DIAMOND - DIAGNOSIS-AIDED CONTROL FOR SOFC POWER SYSTEMS
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WP2 - Specification and System Requirements

D2.1

Specification report on critical faults/failures of SOFC CHP-system

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REV.	DATE	DESCRIPTION	PAGES	CHECKED	APPROVED
0	02/07/2014	Faults / Failures Table	7		
1	05/08/2014	Rev. of Faults / Failures Table	7		
2	06/10/2014	2nd Rev. of Faults / Failures Table			
3	11/11/2014	Remarks removed, priorities added			
4	08.04.2015	Ranking of faults and failure added	9	RM	RM

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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(*) for generating such code please refer to the Procedure Manual, also indicating it in the header of the following pages

(**) indicate the acronym and author

Table of Content

0 EXECUTIVE SUMMARY (3 pages max. all points)

0.1 Description of the deliverable content and purpose

The objective of the present deliverable is to identify and describe faults and failures that may occur during operation of an SOFC system. The deliverable is intended to provide input for generating test protocols in WP3, and as input for the development of diagnostic tools in WP4 and advanced control in WP5.

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

N/A

0.3 Deviation from objectives

N/A

0.4 If relevant: corrective actions

N/A

0.5 If relevant: Intellectual property rights

N/A

1 Introduction

The objective of the DIAMOND project is to improve the performance and enhancing the endurance of SOFC CHP-systems. By monitoring key parameters of the system and analyzing them using a diagnosis tool the state of health of the system can be assessed and the control strategy adapted.

Within the DIAMOND project two SOFC systems are considered; an integrated stack module (HoTbox) (system DIAMOND A) and a mid-scale CHP-system with a conventional layout (system DIAMOND C).

An important step in achieving the targets of the project is making an inventory of possible faults and failures. This is part of Work package 2 of the DIAMOND project. The report was due after 3 months. However, extensive discussions were held among the partners on the subject causing a delay in delivery date, but also a consensus on the most important issues. During the discussion already information was exchanged with WP3, WP4, and WP5.

2 Abbreviations

In this document the following abbreviations will be used.

AU	Air Utilization (inverse of the faradaic air lambda)
FU	Fuel Utilization
MFC	Mass Flow Controller
MFM	Mass Flow Meter
p	Pressure
PV	Process Value (measured value)
SP	Set-Point
T	Temperature

3 Insight from DIAMOND partners

During the DIAMOND workshop meeting WP2&3 (Lucerne, July 1st, 2014) it was decided to send a round a questionnaire in order to give all partners the opportunity to fill in their input for the faults&failures matrix. Every partner was kindly asked to: a) add content to the matrix, b) comment the current content and c) give his opinion in the last column about the relevance for the DIAMOND project (last column).

Four options are possible in the last column “Considered”: A) consider only for “system A”, C) consider only for “system C”, A&C) consider for both systems and No) not considered relevant for the project.

4 Overview of Critical Faults / Failures

The content in column 4 / “detection” is a starting point and as well an anticipation of the results of the DIAMOND project. The main columns in respect to the topic of this deliverable are the first and the last column. The columns “Detection” and “Counter Measures” depend on the actual system design of the two different systems; therefore, the current content has to be a simplification by its nature.

