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Revision history		
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001	28/06/2024	First Issue with General Updates from Initial Draft
002	18/10/2024	Updated following FAT completion
003	19/11/2024	Updates based on the review with Crosswind
004	21/03/2025	Updates based on the review with Crosswind
005	08/08/2025	Updates based on the review with Crosswind

Document Title:	**BLPH Project - Site Acceptance Test (SAT) Procedure**
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Short Title	Megablock Site Acceptance Test
Full Title	Megablock Site Acceptance Test
Abstract	*Site acceptance test for verification of full Megablock system*

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Revision Record

Rev #	Description	Revised By	Date (dd-mm-yyyy)
-	Initial Release	RKN	28-05-2024
1	General updates	RKN	28-06-2024
1.1	General updates	TAN	18-09-2024
2	Update prior to release to CW	PBL	16-10-2024
3	Updates based on review with CW	RKN	19-11-2024
4	Updates based on review with CW	RKN	09-01-2025
5	Updates based on review with CW	RKN	08-08-2025

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1.0 Executive Summary

This document outlines the recommended commissioning activities and site acceptance tests. These tests aim to verify correct installation, and that the system performance onsite matches the performance level shown during FAT. There should be no CAT A items outstanding prior to power up.

2.0 References

- Confirmation of Satisfactory SAT - Signature Page
- PWR008 Ballard commissioning document
- EN 60204 Electrical safety test 10ft
- EN 60204 Electrical safety test 40ft
- EN 60204 Electrical safety test Cng Pltfrm
- F07 & F08, Electrical safety SAT
- F10 Safety checklist
- SPC ID 0103 Cooling Circuit Pressure and Leak Test Procedure
- SPC ID 0104 H2 Leak Test Procedure
- SPC ID 0106 Noise Level Measurement Test Procedure
- SPC ID 0204 System pressure decay test template
- SPC ID 0102 Thermographic - Cooling and Ventilation Test Procedure
- SPC ID 0105 Thermographic - Electrical Test Procedure
- SPC ID 0107 Power Quality Measurement Test Procedure

3.0 Definitions and Acronyms

FC	FCwave™
H2	Hydrogen
FAT	Factory Acceptance Test
SAT	Site Acceptance Test
HT1	High temperature 1050kW cooling system 1
HT2	High temperature 1050kW cooling system 2
LT	Low temperature cooling system

4.0 Objectives and Background

The tests in the document are based on the test matrix in document J99-02 (Aconex K559-2254-CWIWP4202202-J99-002-Rev002)

This document describes the witnessed Site Acceptance Tests. The tests do not include the internal testing that has been done to secure product maturity, mechanical and electrical connections have been done correctly.

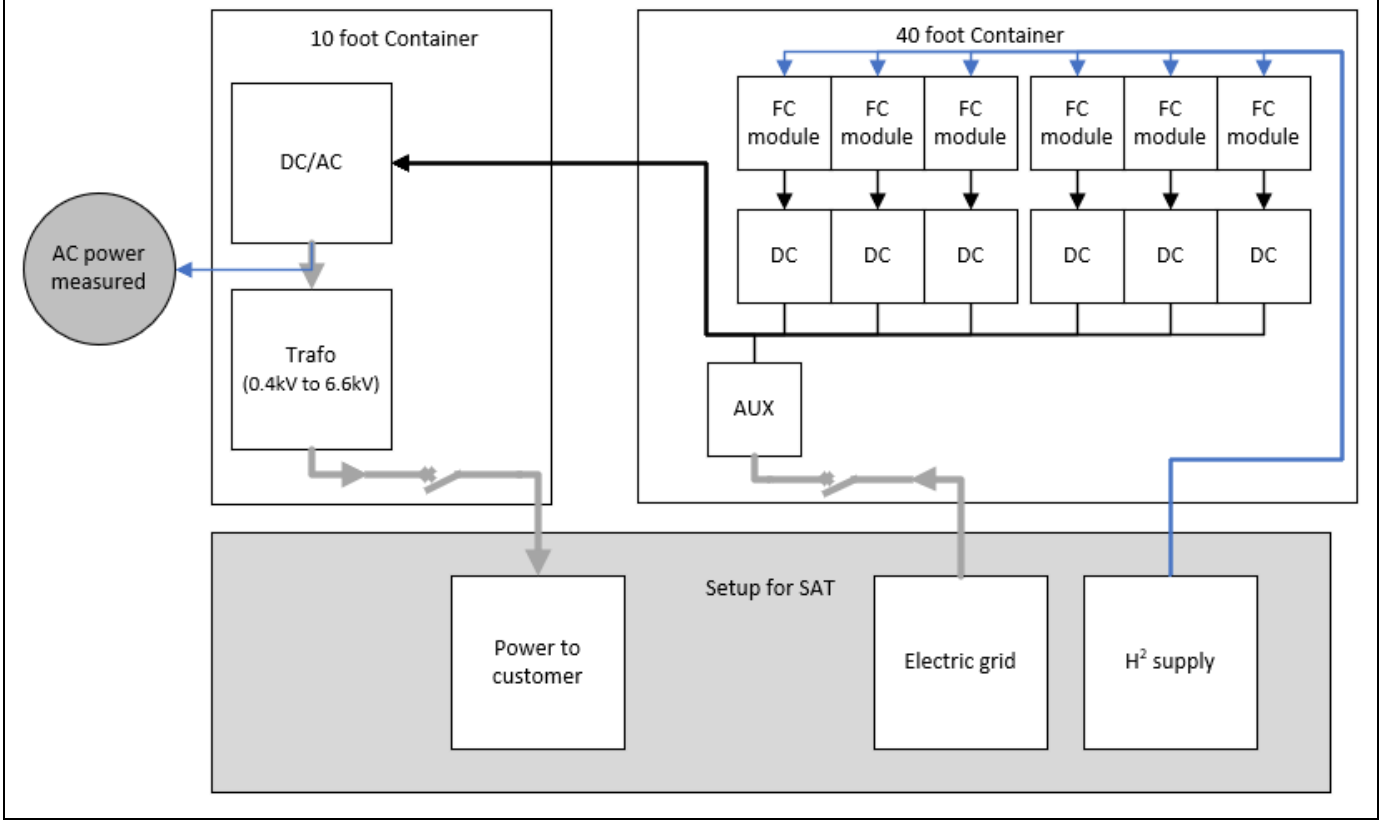
The SAT is not intended to replace an integration test. If third-party features are not yet ready for testing, those specific test cases will be temporarily excluded from the SAT and should be performed during integration testing. This will not affect the overall SAT signoff.

There should be no CAT A items outstanding prior to power up.

The scope of testing is:

- Visual Inspection of the delivered product (Tri-party walkaround)
- Verification of safety systems for the Megablock.
- Production of electrical power to the customer grid to verify performance.

