
- SAE J 2615 : SURFACE VEHICLE RECOMMENDED PRACTICE: Testing Performance of Fuel Cell Systems for Automotive Applications
- SAE J 2574 : FUEL CELL VEHICLE TERMINOLOGY [3]
- European Commission (2006) The Fuel Cells Testing & Standardisation Network, FCTESTNET Fuel cells glossary [6]
- IEC/TS 62282-1 Fuel cell technologies - Part 1: Terminology [7]

Additional information is extracted from the fuel cells standards website [16]. Some national relevant procedures are not available in English language (e.g. Chinese) and so are not been taken into account in this document.

4. Procedure analysis

4.1. Performances characterisation - polarisation curve

The polarization curve is the key indicator of the operational capabilities of a fuel cell stack. The DC voltage of the fuel cell stack can be measured at the individual cell level, and the stack level. Prior to polarisation measurement, operating conditions must be fixed.

4.1.1. FCTES^{QA}

FCTES^{QA} procedures dedicated to polarisation curves are available on FCTES^{QA} website [13; 14]. Procedure includes:

i) an initial stabilisation phase in reference conditions (given by stack manufacturers),

ii) an increase step by step of the current up to the maximum current density, then

iii) a decrease step by step of the load from maximum current density down to 0 A and

iv) finally an increase step by step of the load from 0A back to reference current density. Polarisation curve is recorded during the decreasing current phase as shown on Figure 1. Step duration is not fixed by the procedure but a steady-state criterion is defined for each plateau used to record polarisation curve (Figure 2).

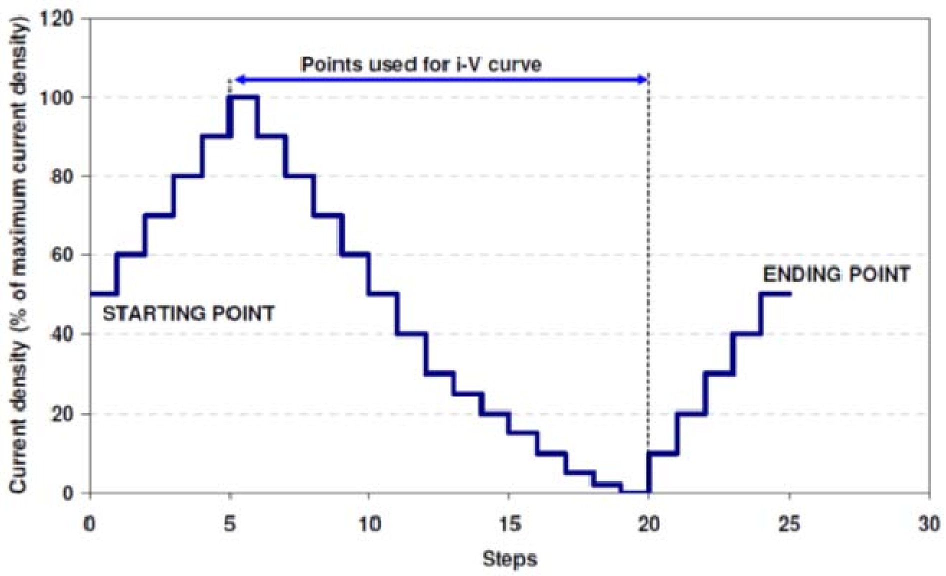

Figure 1: Example of current density cycle with 25 steps of instantaneous change in current density. In this example, the starting and ending points of this profile are chosen to be at 50% of the maximum current density.