Table 1: Matrix of faults and failures

#	Critical fault / failure	Causes	Effect	Detection	Counter Measures	Priority		Considered (A, C, A&C, No, ??)						
						Syst. A	Syst. C	VTT	HyGear	UNISA	CEA	IJS	INEA	HTc
1	Elevated CO content in the exhaust	- Burner T too low - Burner air lambda < 1.2	Danger	- CO sensor - T in the afterburner - Monitoring the air flow - Monitoring the power consumption of the air blower - Monitor fuel utilisation	- Increase T in the afterburner - Increase the SP for the air lambda			A	A&C	A	??	A	A	A
2	Nickel carbonyl formation	- CO in contact with Ni at T 50 – 180°C	Danger	- Monitoring fuel flow and T	- Increase T - Close fuel flow in T-range of 50 - 180°C			C	??	??	A&C	A&C	??	A&C
3	Accumulation of combustible gas mixture in hot compartments	- T below self-ignition T (< 670°C) - Air flow interruption	Danger	- CO sensor - T in the afterburner - Monitoring the air flow - Monitoring the power consumption of the air blower	- Increase T in the afterburner - Change the SP for the air lambda - Decrease the fuel flow - System shutdown			A	A&C	A	A	A	A	A
4	Blockage of the Exhaust	- Brocken / blocked chimney	Danger	- p in the off-gas	- close NG			C	??	??	A	A	A	A
5	Fuel starvation	- Defective MFC / MFM - Software Failure - Erroneous (too low) el. current process value (PV) - Stack sealing failure	Stack damage	- Signature in the voltage? - Deviation in stack performance - T monitoring, e.g. T afterburner - Flow monitoring, e.g. towards the afterburner	- Decrease SP for FU (increase fuel flow) - Close NG in case of leakage somewhere in the system			A&C	A&C	A&C	A&C	A&C	A&C	A&C
6	Air starvation	- Erroneous (too low) el. current PV - Defective MFM/MFC - Stack sealing failure	Cathode damage	- Signature in the voltage? - Stack performance deviation	- Increase SP for electrochemical air lambda			A&C	A&C	A&C	A&C	A&C	A&C	A&C
7	Max cell T exceeds limit	- Erroneous (too low) T PV - Stack leakage (which causes chemical combustion in or near to the stack)	- Sealing damage - Local high T	- Monitoring related T - Detect operation deviations	- Increase cathode flow - Reduce max power output - Cool down cathode air (C)			A&C	A&C	A&C	A&C	A&C	A&C	A&C
8	Cell failure	- Cell crack - Sealing failure	Stack damage	- Signature in the voltage? - Stack temperature increase - Deviation in stack performance - Humidity sensor in the cathode outlet - Lambda sensor at anode outlet (C)	- Decrease FU? - Inverse stack polarization for a short period? - Reduce max power output			A&C	A&C	A&C	A&C	A&C	A&C	A&C
9	Cell short circuit	- Conductive path in sealing - Conductive path outside cell	- Local hot spot - Performance loss	- Decrease of stack voltage - Non consistent potentials reading	- Shut down			C	A&C	??	??	No	A&C	No
10	Stack short circuit	- Electrical insulator failure	System failure	- Temperature rise - Rapid drop of stack voltage and current	-			No	??	A&C	??	A&C	A	No
11	O/C & S/C ratio too low (System A)	- Defective MFC / MFM - Water shortage	Carbon formation	- Water level monitoring in the DI-water buffer storage (if the system comprises such a tank) - Energy consumption for the evaporation - Temperature increase (FP, stack)	- MFC / MFM maintenance - Increase SP for water flow - Increase forming gas and decrease CH4			??	A	A	A	A	A	A
12	O/C & S/C ratio too low (System C)	- Defective MFM in the anode recirculation loop - Blower fault	Carbon formation	- Pressure probe in the recirculation loop - Recirculation blower maintenance	- MFC / MFM maintenance - Increase SP for recirculation flow			C	C	C	C	C	C	C
13	Fuel contamination	- Desulfurization substrate degraded	- Anode damage - Catalyst degradation (Fuel processor)	- Signature in the voltage? - Stack performance deviation	- Maintenance of the desulfurization unit			A&C	A&C	A&C	A&C	A&C	A&C	A&C