Figure 1: Megablock System test overview



5.0 Note on Power Quality Measurements

The power quality measurements are indicative during SAT, as the measured power quality depends also on the customer load dissipating the produced power. Ballard is also not capable of measuring power quality on the 6.6kV bus, and any measurements are done on the 400V side of the output transformer. This results in lower measurements than on the medium voltage side of the output transformer, as the transformer inductance is an integral part of the harmonic dampening of the FC package.

Power quality measurements have been removed from pass/fail criteria.

6.0 Note on Electrical Load

The electrical load that is to dissipate the power generated by the FC package is not in Ballard scope. During step response tests and full load tests, it is required that it is present and able to absorb the power from the FC package.

7.0 Functional tests

7.1 F02 Visual inspection

7.1.1 Test

The test involves an examination of the paint job through visual inspection, assessing the overall build quality, and checking for any dents. The focus is also on evaluating the assembly quality to ensure compliance with weather resistance.

This test is superseded by the tri party walkaround.

7.1.2 Relevant Standard / document

- No reference

7.1.3 Brief Test Plan

- Visual inspection with customer of full system, meaning inside and outside container solution.
- Take comprehensive pictures of the full system and test setup, including close-ups of vital components, with timestamps for reference.

7.1.4 Pass/Fail criteria.

- Visual inspect with customer to review quality of full system.

7.1.5 Test Result

Table 1: Visual inspection – Test Result

Date tested	Item	Result	Pass/Fail	Notes

7.2 F07 Electrical safety test – 10-foot container

7.2.1 Test

Follow designated standard to conduct electrical safety test, grounding continuity and high potential.

7.2.2 Relevant Standard / document

- EN 60204 Electrical safety test 10ft
- F07 & F08, Electrical safety SAT

7.2.3 Brief Test Plan

- According to EN 60204-1

7.2.4 Pass/Fail criteria.

- All relevant checks in EN 60204-1 chapter 18 passed.

7.2.5 Test Result

Table 2: Electrical safety test - Test results

Date tested	Item	Result	Pass/Fail	Notes

Table 3: Electrical safety test - calibration equipment

Unit	Equipment number	Calibration due date	Equipment used for

7.3 F08 Electrical safety test – 40-foot container

7.3.1 Test

Follow designated standard to conduct electrical safety test, grounding continuity and high potential.

7.3.2 Relevant Standard / document

- EN 60204 Electrical safety test 40ft
- EN 60204 Electrical safety test Cng Pltfrm
- F07 & F08, Electrical safety SAT

7.3.3 Brief Test Plan

- According to EN 60204-1

7.3.4 Pass/Fail criteria.

- All relevant checks in EN 60204-1 chapter 18 passed.

7.3.5 Test Result

Table 4: Electrical safety test - Test Result

Date tested	Item	Result	Pass/Fail	Notes

Table 5: Electrical safety test - Calibration equipment

Unit	Equipment number	Calibration due date	Equipment used for

7.4 F10 Safety

7.4.1 Test

Conduct tests of safety inputs and outputs, including emergency stop buttons, smoke detectors, gas detectors and external connections.

7.4.2 Relevant Standard / document

- F10 Safety checklist

7.4.3 Brief Test Plan

- Trigger each safety input according to checklist.
  - Emergency pushbuttons
  - Smoke detectors test
  - H2 sensor test
  - External safety switches
  - External feedback

7.4.4 Pass/Fail criteria.

- Verified according to checklist.
- Each item triggers the correct alarm

7.4.5 Test Result

Table 6: Safety - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Emergency pushbuttons			
	Smoke detectors			
	H2 sensors			
	External safety switches			
	External feedback			

Table 7: Safety – Calibration/Equipment

Unit	Equipment number	Calibration due date	Equipment used for

7.5 F18 H_2 Leakage test

7.5.1 Test procedure

All pipework and H2 instrumentation subassemblies must be inspected, recorded, verified and pass in accordance with the procedure in section 5.4 in *SPC ID 0104 H2 Leak Test Procedure Rev 002* prior to full system SAT.

System H2 leakage test is done system pressure decay test, according to section 5.5 in *SPC ID 0104 H2 Leak Test Procedure Rev 002*.

7.5.2 Pass/Fail criteria.

Pressure decay test with a maximum leakage no greater than specified in test procedure.

Result details are documented in the template *SPC ID 0204 System pressure decay test template*

Parameter	Value	Description
L_A [Nm^3/h]	**2,72 – 3,58 x10^{-3}**	**Maximum allowed pressure decay to pass pressure decay test, where L_A = L_S + L_Mu**
L_S [Nm^3/h]	0	Summarized expected leak rates of all components in the system (per design leak rate).
L_Mu [Nm^3/h]	2,72 – 3,58 x10^{-3}	Calculated accuracy of the measuring system, used to perform the test.
L_C [Nm^3/h]	2,7x10^{-5}	Maximum allowed leak rate for a given pipe section, where integrity/operability of the system may be maintained safely

7.5.3 Test Result

Table 8: H2 leakage - Test Result

Date tested	Item	Leakage rate L_1 [Nm^3/h]	Pass/Fail	Notes
	H2 line 1			
	H2 line 2			
	H2 line 3			
	H2 line 4			
	H2 line 5			
	H2 line 6			

8.0 Operational tests

Operations are done using operator HMI or remote HMI in normal operating mode.

8.1 O01 System Start/Stop - Normal low load operation.

8.1.1 Test

Fuel Cell system can start, deliver minimum power and perform controlled stop without faults. This test is based on DC power.

8.1.2 Relevant Standard / document

- No reference

8.1.3 Brief Test Plan

- All FC in standby
- Request 100kW DC
- Delay 120 seconds
- Request zero power
- Repeat with new preferred FC until all tested.

8.1.4 Pass/Fail criteria.

- Fuel Cell Package starts without faults.
- No persistent system alarms.
- Correct available power signal.
- DC Power output within +/-5% and stable in less than 60 seconds
- Fuel Cell Package stops without faults.
- Fuel Cell in stand-by in less than 120 seconds.

8.1.5 Test Result

Table 9: System Start/Stop – Normal low load operation - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	FCwave 1			
	FCwave 2			
	FCwave 3			
	FCwave 4			
	FCwave 5			
	FCwave 6			

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8.2 O09 Load Test – step response 0 to 35%

8.2.1 Test

Test step response by adding 35% load in one step from no load while measuring AC power quality.

8.2.2 Relevant Standard / document

- N/A

8.2.3 Brief Test Plan

- All FC in stand-by.
- Apply set point by requesting 350kW AC

8.2.4 Pass/Fail criteria.

- AC output: +/- 10% actual to curve at any time.
- No persistent system alarms.

8.2.5 Test Result

Table 10: Load Test - step response 0 to 35% - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Step response 0-35%			
	AC power quality		Indicative	

8.3 O10 Load Test – step response 35% to 70%

8.3.1 Test

Test step response by adding 35% load in one step to reach 70% load while measuring AC power quality.