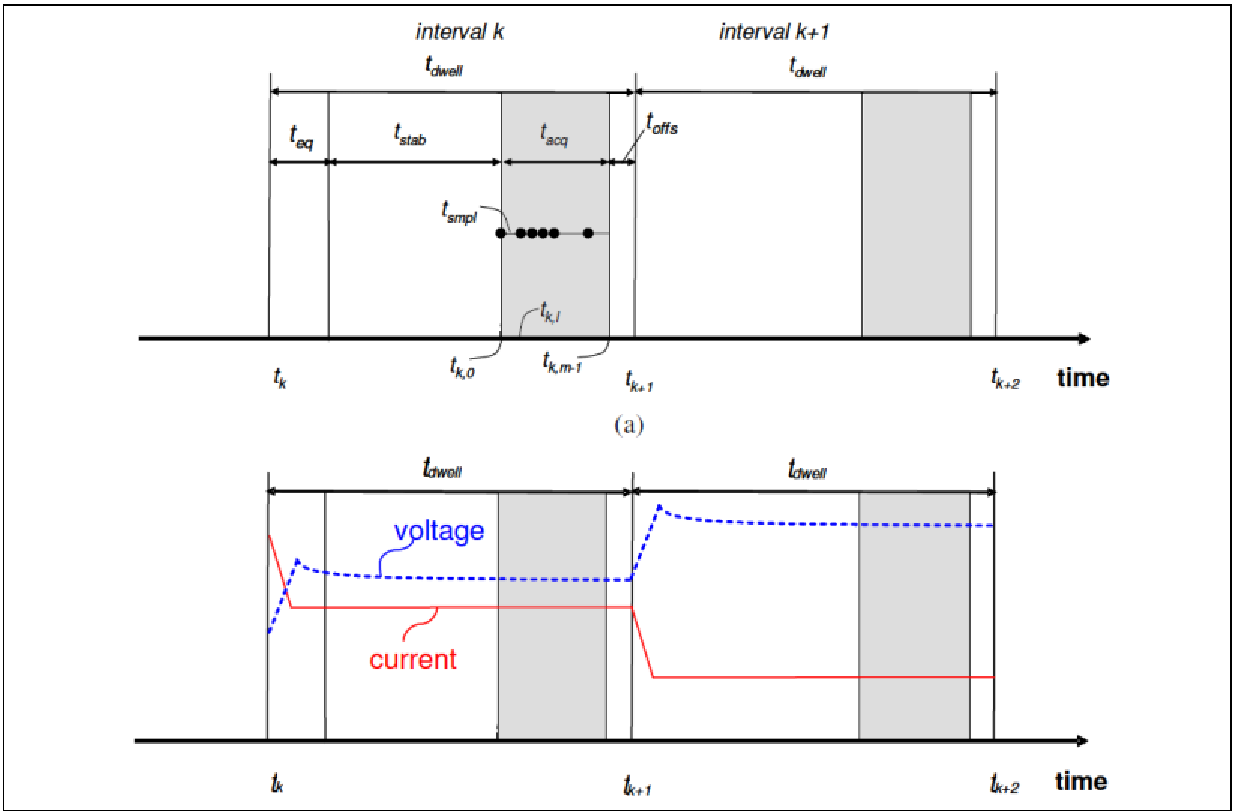

Figure 2: Schematic of the timeline for two consecutive set points k and k+1 of test step 3 each having a dwell time of same duration (a). The test input and output (test variables) are sampled l times at tk,l (0≤l≤m-1) to collect m measurements with a sampling interval of tsmpl during tacq. The principle profile of the current as a main test input and of the resulting stack voltage as a major test output are shown for the two intervals k and k+1 where the current decreases at the beginning of each interval (b). This is representative for the ramping down of the current at anyone set point k and k+1 between (inclusive) the maximum current density and the minimum current density in step 3 of the test.

4.1.2. US Department Of Energy

DOE procedures to record polarisation curve are similar to FCTES^{QA} procedure. The polarisation curve at current density levels of 0, 10, 200, 500, 700, 1000, 1200, 1500 mA/cm^2 (or maximum current possible) will be carried out at constant fuel and oxidant stoichiometries at all of these operating points. A stabilization time of 15 minutes will be used at each current level with data averaged over the last 5 minutes. The curve will be completed with monotonically increasing and then decreasing current densities. The current densities at which 0.88, 0.80, 0.75, 0.65, and 0.60 V are obtained will be recorded and established as the bases for the subsequent steady-state and variable load tests. Results obtained using DOE and FCTES^{QA} procedure are compared in

Figure 3 for a 15 kW stack [1]. As shown in this figure, the two protocols are equivalent to test the stack performances.