#	Critical fault / failure	Causes	Effect	Detection	Counter Measures	Priority		Considered (A, C, A&C, No, ??)						
						Syst. A	Syst. C	VTT	HyGear	UNISA	CEA	IJS	INEA	HTc
14	Air contamination	- Air filter defective - Impurities in gas form in the ambient air	Cathode damage	- Signature in the voltage? - Stack performance deviation - Increased pressure drop	- Maintenance of the filter - Avoid air impurities			A	A&C	A&C	A	A	A&C	A
15	Fuel interruption	- Gas grid failure - Valve / MFC failure - Software failure	- System shutdown - Stack damages - System non-operational	- p drop at the fuel inlet - Drop of stack performance	- MFC / MFM maintenance			No	No	A&C	A	A&C	A&C	A
16	Power electronics failure	- electricity network failure - Hard ware failure	System shutdown	- Current PV zero	- Maintenance - Sufficient ventilation			No	No	No	A	A	A	A
17	Software fault / failure / crash	- Control hardware failure - Software intrinsic problems	- Risk of Danger - System malfunction	- Watch dog	- Intensive software debugging - Sufficient ventilation			No	No	No	No	No	A	A
18	Internal leakage, anode to cathode	- Cell crack	Stack damage: - Local hot spot	- Change in stack voltage	- Balance differential pressure anode and cathode			C	??	A&C	A&C	A&C	A&C	No
19	Internal leakage, cathode to anode	- Cell crack	Stack damage: - Local hot spot	- Change in stack voltage - Lambda sensor at anode outlet	- Balance differential pressure anode and cathode			C	??	A&C	A&C	A&C	A&C	A&C
20	External leakage anode side	- External sealing crack - Welding failure	Explosive mixture in dome	- Change in stack voltage - Pressure drop on anode side - Increase of FU	- Ventilate dome - Reduce fuel flow			C	??	A&C	A&C	A&C	A&C	A&C
21	External leakage cathode side	- External sealing crack	Stack damage	- Change in stack voltage - Change of stack delta T - Pressure drop on cathode side	- Adaptation of air flow			C	??	A&C	A&C	A&C	A&C	A&C
22	Air blower malfunctioning, lower flow	- Blower bearing wear - Air blower control fault - Defective MFM/MFC	Stack damage: - Thermal shock	- Change in stack voltage/current - Change in stack temperature (delta T) - Blower power consumption - Increase of AU	- Maintenance			C	??	A&C	A&C	A&C	A&C	A&C
23	Air blower malfunctioning, higher flow	- Air blower control fault - Defective MFM/MFC	Stack damage: - Thermal shock	- Blower power consumption - Change in stack temperature - Decrease of AU	- Maintenance			C	??	A&C	A&C	No	??	No
24	Recycle loop closed (C)	- Recycle blower fault	System shutdown	- Temperature rise - Change in stack voltage - High FU - Performance drop	- Increase fuel supply			C	??	C	C??	C	C	C
25	No water supply (A)	- Water pump failure - Water piping clogging	System damage	- Temperature rise - Change in stack voltage - Low S/C ratio - High FU - Performance drop	- Maintenance			??	??	A	??	A	A	A
26	No water supply (C)	-		-	-			No	??	C	??	C	C	C

5 Ranking of faults an failures

The faults and failures of the table in chapter 4 have been ranked by the partners based on their knowledge and experience. The outcome of this ranking is shown in the tables below. The column called “importance” describes the priority level (1 → High priority, 14→ lower priority).

Table 2: Ranking of faults and failure for system A

System A		
#	**Critical fault / failure**	**Importance**
5	Fuel starvation	1
6	Air starvation	1
11	O/C & S/C ratio too low	1
7	Max cell T exceeds limit	2
17	Internal leakage, anode to cathode	2
18	Internal leakage, cathode to anode	2
19	External leakage anode side	2
20	External leakage cathode side	3
14	Fuel interruption	4
21	Air blower malfunctioning, lower flow	4
24	No water supply	4
8	Cell failure	5
22	Air blower malfunctioning, higher flow	5
10	Stack short circuit	6
12	Fuel contamination	7
9	Cell short circuit	8
15	Power electronics failure	8
1	Elevated CO content in the exhaust	9
3	Accumulation of combustible gas mixture in hot compartments	10
4	Blockage of the Exhaust	10
16	Software fault / failure / crash	10
2	Nickel carbonyl formation	11
13	Air contamination	11

System C		
#	**Critical fault / failure**	**Importance**
5	Fuel starvation	1
6	Air starvation	2
11	O/C & S/C ratio too low	2
19	External leakage anode side	3
20	External leakage cathode side	4
17	Internal leakage, anode to cathode	5
18	Internal leakage, cathode to anode	5
21	Air blower malfunctioning, lower flow	5
22	Air blower malfunctioning, higher flow	6
7	Max cell T exceeds limit	7
14	Fuel interruption	7
8	Cell failure	8
12	Fuel contamination	8
23	Recycle loop closed (C)	8
9	Cell short circuit	9
1	Elevated CO content in the exhaust	10
10	Stack short circuit	10
15	Power electronics failure	11
24	No water supply	11
2	Nickel carbonyl formation	12
4	Blockage of the Exhaust	12
13	Air contamination	12
16	Software fault / failure / crash	13
3	Accumulation of combustible gas mixture in hot compartments	14

The ranking of all these possible faults and failure does not mean that the critical faults and failures with a low importance can be neglected as all can lead to a catastrophic degradation or destruction of the stack. The purpose of this ranking is here to create the order in which the problems have to be solved.