8.3.2 Relevant Standard / document

- N/A

8.3.3 Brief Test Plan

- 3 FC running delivering 350kW AC steady state.
- 3 FC in stand-by
- Apply set point by requesting 700kW AC power.

8.3.4 Pass/Fail criteria.

- No persistent system alarms.

8.3.5 Test Result

Table 11: Load Test - step response 35% to 70% - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Step response 35%-70%			
	AC power quality		Indicative	

8.4 O11 Load Test – step response 65% to 100%

8.4.1 Test

Test step response by adding 35% load in one step to reach full load while measuring AC power quality.

8.4.2 Relevant Standard / document

- N/A

8.4.3 Brief Test Plan

- 6 FC running delivering 650kW AC steady state.
- Apply set point by requesting 1000kW AC power.

8.4.4 Pass/Fail criteria.

- AC output: +/- 10% actual to curve at any time.
- No persistent system alarms.

8.4.5 Test Result

Table 12: Load Test - step response 65% to 100% - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Step response 65%-100%			
	AC power quality		Indicative	

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8.5 O12 Load Test – 100% stability test - 3 hours.

8.5.1 Test

Test steady state at 100% load for 3 hours while measuring power quality.

This test is also dependent on the hydrogen supply for the system.

8.5.2 Relevant Standard / document

- N/A

8.5.3 Brief Test Plan

- 6 FC running delivering 1000kW steady state.

8.5.4 Pass/Fail criteria

- AC output: +/- 10% actual to curve at any time.
- No persistent system alarms.

8.5.5 Test Result

Table 13: Load Test – Steady state 100% load - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Full load test			
	AC power quality		Indicative	

8.6 O13 Load Test – step response 100% to 50%

8.6.1 Test

Test step response by removing 50% load in one step at full load while measuring power quality.

8.6.2 Relevant Standard / document

- N/A

8.6.3 Brief Test Plan

- 6 FC running delivering 1000kW steady state.
- Request 500kW AC.

8.6.4 Pass/Fail criteria.

- AC output: +/- 10% actual to curve at any time.
- No persistent system alarms.

8.6.5 Test Result

Table 14: Load Test - step response 100% to 50% - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Step response 100%-50%			
	AC power quality		Indicative	

8.7 O14 Load Test – step response 50% to 0%

8.7.1 Test

Test step response by removing 50% load in one step to no load while measuring AC power quality.

8.7.2 Relevant Standard / document

- N/A

8.7.3 Brief Test Plan

- 3-6 FC running delivering 500kW AC.
- Request 0% and apply set point.

8.7.4 Pass/Fail criteria.

- AC output: +/- 10% actual to curve at any time.
- No persistent system alarms.

8.7.5 Test Result

Table 15: Load Test - step response 50% to 0% - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	Step response 50%-0%			
	AC power quality	n/a	n/a	Unit not producing power

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Title	F07 & F08 Electrical safety test - 40 ft and 10 ft container
Project	601456B CrossWind BLPH
Test date [DD-MM-YYYY]	
Test location	
Test performed by	

Grounding continuity
EN 60204-1:2018 - Section 18.2.2 - Test 1
Test performed with a test current of 10A

Main location	Location	Measurement FAT	Unit	Measurement SAT
40ft container	Busbar to busbar	0,024	Ohm	
	Module 1	0,018	Ohm	
	DC/DC cabinet 1	0,023	Ohm	
	Module 2	0,024	Ohm	
	DC/DC cabinet 2	0,019	Ohm	
	Module 3	0,026	Ohm	
	DC/DC cabinet 3	0,016	Ohm	
	Module 4	0,026	Ohm	
	DC/DC cabinet 4	0,016	Ohm	
	Module 5	0,024	Ohm	
	DC/DC cabinet 5	0,017	Ohm	
	Module 6	0,029	Ohm	
	DC/DC cabinet 6	0,015	Ohm	
	Control cabinet	0,021	Ohm	
	Control cabinet right door	0,032	Ohm	
	Lifting crane track, dolly	0,028	Ohm	
	LT piping	0,031	Ohm	
	Isolation transformer cover	0,039	Ohm	
	Cable tray	0,019	Ohm	

Main location	Location	Measurement FAT	Unit	Measurement SAT
10ft container	Busbar to busbar	0,019	Ohm	
	Main DC/Acpoint 1	0,032	Ohm	
	Main DC/Acpoint 2	0,024	Ohm	
	Main DC/Acpoint 3	0,027	Ohm	
	DC/AC conduncter point 1	0,037	Ohm	
	DC/AC conduncter point 2	0,022	Ohm	
	DC/AC conduncter point 3	0,023	Ohm	
	LT coolant pipe	0,024	Ohm	
	Cable tray	0,02	Ohm	
	Main transforer grounding bolt	0,023	Ohm	
	Main transformer chassis	0,02	Ohm	
	Cable tray	0,022	Ohm	

Title	F07 & F08 Electrical safety test - 40 ft and 10 ft container
Project	601456B CrossWind BLPH
Test date [DD-MM-YYYY]	
Test location	
Test performed by	

Isolation resistance
EN 60204-1:2018 - Section 18.3
Test performed with a test voltage of 1000V

Main location	Location	Measurement FAT	Unit	Measurement SAT
40 ft container	L1-PE	> 999.9	MOhm	
	Cooling skid L1	10,01	Mohm	
	Colling skid L2	6,252	Mohm	
	Cooling skid L3	12,81	Mohm	
	AUX supply L1	251	Mohm	
	AUX supply L2	337	MOhm	
	AUX supply L3	237	Mohm	

Main location	Location	Measurement FAT	Unit	Measurement SAT
10ft container	L1+L2+L3-PE on AC circuit	592	Mohm	

Title	F07 & F08 Electrical safety test - 40 ft and 10 ft container
Project	601456B CrossWind BLPH
Test date [DD-MM-YYYY]	
Test location	
Test performed by	

Isolation resistance

EN 60204-1:2018 - Section 18.4

Test performed with a test voltage of 2500VAC

Main location	Location	Measurement FAT	Unit	Measurement SAT
40ft container	PE and L1	0	mA	
	PE and L2	0	mA	
	PE and L3	0	mA	

Main location	Location	Measurement FAT	Unit	Measurement SAT
10 FT container	PE and L1	7,1	mA	
	PE and L2	7,1	mA	
	PE and L3	7	mA	

Title	F10 Safety checklist
Project	601456B CrossWind BLPH
Test date [DD-MM-YYYY]	
Test location	
Test performed by	

Checklist for safety inputs

Main location	Location	Checked
40ft container	Emergency pushbuttons	
	40ft side door	
	UC50	
	UC30	
	Smoke detector	
	Left	
	Middle	
	Right	
	H2 sensor	
	Left	
	Middle	
	Right	
	External safety swithces	
	External feedback	

Megablock		40ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

1. Introduction

The Megablock system contains many components utilizing potentially dangerous voltages and currents. It is a safety requirement that the electrical safety is tested before a product is shipped.