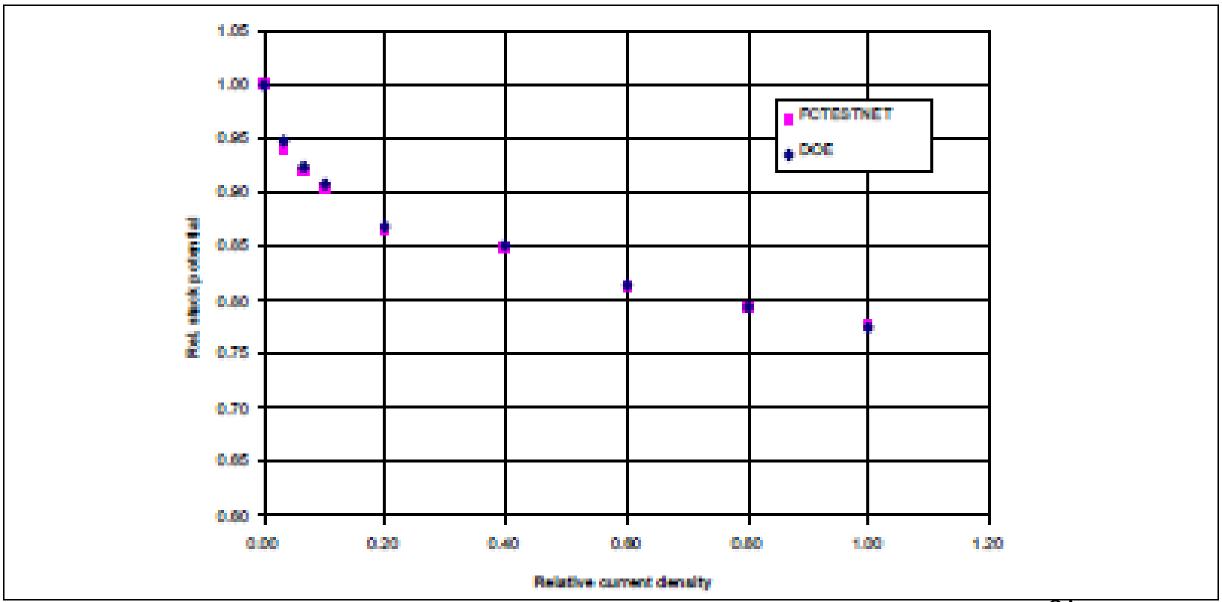

Figure 3 : Example polarisation curve recorded using DOE and FCTES^{QA} procedures on 15 kW stack [1].

4.1.3. SAE [4]

Polarisation curve procedure from SAE [4] are recorded from OCV to maximum load and then back down to OCV so as to get an ‘upward’ and ‘downward’ polarization. In the test report, the direction of the polarization should be reported. Polarization curves are obtained step by step and dwell time are fixed to 5 min for each plateau except for OCV measurement (only 1 minute). Step increment value is set at 200 mA/cm^2 until 0.4 V/cell or test stand limit is reached.

4.1.4. JIS [8]

Polarisation curve procedure described on JIS document is built using the same trend than previous procedures. Nevertheless, the step current value is not defined whereas dwell time is fixed by a stability criterion. Then, for each measurement the difference between maximum value and minimum value of cell stack voltage shall be within 0.5% of reference voltage.

4.1.5. U.S. DRIVE FCCT [5]

The polarization curve according to the U.S DRIVE partnership [5] is obtained by step by step from OCV up to 1 A/cm² for fixed parameters and fixed test point run time. This procedure is dedicated to automotive applications.

4.2. Operating Parameters Sensitivity studies

The objectives of these procedures are to identify the effects of working parameters on fuel cell stack performance. Excepting the study parameters, working conditions of the conditions are fixed during the experiment.

FCTES^{QA} procedures deal with pressure [10] and gas stoichiometry [12] effects on stack performances. SAE and JIS C8832 procedures evaluate the impact of stoichiometry, gas compositions, temperature and pressure [4; 8]. The impact of parameters is evaluated for different current densities. An example of FCTES^{QA} procedures dealing with the stoichiometry impact on stack performances is presented on Figure 4.

