DIAMOND - DIAGNOSIS-AIDED CONTROL FOR SOFC POWER SYSTEMS
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Deliverable 7.6

Summary of DIAMOND-A/C system evaluation tests

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Document Type	
PRO	Technical/economic progress report (internal work package reports indicating work status)
DEL	Technical reports identified as deliverables in the Description of Work
MoM	Minutes of Meeting
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1 Executive summary

1.1 Description of the deliverable content and purpose

This deliverable summarizes the algorithm evaluation testing carried out within the European join research and innovation action DIAMOND. In this document, the focus is on the common, general level aspects of the testing efforts. Details of each test run can be found in the documents listed under Section 1.5 as well as in the public scientific literature.

In DIAMOND, algorithms for the monitoring, estimation and control of SOFC systems' state of health, lifetime and efficiency were developed. The algorithms were implemented in industry standard process control devices and subsequently integrated into SOFC systems used for algorithm evaluation. Two different SOFC systems were used in the evaluation tests:

- DIAMOND-A - a pre-commercial micro-CHP system in the power class of 2.5 kW
- DIAMOND-C - a laboratory-installed, highly instrumented CHP system of 6 kW power

Extensive testing efforts took place with both systems. In particular, cold testing, hot dummy-testing (system w/o SOFC stack), nominal characterization tests of both systems and finally complete system level algorithm evaluation tests. In addition, existing measurement data from the systems' operation was utilized for algorithm development before fresh data became available.

1.2 Brief description of the state of the art and the innovation brought

Several algorithms for general monitoring and estimation as well as control have been developed before the DIAMOND project. Also many of these were adopted for the SOFC in either a simulated environment or in experimental laboratory arrangements. Also many of the DIAMOND partners (including HYG, UNISA, VTT, CEA, HTc) have participated this development effort in preceding European projects such as DeSign and GENIUS. The final implementation and validation phase of algorithms in an industrially relevant setting has, however, not been reached in the existing works to the extent as was done in the DIAMOND project. In brief, the DIAMOND project testing effort realized a thorough pre-commercial evaluation of the developed and implemented algorithms in a 100% industrially relevant setup.

The testing work carried out in the DIAMOND project revealed several aspects of SOFC system diagnostic and control algorithm development work, which have to be taken into account in similar future projects. At the same, the status of commercially relevant SOFC system diagnostic and control algorithms was pushed forward significantly. In summary the following main results were obtained in the testing work, all in an industrially/commercially relevant system level setting:

- The validation of the functionality and effectiveness of an advanced SOFC system control algorithm, and the applied development procedures
- The validation of the functionality of novel SOFC stack state-of-health estimation and stack lifetime prognosis algorithm
    - Subsequently, the validation of the functionality a supervisory controller algorithm based on estimated SOFC stack remaining useful life and efficiency
- The validation of the functionality and effectiveness of such diagnostically relevant algorithms as (i) the SOFC stack THD index calculation algorithm for realized fuel utilization monitoring and (ii) the online fuel gas composition estimation
- The functionality validation of model-based SOFC system balance-of-plant component fault detection and isolation.

1.3 Deviation from objectives

Several challenges were encountered during the practical system level testing work. The most severe of these were caused by a delay (or refusal) of stack delivery. In particular, the first round of tests with the DIAMOND-A system were delayed by difficulties in hardware delivery and deployment internally in the consortium. Simultaneously, the initiation of testing with the DIAMOND-C system was significantly hampered by one stack provider (external from the consortium) finally refusing to deliver stacks after a lengthy preparation and negotiation process. These challenges were responded to with the corrective measures explained below.

1.4 Corrective actions

Firstly, in order to enable the algorithm development partners to proceed with their work, existing measurement data from the DIAMOND A/C systems was collected and provided to these partners (instead of providing the actual in-project characterization measurement data). This solution turned out successful, and the algorithm development could go forward in a productive manner.

Secondly, to correct the non-successful stack acquisition process, a quick round of re-connecting with previously contacted stack providers was carried out and a new stack provider was found. A significant internal SOFC test system modification process was engaged in at VTT to facilitate the testing with the DIAMOND-C system with an entirely new type of SOFC stack than before.

Thirdly, project coordination took measures to extend the project duration, so to allow sufficient time for system level testing. A six-month extension to the project duration was agreed upon with the FCH JU and this turned out well sufficient, leading to good test results reached within the duration of the extended project.

1.5 Original documentation

The full description of the testing effort is detailed in the following project deliverables:

- D3.3 Presentation of experimental results at system level
- D7.1 Evaluation test plan for control and diagnosis algorithms
- D7.2 Report of the 1st evaluation tests with the DIAMOND-A unit
- D7.3 Report of the 1st evaluation tests with the DIAMOND-C unit
- D7.4 Report of the 2nd evaluation tests with the DIAMOND-A unit
- D7.5 Report of the 2nd evaluation tests with the DIAMOND-C unit

2 Overview of test efforts

Several separate system level test runs were prepared and executed during the project. These are described below per test system.

DIAMOND-A:

1) Prototype operational testing; short test run with one stack box dedicated for the testing purposes
2) System characterization; system refurbished with new stack box, step changes in current, I-V curves, and long term operation at various conditions >6000 hours
3) Algorithm evaluation test run; system refurbished with new stack box, tuning control and parameterization of algorithms, ca. 1000 hours

DIAMOND-C:

1) System operability test; short test run with old, de-functional stacks to check balance-of-plant and instrumentation operability after downtime period
2) Hot dummy testing; system operability testing with dummy-stack after stack module modifications related to stack refurbishment, ca. 300 hours
3) System characterization; system refurbished with new stacks and stack module, operational testing and characterization of system in various operating conditions, ca. 400 hours
4) Cold testing with modified system for embedded THD algorithm development, ca. 150 hours
5) Algorithm evaluation; tuning of controllers, parameterization of algorithms and evaluation of algorithm output under various conditions, ca. 700 hours

In addition, several component tests were carried out to facilitate system refurbishment and modification.

3 Conclusions

A significant collaborative system level testing effort was carried out as the co-operation of all the DIAMOND project partners. Two separate SOFC power systems were used in the testing and multiple algorithms for the monitoring, control and diagnostics of SOFC systems were validated in a commercially-relevant context as result of the tests.