The testing is done according to the standard EN60204-1 Chapter 18, from which the tests in this document are described with room to note test results.

2. Revision Record

Rev #	Author	Description	Revised By	Date
1.0	PBL	Initial Release		09/11-2023
2.0	PBL	Adapted from 40ft Coolant Skid document		04/07-2024
3.0	CJA	Adapted from 10ft power converter container document		15/10-2024
4.0	RKN	General review		09/01-2025

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Table 6 – Summary Table 13

5. Purpose and structure of this document

As Megablock is a large system, containing several parts assembled individually and brought together to fulfill the customer requirements, the components are tested individually.

With each component tested before final assembly, the interconnect must be tested, both before initial operation and after any disassembly, e.g. after shipping.

The purpose of this document is to compare the requirements outlined in EN60204-1 Chapter 18 against following testing performed Megablock components.

This is required for the CE approval of the Megablock Fuel Cell Power Plant.

This document is structured as follows:

1. The requirements from EN60204-1 are outlined:
    a. Section 7
2. Test Specifications to comply with the requirement outlined above.
    a. Sections 10 to 16
3. Summary table
    a. Section 17

6. References

Document	Title	Author
DS/EN 60204-1:2018	Safety of machinery – Electrical equipment of machines – Part 1: General Requirements	CENELEC

Table 1 – References

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7. Requirements from EN60204-1 Ch 18

Figure 1 is reproduced from the EN60204-1 Ch18.1:

18.1 General

The extent of verification will be given in the dedicated product standard for a particular machine. Where there is no dedicated product standard for the machine, the verifications shall always include the items a), b), c) and h) and may include one or more of the items d) to g):

a) verification that the electrical equipment complies with its technical documentation;
b) verification of continuity of the protective bonding circuit (Test 1 of 18.2.2);
c) in case of fault protection by automatic disconnection of supply, conditions for protection by automatic disconnection shall be verified according to 18.2;
d) insulation resistance test (see 18.3);
e) voltage test (see 18.4);
f) protection against residual voltage (see 18.5);
g) verification that the relevant requirements of 8.2.6 are met;
h) functional tests (see 18.6).

Figure 1 – Excerpt from EN60204-1:2018, Chapter 18.1

The mapping between the headlines from the standard and the requirement ID used in this document is listed in Table 2.

Requirement headline	EN60204-1 Chapter 18.1	EN60204-1 Chapter	Requirement ID
Verification that the electrical equipment complies with its technical documentation	A	n/a	A1
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	B	18.2.2 – Test #1	A2
Verification of conditions for protection by automatic disconnection of supply	C	18.2	A3
Insulation resistance tests	D	18.3	A4
Voltage tests	E	18.4	A5
Protection against residual voltages	F	18.5	A6
Verification that the relevant requirements of 8.2.6 are met	G	8.2.6	A7

Table 2 – Requirement headlines, chapter, and ID mapping

Functional testing of the equipment is outside the scope of this document.

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Megablock		40ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

8. Test Equipment.

The test equipment is a CE MultiTester, manufactured by Metrel.

Test Equipment	Ballard Equipment ID	Calibration valid until:

9. Device Under Test

The device to be tested is the 40ft Fuel Cell Container for the Megablock project.

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Megablock		40ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

10. A1 – Verification that the electrical equipment complies with its technical documentation

EN60204-1 requirements:

a) verification that the electrical equipment complies with its technical documentation;

Figure 2 – EN60204-1:2018, Chapter 18.1

Megablock Component requirements:

Inspection of the electrical equipment and cabinets to ensure congruence between documentation and equipment/cabinet.

Megablock Component validation:

Component	40ft Container
Result (pass/fail)	
Date and Initials	

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11. A2 – Verification of continuity of the protective bonding circuit

EN60204-1 requirements:

18.2.2 Test 1 – Verification of the continuity of the protective bonding circuit

The resistance between the PE terminal (see 5.2 and Figure 4) and relevant points that are part of the protective bonding circuit shall be measured with a current between at least 0,2 A and approximately 10 A derived from an electrically separated supply source (for example SELV, see 414 of IEC 60364-4-41:2005) having a maximum no-load voltage of 24 V AC or DC.

The resistance measured shall be in the expected range according to the length, the cross sectional area and the material of the related protective conductors and protective bonding conductor(s).

Earthed PELV supplies can produce misleading results in this test and therefore shall not be used.

Figure 3 – EN60204-1:2018, Chapter 18.2.2

Megablock Component requirements:

The EN60204-1 Chapter 18.2.2, Test #1 specifies a current of 10A.

Megablock Component bonding resistance test is performed with a current of 10A and a test period of 10 seconds.

Megablock Component validation:

The primary earthing point for the 40ft Fuel Cell Container is the main ground bar located in +UC50.

Each component is verified and compared to expected values for the following locations.

ID	Test Point	Expected Value	Recorded Value
1	Busbar to busbar	<100mΩ	
2	Module 1		
3	DC/DC cabinet 1		
4	Module 2		
5	DC/DC cabinet 2		
6	Module 3		
7	DC/DC cabinet 3		
8	Module 4		
9	DC/DC cabinet 4		
10	Module 5		
11	DC/DC cabinet 5		

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12	Module 6		
13	DC/DC cabinet 6		
14	Control cabinet		
15	Control cabinet right door		
16	Lifting crane track, dolly		
17	LT piping		
18	Isolation transformer cover		
19	Cable tray		

Table 3 – Bonding Resistance Test point and expected resistance values.

When performing the test, ensure the connection between the test leads and the equipment is not contributing to inaccurate measurements.

12. A3 - Verification of conditions for protection by automatic disconnection of supply

EN60204-1 requirements:

18.2 Verification of conditions for protection by automatic disconnection of supply

18.2.1 General

The conditions for automatic disconnection of supply (see 6.3.3) shall be verified by tests.

Test 1 verifies the continuity of the protective bonding circuit.

Figure 4 – EN60204-1:2018, Chapter 18.2

Megablock Component requirements:

As specified in chapter 18.2.1, Test #1 is performed (see section 11).

Chapter 18.2.1 further specifies testing of Residual Current Devices (RCD) according to manufacturer specifications.

Megablock RCD Testing:

All RCD (Residual Current Device) in the Megablock system is equipped with self-test functionality from the manufacturer. This takes the shape of a push button, which must cause the RCD device to trip when actuated.