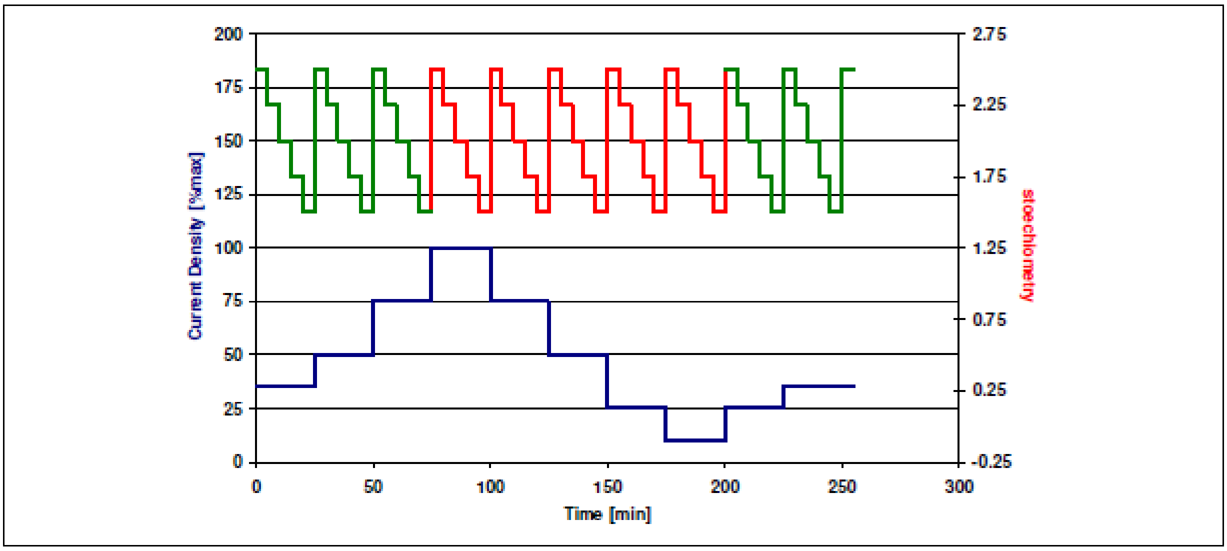

Figure 4: Example of one complete current density with 5 set points k and stoichiometry cycles of the 5 reactant stoichiometry values h at each set point.

Except for the evaluation of gas composition on the stack performances [4], all the procedures are built on the same pattern than FCTES^{QA} procedures. Differences between these procedures mainly come from the way to set the working point where performances are recorded. FCTES^{QA} procedures fix absolute values (for stoichiometry and pressure respectively) whereas SAE procedures indicate values related to a percentage of reference conditions and JIS procedures does not give value for working points to be evaluate. Nevertheless, it can be noted that gas composition impacts on the stack performances are evaluated using polarisation curve in SAE document [4].

4.3. Ageing studies

Ageing test procedures deal with the effect of long term evolution on stack performances. These procedures depend strongly on the application to be evaluated or on the ageing phenomenon highlighted during the test. Durability tests can be classified in two classes.

4.3.1. Long term durability steady test

These procedures describe how to evaluate the durability of a stack under steady state conditions. A $FCTES^{QA}$ module is dedicated to long term durability steady test under constant current density [11]. In this module, the voltage deviations ΔV is monitored both at OCV (measured at the beginning of the polarization curves [13]) and on load. The voltage evolution is calculated over the complete duration of the measurement step, in order to evaluate a “performance progression rate” (normally the “degradation rate”) $\Delta V_{OCV}/dt$ and $\Delta V_{iload}/dt$. These values correspond to the slopes of the plots giving the voltages versus time. The performance loss is calculated in % at i_{load} as follow:

- [Vinitial at i @ 20% Pnom – Vfinal at i @ 20% Pnom] / Vinitial at i @ 20% Pnom
- [Vinitial at i @ 100% Pnom – Vfinal at i @ 100% Pnom] / Vinitial at i @ 100% Pnom
- [Pinitial at i @ 20% Pnom – Pfinal at i @ 20% Pnom] / Pinitial at i @ 20% Pnom
- [Pinitial at i @ 100% Pnom – Pfinal at i @ 100% Pnom] / Pinitial at i @ 100% Pnom

SAE procedures evaluate the voltage stability of a stack sub-system at 0.1 and 0.8 A/cm² during 8 hours [4]. The evaluation of voltage deviation is not mentioned in the module. DOE steady state protocols are related to DOE targets in term of durability. This protocol is resumed in Table 1.