6 ANNEXES

6.1 Results of prioritization

The vote for the prioritization has been made with an excel file. The results with the details of the vote of each partner is shown in the Figure 1.

	Critical fault / failure	min A)	max A)	min C)	max C)	(A) Sum	(C) Sum	(A) Sum divided by 7	(C) Sum divided by 7	(A) VTT	(C) VTT	(A) HyGear	(C) HyGear	(A) UNISA	(C) UNISA	(A) CEA	(C) CEA	(A) IJS	(C) IJS	(A) INEA	(C) INEA	(A) HTc	(C) HTc
1	Elevated CO content in the exhaust	1	5	1	4	18	16	2.571429	2.285714	3	4	1	1	4	4	1	1	3	1	1	1	5	4
2	Nickel carbonyl formation	1	4	1	4	16	14	2.285714	2	3	1	2	2	3	3	1	1	4	4	1	1	2	2
3	Accumulation of combustible gas mixture in hot compartments	1	4	1	4	17	11	2.428571	1.571429	3	1	1	1	4	4	1	1	3	1	1	1	4	2
4	Blockage of the Exhaust	1	4	1	4	17	14	2.428571	2	3	4	3	3	2	2	1	1	3	1	1	1	4	2
5	Fuel starvation	3	5	1	5	30	30	4.285714	4.285714	3	5	5	5	4	4	5	5	5	5	3	1	5	5
6	Air starvation	3	5	1	5	30	29	4.285714	4.142857	3	4	5	5	4	4	5	5	5	5	3	1	5	5
7	Max cell T exceeds limit	1	5	1	5	26	23	3.714286	3.285714	3	5	3	3	4	4	1	1	5	5	5	1	5	4
8	Cell failure	1	5	1	5	22	21	3.142857	3	3	4	5	5	4	4	1	1	4	4	3	1	2	2
9	Cell short circuit	1	5	1	5	19	18	2.714286	2.571429	3	4	5	5	4	4	1	1	1	1	3	1	2	2
10	Stack short circuit	1	4	1	4	21	16	3	2.285714	3	1	4	4	4	4	1	1	1	1	4	1	4	4
11	O/C & S/C ratio too low	3	5	1	5	30	29	4.285714	4.142857	3	4	5	5	4	4	5	5	5	5	3	1	5	5
12	Fuel contamination	1	5	1	5	20	21	2.857143	3	3	4	3	3	4	4	1	1	5	5	1	1	3	3
13	Air contamination	1	4	1	4	16	14	2.285714	2	3	1	3	3	4	4	1	1	1	1	1	1	3	3
14	Fuel interruption	1	5	1	5	23	23	3.285714	3.285714	3	4	3	3	4	4	1	1	5	5	3	1	4	5
15	Power electronics failure	1	4	1	5	19	15	2.714286	2.142857	3	1	1	1	2	2	1	1	4	4	4	1	4	5
16	Software fault / failure / crash	1	5	1	5	17	12	2.428571	1.714286	3	1	1	1	2	2	1	1	1	1	4	1	5	5
17	Internal leakage, anode to cathode	3	5	1	5	26	25	3.714286	3.571429	3	4	5	5	3	3	5	5	3	3	3	1	4	4
18	Internal leakage, cathode to anode	3	5	1	5	26	25	3.714286	3.571429	3	4	5	5	3	3	5	5	4	4	3	1	3	3
19	External leakage anode side	2	5	2	5	26	27	3.714286	3.857143	3	4	5	5	3	3	5	5	4	4	2	2	4	4
20	External leakage cathode side	2	5	2	5	25	26	3.571429	3.714286	3	4	5	5	3	3	5	5	4	4	3	3	2	2
21	Air blower malfunctioning, lower flow	1	5	1	5	23	25	3.285714	3.571429	3	5	3	3	4	4	1	1	5	5	4	4	3	3
22	Air blower malfunctioning, higher flow	1	5	1	5	22	24	3.142857	3.428571	3	5	1	1	5	5	1	1	4	4	5	5	3	3
23	Recycle loop closed (C)	#REF!	#REF!		1	5		21		3		5		2		4		1		4		1	
24	No water supply	1	5	1	5	23	15	3.285714	2.142857	3	1	2	2	4	4	1	1	5	5	3	1	5	1

Usage:

Specify number from 1 .. 5:

1 **No!** 2 No 3 Maybe No opinion I don't know 4 Yes 5 **Yes!**

Figure 1: Prioritization vote of each partner