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Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

For the test, first enable all RCD circuits, and then actuate the self-test button on the devices. The devices must trip within 1 second. After the trip, use a multimeter to verify that the output of the device has no voltage (<10VAC)

Component	RCD Devices in UC20 (40ft Control Cabinet)
Result – 3ph RCD	
Result – 1ph RCD/MCCB	
Date and Initials	

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13. A4 - Insulation resistance tests

EN60204-1 requirements:

18.3 Insulation resistance tests

When insulation resistance tests are performed, the insulation resistance measured at 500 V DC between the power circuit conductors and the protective bonding circuit shall be not less than 1 MΩ. The test may be made on individual sections of the complete electrical installation.

Figure 5 – EN60204-1:2018, Chapter 18.3

Megablock Component requirements:

Before performing this test, isolate all fuel cell DCDC converters from the DC bus (Cabinets UC01 to UC05)

Use a set of test leads and alligator clips to create a single AC node (3 phases shorted together)

The Megablock Component insulation requirements are higher than as specified chapter 18.3. The test is specified in Table 4):

Test point	Pass criteria	Test Voltage [VDC]
Internal side of the output breaker	>1MΩ	500

Table 4 – Megablock Component Power Circuit Insulation Resistance Requirements

Megablock Component validation:

Each component is verified and compared to pass criteria in Table 4.

Component	Fuel Cell Container
Result – AC Node (value and pass/fail)	
Date and Initials	

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Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

14. A5 – Voltage tests

EN60204-1 requirements:

18.4 Voltage tests

When voltage tests are performed, test equipment in accordance with IEC 61180-2 should be used.

The test voltage shall be at a nominal frequency of 50 Hz or 60 Hz.

The maximum test voltage shall have a value of twice the rated supply voltage of the equipment or 1 000 V, whichever is the greater. The maximum test voltage shall be applied between the power circuit conductors and the protective bonding circuit for at least 1 s. The requirements are satisfied if no disruptive discharge occurs.

Components and devices that are not rated to withstand the test voltage and surge protection devices which are likely to operate during the test shall be disconnected during testing.

Components and devices that have been voltage tested in accordance with their product standards may be disconnected during testing.

Figure 6 – EN60204-1:2018, Chapter 18.4

Megablock Component requirements:

The requirements from EN 60204-1:2018, Chapter 18.4 is compared in Table 5.
AC Voltage for Megablock Components is at most 480V, so twice the supply voltage is 960Vac.

Parameter	EN 60204-1:2018, Chapter 18.4	Megablock Component Testing
Voltage [VAC]	960	2500
Frequency [Hz]	50 or 60	50
Duration [sec]	1	10
Maximum Current [mA]	No arcing	5

Table 5 – Voltage Test Requirements

Megablock Component validation:

Connection point is internal side of main output breaker.

Component	Fuel Cell Container
Voltage Test – L1 (value and pass/fail)	
Voltage Test – L2 (value and pass/fail)	
Voltage Test – L3 (value and pass/fail)	
Date and Initials	

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Megablock		40ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	4.0.0

15. A6 – Protection against residual voltages

EN60204-1 requirements:

18.5 Protection against residual voltages

Where appropriate, tests shall be performed to ensure compliance with 6.2.4.

Figure 7 – EN60204-1:2018, Chapter 18.5

6.2.4 Protection against residual voltages

Live parts having a residual voltage greater than 60 V when the supply is disconnected shall be discharged to 60 V or less within a time period of 5 s provided that this rate of discharge does not interfere with the proper functioning of the equipment. Exempted from this requirement are components having a stored charge of 60 μC or less. Where this specified rate of discharge would interfere with the proper functioning of the equipment, a durable warning notice drawing attention to the hazard and stating the delay required before the enclosure may be opened shall be displayed at an easily visible location on or immediately adjacent to the enclosure that contains the live parts.

In the case of plugs or similar devices, the withdrawal of which results in the exposure of conductors (for example pins), the discharge time to 60 V shall not exceed 1 s, otherwise such conductors shall be protected to at least IP2X or IPXXB. If neither a discharge time of 1 s nor a protection of at least IP2X or IPXXB can be achieved (for example in the case of removable collectors on conductor wires, conductor bars, or slip-ring assemblies, see 12.7.4), additional switching devices or an appropriate warning, for example a warning sign drawing attention to the hazard and stating the delay required shall be provided. When the equipment is located in places open to all persons, which can include children, warnings are not sufficient and therefore a minimum degree of protection against contact with live parts to IP4X or IPXXD is required.

Figure 8 – EN60204-1:2018, Chapter 6.2.4

Megablock Component requirements:

Identical to EN60204-1 requirements.

Megablock Component validation:

No live parts of the Megablock Component system are accessible without disassembling barriers or accessing electrical cabinets. All connectors are IP2X or higher in unmated state in applications higher than 60V (power system)

Frequency converters and motor drives are marked with applicable durations before internal capacitors are discharged.

Maintenance procedures for the Megablock Component module include a manual verification before any work on exposed components is permitted.

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16. A7 – Verification that the relevant requirements of 8.2.6 are met

EN60204-1 requirements:

8.2.6 Additional requirements for electrical equipment having earth leakage currents higher than 10 mA

Where electrical equipment has an earth leakage current that is greater than 10 mA AC or DC in any protective conductor, one or more of the following conditions for the integrity of each section of the associated protective bonding circuit that carries the earth leakage current shall be satisfied:

a) the protective conductor is completely enclosed within electrical equipment enclosures or otherwise protected throughout its length against mechanical damage;

b) the protective conductor has a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al;

c) where the protective conductor has a cross-sectional area of less than 10 mm^2 Cu or 16 mm^2 Al, a second protective conductor of at least the same cross-sectional area is provided up to a point where the protective conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al. This can require that the electrical equipment has a separate terminal for a second protective conductor.

d) the supply is automatically disconnected in case of loss of continuity of the protective conductor;

e) where a plug-socket combination is used, an industrial connector in accordance with IEC 60309 series, with adequate strain relief and a minimum protective earthing conductor cross-section of 2,5 mm^2 as part of a multi-conductor power cable is provided.

A statement shall be given in the instructions for installation that the equipment shall be installed as described in this 8.2.6.

Figure 9 – EN60204-1:2018, Chapter 8.2.6

Megablock Component requirements:

The Megablock Component does not have a leakage current higher than 10mA.

Megablock Component validation:

The protection against excessive leakage current is twofold:

- Ground fault detection is installed with a proven component (Bender Isometer). Detection of ground fault causes system shutdown and service technician is dispatched.
- Conductivity measurement of internal coolant is a part of the regular maintenance procedures (see N01-003 Service and Maintenance Manual)

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17. Summary Table

The requirements from sections 10 to 16, together with results are summarized below in Table 6:

Requirement headline	EN60204-1 Chapter	Req ID	Pass/Fail?
Verification that the electrical equipment complies with its technical documentation	n/a	A1	
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	18.2.2 – Test #1	A2	
Verification of conditions for protection by automatic disconnection of supply	18.2	A3	
Insulation resistance tests	18.3	A4	
Voltage tests	18.4	A5	
Protection against residual voltages	18.5	A6	
Verification that the relevant requirements of 8.2.6 are met	8.2.6	A7	

Table 6 – Summary Table

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Megablock		10ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

1. Introduction

The Megablock system contains many components utilizing potentially dangerous voltages and currents. It is a safety requirement that the electrical safety is tested before a product is shipped.