Table 1: DOE steady state protocols

Test **Total time 2,000 hours** **Realistic systems conditions will be used at each operating point.**	**Approx. Test Time [hours]**
Cell Conditioning according to developer's established procedures	As required
Checkout / Verification Tests The cell or cell stack will be cycled between current levels sequentially from 10 mA/cm^2 to 1000 mA/cm^2 to verify proper operation and integration of the cell and test equipment.	8
Initial Sequential Polarization Curve, basis for degradation calculations A polarization curve at current levels of 0, 10, 200, 500, 700, 1000, 1200, 1500 mA/cm^2 (or maximum current possible) will be attempted at constant fuel and oxidant stoichiometries at all of these operating points. A stabilization time of 15 minutes will be used at each current level with data averaged over the last 5 minutes. The curve will be completed with monotonically increasing and then decreasing current densities. The current densities at which 0.88, 0.80, 0.75, 0.65, and 0.60 V are obtained will be recorded and established as the bases for the subsequent steady-state and variable load tests.	8
Random Polarization Curve Current density levels of 0, 10, 200, 500, 700, 1000, 1200, 1500 mA/cm^2 will be conducted. A stabilization period will be used at each current density. The current densities will be varied randomly rather than monotonically. Each current density level will occur twice in the sequence but the same current density will not be used for two successive points.	8
Transient Response A one-step current transient (C_{65} to C_{88}) will be tested using the developer's recommended combination of air and fuel stoichiometries and dew points. This test will also be performed in reverse (C_{88} to C_{65}) after a 15-minute stabilization period.	4
Constant Current The cell will be operated at the current density at which 25% maximum power is achieved at constant specified operating conditions of temperature, pressure, stoichiometries, etc. The testing will be continuous except for periodic diagnostic testing (approximately every 200-250 hours). Durability will be reported as specified in Section 1.	1750
End of Test Diagnostics Data will be taken to quantify changes since test initiation in polarization curves, cell resistance, and crossover to establish end-of-life performance. The conditions of the End of Test Diagnostics must be the same as the initial tests.	200

4.3.2. Dynamic load cycling ageing test

These procedures describe how to evaluate the durability of a stack under load cycling. A FCTES^{QA} module is dedicated to long term durability under dynamic load cycling [9]. Dynamic load cycling are composed by a low power stationary phase at i=0.2 i_{nom} followed by a ramp from i=0.2 i_{nom} to i=i_{nom} during 20 s. i_{nom} is defined as the current for which maximum stack power during normal operation is obtained. Maximum duration of the test, t_{max}, is defined between 500 and 10,000 hours and the cycle is stopped is interrupted each t_{max}/10 in order to record a polarisation curve according

FCTES[QA] TM ST 5.3 module [13]. As previously voltage deviations ΔV and performance loss $\Delta V_{OCV}/dt$ and $\Delta V_{iload}/dt$ are calculated.

DOE and US fuel cell council suggest another Dynamic Test Protocol (DTP) [17] in relation with DOE durability objectives. Protocol and cycling profile are resumed in Table 2 and Figure 5, respectively.

Table 2: DOE DTP

Test **Total time 2,000 hours** **Realistic systems conditions will be used at each operating point.**	**Approximate Test Time [hours]**
Cell Conditioning according to developer's established procedures	As required
Checkout / Verification Tests The cell or cell stack shall be cycled between current levels sequentially from 10 mA/cm^2 to 1000 mA/cm^2 to verify proper operation and integration of the cell and test equipment.	8
Initial Sequential Polarization Curve, , basis for degradation calculations A polarization curve at current levels of 0, 10, 200, 500, 700, 900, 1000, 1200, 1500 mA/cm^2 will be obtained at constant-fuel and oxidant stoichiometries at all of these operating points. A stabilization time of 15 minutes will be used at each current level with data averaged over the last 5 minutes. The curve will be completed with monotonically increasing and then decreasing current densities. The current densities at which 0.88, 0.80, 0.75, 0.65, and 0.60 V are obtained will be recorded and established as the bases for the subsequent steady-state and the variable load tests.	8
Cycling Profile The fuel cell will be operated using the cycle profile shown in Figure 5. NOTE THAT THE FIRST STEP (15 sec) OF EACH 360-second CYCLE IS AT OPEN CIRCUIT. At each current level, fuel and oxidant compositions and flows rates will be adjusted to reflect realistic system conditions during a driving cycle. The cycles will be continuous except for periodic diagnostic testing (approximately every 200-250 hours). Periodic diagnostics will include cell resistance and hydrogen crossover, shorting resistance and a constant-stoichiometry polarization curve.	1800
End of Test Diagnostics End of test diagnostic data will be taken to quantify changes since test initiation in polarization curves, cell resistance, and crossover. The conditions of the End of Test Diagnostics must be the same as the initial tests.	150