The testing is done according to the standard EN60204-1 Chapter 18, from which the tests in this document are described with room to note test results.

2. Revision Record

Rev #	Author	Description	Revised By	Date
1.0	PBL	Initial Release		09/11-2023
2.0	PBL	Adapted from 40ft Coolant Skid document		04/07-2024
3.0	RKN	General review		09/01-2025

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5. Purpose and structure of this document

As Megablock is a large system, containing several parts assembled individually and brought together to fulfill the customer requirements, the components are tested individually.

With each component tested before final assembly, the interconnect must be tested, both before initial operation and after any disassembly, e.g. after shipping.

The purpose of this document is to compare the requirements outlined in EN60204-1 Chapter 18 against following testing performed Megablock components.

This is required for the CE approval of the Megablock Fuel Cell Power Plant.

This document is structured as follows:

1. The requirements from EN60204-1 are outlined:
    a. Section 7
2. Test Specifications to comply with the requirement outlined above.
    a. Sections 10 to 16
3. Summary table
    a. Section 17

6. References

Document	Title	Author
DS/EN 60204-1:2018	Safety of machinery – Electrical equipment of machines – Part 1: General Requirements	CENELEC

Table 1 – References

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7. Requirements from EN60204-1 Ch 18

Figure 1 is reproduced from the EN60204-1 Ch18.1:

18.1 General

The extent of verification will be given in the dedicated product standard for a particular machine. Where there is no dedicated product standard for the machine, the verifications shall always include the items a), b), c) and h) and may include one or more of the items d) to g):

a) verification that the electrical equipment complies with its technical documentation;
b) verification of continuity of the protective bonding circuit (Test 1 of 18.2.2);
c) in case of fault protection by automatic disconnection of supply, conditions for protection by automatic disconnection shall be verified according to 18.2;
d) insulation resistance test (see 18.3);
e) voltage test (see 18.4);
f) protection against residual voltage (see 18.5);
g) verification that the relevant requirements of 8.2.6 are met;
h) functional tests (see 18.6).

Figure 1 – Excerpt from EN60204-1:2018, Chapter 18.1

The mapping between the headlines from the standard and the requirement ID used in this document is listed in Table 2.

Requirement headline	EN60204-1 Chapter 18.1	EN60204-1 Chapter	Requirement ID
Verification that the electrical equipment complies with its technical documentation	A	n/a	A1
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	B	18.2.2 – Test #1	A2
Verification of conditions for protection by automatic disconnection of supply	C	18.2	A3
Insulation resistance tests	D	18.3	A4
Voltage tests	E	18.4	A5
Protection against residual voltages	F	18.5	A6
Verification that the relevant requirements of 8.2.6 are met	G	8.2.6	A7

Table 2 – Requirement headlines, chapter, and ID mapping

Functional testing of the equipment is outside the scope of this document.

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8. Test Equipment.

The test equipment is a CE MultiTester, manufactured by Metrel.

Test Equipment	Ballard Equipment ID	Calibration valid until:

9. Device Under Test

The device to be tested is the 10ft container for the Megablock project.

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10. A1 – Verification that the electrical equipment complies with its technical documentation

EN60204-1 requirements:

a) verification that the electrical equipment complies with its technical documentation;

Figure 2 – EN60204-1:2018, Chapter 18.1

Megablock Component requirements:

Inspection of the electrical equipment and cabinets to ensure congruence between documentation and equipment/cabinet.

Megablock Component validation:

Component	10ft Container
Result (pass/fail)	
Date and Initials	

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11. A2 – Verification of continuity of the protective bonding circuit

EN60204-1 requirements:

18.2.2 Test 1 – Verification of the continuity of the protective bonding circuit

The resistance between the PE terminal (see 5.2 and Figure 4) and relevant points that are part of the protective bonding circuit shall be measured with a current between at least 0,2 A and approximately 10 A derived from an electrically separated supply source (for example SELV, see 414 of IEC 60364-4-41:2005) having a maximum no-load voltage of 24 V AC or DC.

The resistance measured shall be in the expected range according to the length, the cross sectional area and the material of the related protective conductors and protective bonding conductor(s).

Earthed PELV supplies can produce misleading results in this test and therefore shall not be used.

Figure 3 – EN60204-1:2018, Chapter 18.2.2

Megablock Component requirements:

The EN60204-1 Chapter 18.2.2, Test #1 specifies a current of 10A.

Megablock Component bonding resistance test is performed with a current of 10A and a test period of 10 seconds.

Megablock Component validation:

The primary earthing point for the Power Converter Container is the main ground bar located at the rear of the main output breaker (=BA30-FC30).

Each component is verified and compared to expected values for the following locations.

ID	Test Point	Expected Value	Recorded Value
1	Busbar to busbar	<100mΩ	
2	Main DC/Acpoint 1		
3	Main DC/Acpoint 2		
4	Main DC/Acpoint 3		
5	DC/AC conduncter point 1		
6	DC/AC conduncter point 2		
7	DC/AC conduncter point 3		
8	LT coolant pipe		
9	Cable tray		

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10	Main transforer grounding bolt		
11	Main transformer chassis		
12	Cable tray		

Table 3 – Bonding Resistance Test point and expected resistance values.

When performing the test, ensure the connection between the test leads and the equipment is not contributing to inaccurate measurements.

12. A3 - Verification of conditions for protection by automatic disconnection of supply

EN60204-1 requirements:

18.2 Verification of conditions for protection by automatic disconnection of supply

18.2.1 General

The conditions for automatic disconnection of supply (see 6.3.3) shall be verified by tests.

Test 1 verifies the continuity of the protective bonding circuit.

Figure 4 – EN60204-1:2018, Chapter 18.2

Megablock Component requirements:

As specified in chapter 18.2.1, Test #1 is performed (see section 11). Chapter 18.2.1 further specifies testing of Residual Current Devices (RCD) according to manufacturer specifications.

Megablock Component module does not contain any RCD devices.

13. A4 - Insulation resistance tests

EN60204-1 requirements:

18.3 Insulation resistance tests

When insulation resistance tests are performed, the insulation resistance measured at 500 V DC between the power circuit conductors and the protective bonding circuit shall be not less than 1 MΩ. The test may be made on individual sections of the complete electrical installation.

Figure 5 – EN60204-1:2018, Chapter 18.3

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Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

Megablock Component requirements:

Before performing this test, isolate all fuel cell DCDC converters from the DC bus (Cabinets UC01 to UC06)

Use a set of test leads and alligator clips to create a single AC node (3 phases shorted together)

The Megablock Component insulation requirements are higher than as specified chapter 18.3. The test is specified in Table 4):

Test point	Pass criteria	Test Voltage [VDC]
=LA01+UC31-QB01	>1MΩ	500

Table 4 – Megablock Component Power Circuit Insulation Resistance Requirements

Megablock Component validation:

Each component is verified and compared to pass criteria in Table 4.

Component	Power Converter Container
Result – AC Node (value and pass/fail)	
Date and Initials	

14. A5 – Voltage tests

EN60204-1 requirements:

18.4 Voltage tests

When voltage tests are performed, test equipment in accordance with IEC 61180-2 should be used.

The test voltage shall be at a nominal frequency of 50 Hz or 60 Hz.

The maximum test voltage shall have a value of twice the rated supply voltage of the equipment or 1 000 V, whichever is the greater. The maximum test voltage shall be applied between the power circuit conductors and the protective bonding circuit for at least 1 s. The requirements are satisfied if no disruptive discharge occurs.

Components and devices that are not rated to withstand the test voltage and surge protection devices which are likely to operate during the test shall be disconnected during testing.

Components and devices that have been voltage tested in accordance with their product standards may be disconnected during testing.

Figure 6 – EN60204-1:2018, Chapter 18.4

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Megablock Component requirements:

The requirements from EN 60204-1:2018, Chapter 18.4 is compared in Table 5.
AC Voltage for Megablock Components is at most 480V, so twice the supply voltage is 960Vac.

Parameter	EN 60204-1:2018, Chapter 18.4	Megablock Component Testing
Voltage [VAC]	960	2500
Frequency [Hz]	50 or 60	50
Duration [sec]	1	10
Maximum Current [mA]	No arcing	5

Table 5 – Voltage Test Requirements

Megablock Component validation:

Connection point is internal side of main output breaker.

Component	Power Converter Container
Voltage Test – L1 (value and pass/fail)	
Voltage Test – L2 (value and pass/fail)	
Voltage Test – L3 (value and pass/fail)	
Date and Initials	

15. A6 – Protection against residual voltages

EN60204-1 requirements:

18.5 Protection against residual voltages

Where appropriate, tests shall be performed to ensure compliance with 6.2.4.

Figure 7 – EN60204-1:2018, Chapter 18.5

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Megablock		10ft Container Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

6.2.4 Protection against residual voltages

Live parts having a residual voltage greater than 60 V when the supply is disconnected shall be discharged to 60 V or less within a time period of 5 s provided that this rate of discharge does not interfere with the proper functioning of the equipment. Exempted from this requirement are components having a stored charge of 60 µC or less. Where this specified rate of discharge would interfere with the proper functioning of the equipment, a durable warning notice drawing attention to the hazard and stating the delay required before the enclosure may be opened shall be displayed at an easily visible location on or immediately adjacent to the enclosure that contains the live parts.

In the case of plugs or similar devices, the withdrawal of which results in the exposure of conductors (for example pins), the discharge time to 60 V shall not exceed 1 s, otherwise such conductors shall be protected to at least IP2X or IPXXB. If neither a discharge time of 1 s nor a protection of at least IP2X or IPXXB can be achieved (for example in the case of removable collectors on conductor wires, conductor bars, or slip-ring assemblies, see 12.7.4), additional switching devices or an appropriate warning, for example a warning sign drawing attention to the hazard and stating the delay required shall be provided. When the equipment is located in places open to all persons, which can include children, warnings are not sufficient and therefore a minimum degree of protection against contact with live parts to IP4X or IPXXD is required.

Figure 8 – EN60204-1:2018, Chapter 6.2.4

Megablock Component requirements:

Identical to EN60204-1 requirements.

Megablock Component validation:

No live parts of the Megablock Component system are accessible without disassembling barriers or accessing electrical cabinets. All connectors are IP2X or higher in unmated state in applications higher than 60V (power system)

Frequency converters and motor drives are marked with applicable durations before internal capacitors are discharged.

Maintenance procedures for the Megablock Component module include a manual verification before any work on exposed components is permitted.

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16. A7 – Verification that the relevant requirements of 8.2.6 are met

EN60204-1 requirements:

8.2.6 Additional requirements for electrical equipment having earth leakage currents higher than 10 mA

Where electrical equipment has an earth leakage current that is greater than 10 mA AC or DC in any protective conductor, one or more of the following conditions for the integrity of each section of the associated protective bonding circuit that carries the earth leakage current shall be satisfied:

a) the protective conductor is completely enclosed within electrical equipment enclosures or otherwise protected throughout its length against mechanical damage;

b) the protective conductor has a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al;

c) where the protective conductor has a cross-sectional area of less than 10 mm^2 Cu or 16 mm^2 Al, a second protective conductor of at least the same cross-sectional area is provided up to a point where the protective conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al. This can require that the electrical equipment has a separate terminal for a second protective conductor.

d) the supply is automatically disconnected in case of loss of continuity of the protective conductor;

e) where a plug-socket combination is used, an industrial connector in accordance with IEC 60309 series, with adequate strain relief and a minimum protective earthing conductor cross-section of 2,5 mm^2 as part of a multi-conductor power cable is provided.

A statement shall be given in the instructions for installation that the equipment shall be installed as described in this 8.2.6.

Figure 9 – EN60204-1:2018, Chapter 8.2.6

Megablock Component requirements:

The Megablock Component does not have a leakage current higher than 10mA.

Megablock Component validation:

The protection against excessive leakage current is twofold:

- Ground fault detection is installed with a proven component (Bender Isometer). Detection of ground fault causes system shutdown and service technician is dispatched.
- Conductivity measurement of internal coolant is a part of the regular maintenance procedures (see N01-003 Service and Maintenance Manual)

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17. Summary Table

The requirements from sections 10 to 16, together with results are summarized below in Table 6:

Requirement headline	EN60204-1 Chapter	Req ID	Pass/Fail?
Verification that the electrical equipment complies with its technical documentation	n/a	A1	
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	18.2.2 – Test #1	A2	
Verification of conditions for protection by automatic disconnection of supply	18.2	A3	
Insulation resistance tests	18.3	A4	
Voltage tests	18.4	A5	
Protection against residual voltages	18.5	A6	
Verification that the relevant requirements of 8.2.6 are met	8.2.6	A7	

Table 6 – Summary Table

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Megablock		Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

1. Introduction

The Megablock system contains many components utilizing potentially dangerous voltages and currents. It is a safety requirement that the electrical safety is tested before a product is shipped.

The testing is done according to the standard EN60204-1 Chapter 18, from which the tests in this document are described with room to note test results.