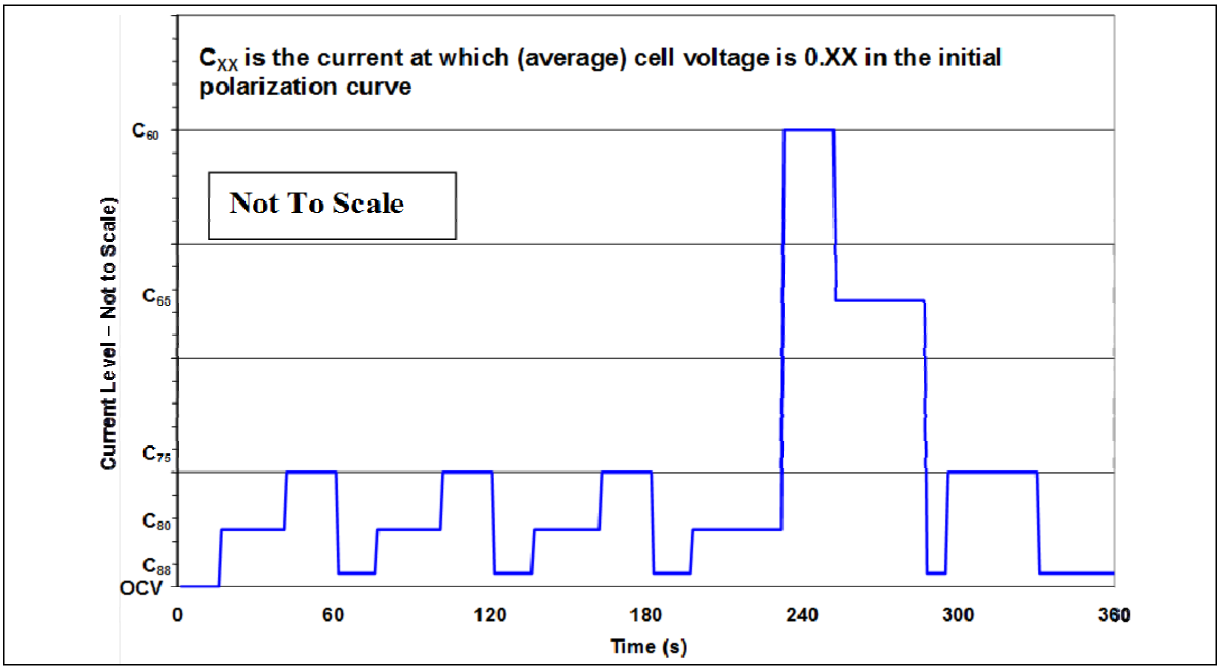

Figure 5 : DOE cycling profile from [17].

The comparison between FCTES[QA] and DOE procedures using a 15 kW stack provided by NEDSTACK [1] shows that the two procedures are not equivalent and the DSP induces a more important decrease of stack performances.

Two SAE procedures are dedicated to determine the stack response to step change in load demand and to a ramp change in load demand [4]. Although these two procedures are dedicated to the dynamic response of the stack, no evaluation of the load change on the stack ageing is mentioned in the document. For automotive applications, FCTT of U.S. drive partnership proposes two cycles under wet and dry conditions [5]. In “wet” cycle, two load steps are fixed to 0.02 $A.cm^{-2}$ and to 1.2 $A.cm^{-2}$ whilst gas dew point temperatures are set to 83°C. In “dry” cycle, the load is fixed to 0.02 $A.cm^{-2}$ and to 0.1 $A.cm^{-2}$ whilst gas dew point temperatures are set to 53°C. In these two procedures, the stack temperature is 80°C and gas stoichiometry remains constant during the steps.

4.4. Stack electrochemical characterisations

Except polarisation curves methodology, no procedures are found to be totally convenient with stack electrochemical characterisation. Nevertheless, procedures dedicated to single cell would be relevant to determine Electrochemical Catalyst Surface Activity (ECSA) and permeation properties of a MEA inside a stack [18].

4.5. Procedures dedicated to safety

4.5.1. Leak test procedures

IEC 62282-2 gives some recommendations regarding the tightness level of fuel cell modules. Gas leakage from stack compartment to outside and between stack compartments are characterised in stack reference conditions (pressure and temperature). These measurements are based on the gas flow measurement under constant pressure in the stack [15]. Although detailed protocol to defined level of leakage of a stack module is beyond the IEC 62282-2 scope, the USFCC procedures are dedicated to leakage test requirements for fuel cells [19].

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