2. Revision Record

Rev #	Author	Description	Revised By	Date
1.0	PBL	Initial Release		9/11-2023
2.0	PBL	General updates		21/10-2024
3.0	RKN	General review		09/01-2025

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Megablock		Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

Table 6 – Summary Table 14

5. Purpose and structure of this document

As Megablock is a large system, containing several parts assembled individually and brought together to fulfill the customer requirements, the components are tested individually.

With each component tested before final assembly, the interconnect must be tested, both before initial operation and after any disassembly, e.g. after shipping.

The purpose of this document is to compare the requirements outlined in EN60204-1 Chapter 18 against following testing performed Megablock components.

This is required for the CE approval of the Megablock Fuel Cell Power Plant.

This document is structured as follows:

1. The requirements from EN60204-1 are outlined:
    a. Section 7
2. Test Specifications to comply with the requirement outlined above.
    a. Sections 10 to 16
3. Summary table
    a. Section 17

6. References

Document	Title	Author
DS/EN 60204-1:2018	Safety of machinery – Electrical equipment of machines – Part 1: General Requirements	CENELEC

Table 1 – References

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7. Requirements from EN60204-1 Ch 18

Figure 1 is reproduced from the EN60204-1 Ch18.1:

18.1 General

The extent of verification will be given in the dedicated product standard for a particular machine. Where there is no dedicated product standard for the machine, the verifications shall always include the items a), b), c) and h) and may include one or more of the items d) to g):

a) verification that the electrical equipment complies with its technical documentation;
b) verification of continuity of the protective bonding circuit (Test 1 of 18.2.2);
c) in case of fault protection by automatic disconnection of supply, conditions for protection by automatic disconnection shall be verified according to 18.2;
d) insulation resistance test (see 18.3);
e) voltage test (see 18.4);
f) protection against residual voltage (see 18.5);
g) verification that the relevant requirements of 8.2.6 are met;
h) functional tests (see 18.6).

Figure 1 – Excerpt from EN60204-1:2018, Chapter 18.1

The mapping between the headlines from the standard and the requirement ID used in this document is listed in Table 2.

Requirement headline	EN60204-1 Chapter 18.1	EN60204-1 Chapter	Requirement ID
Verification that the electrical equipment complies with its technical documentation	A	n/a	A1
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	B	18.2.2 – Test #1	A2
Verification of conditions for protection by automatic disconnection of supply	C	18.2	A3
Insulation resistance tests	D	18.3	A4
Voltage tests	E	18.4	A5
Protection against residual voltages	F	18.5	A6
Verification that the relevant requirements of 8.2.6 are met	G	8.2.6	A7

Table 2 – Requirement headlines, chapter, and ID mapping

Functional testing of the equipment is outside the scope of this document.

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Megablock		Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

8. Test Equipment.

Test Equipment	Ballard Equipment ID	Calibration valid until:

9. Device Under Test

The device to be tested is the coolant skid for the Megablock project. A rendering is shown below with selected items highlighted.

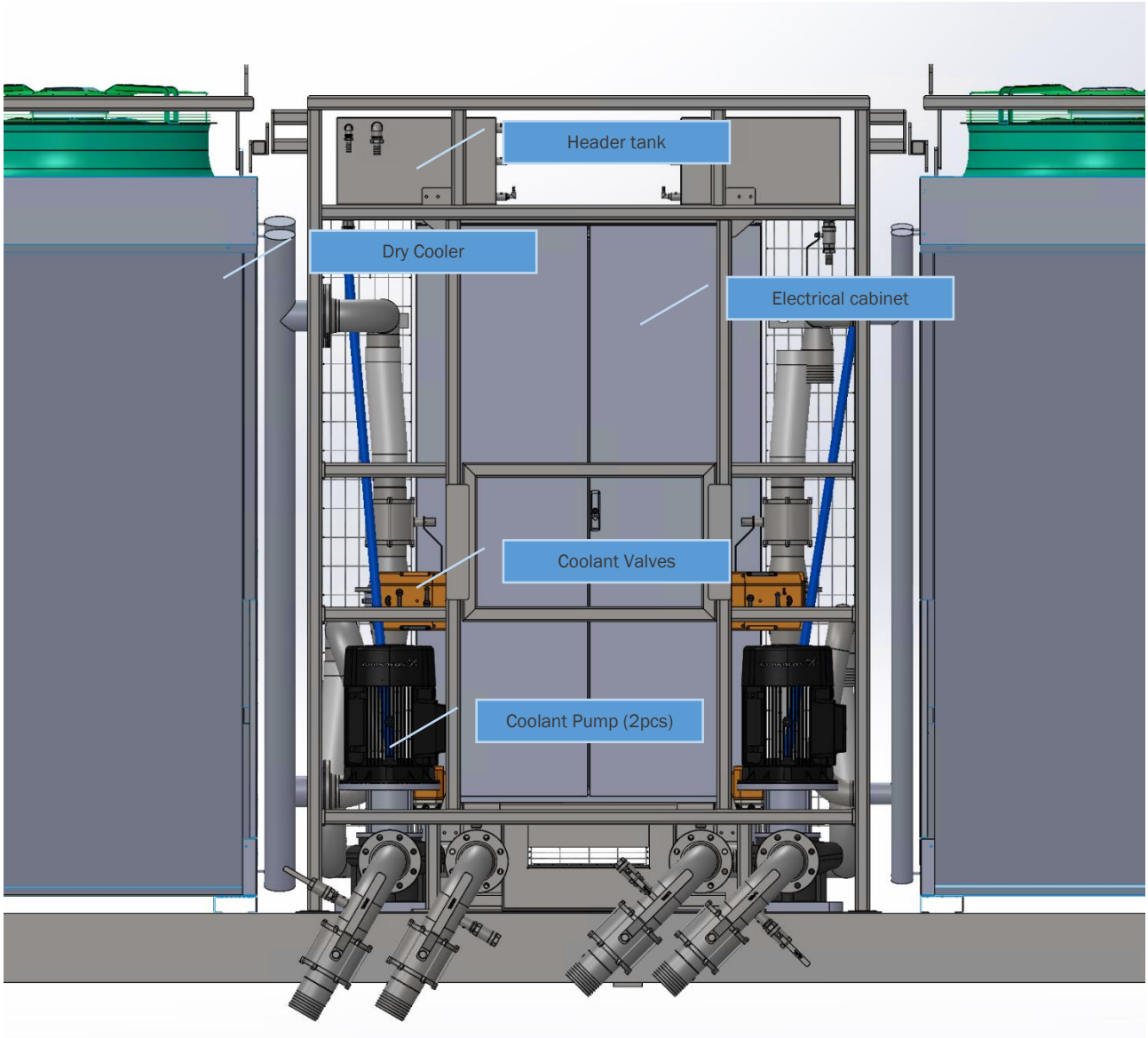


Figure 2 – Front view of coolant skid centre section with callouts.

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Megablock		Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

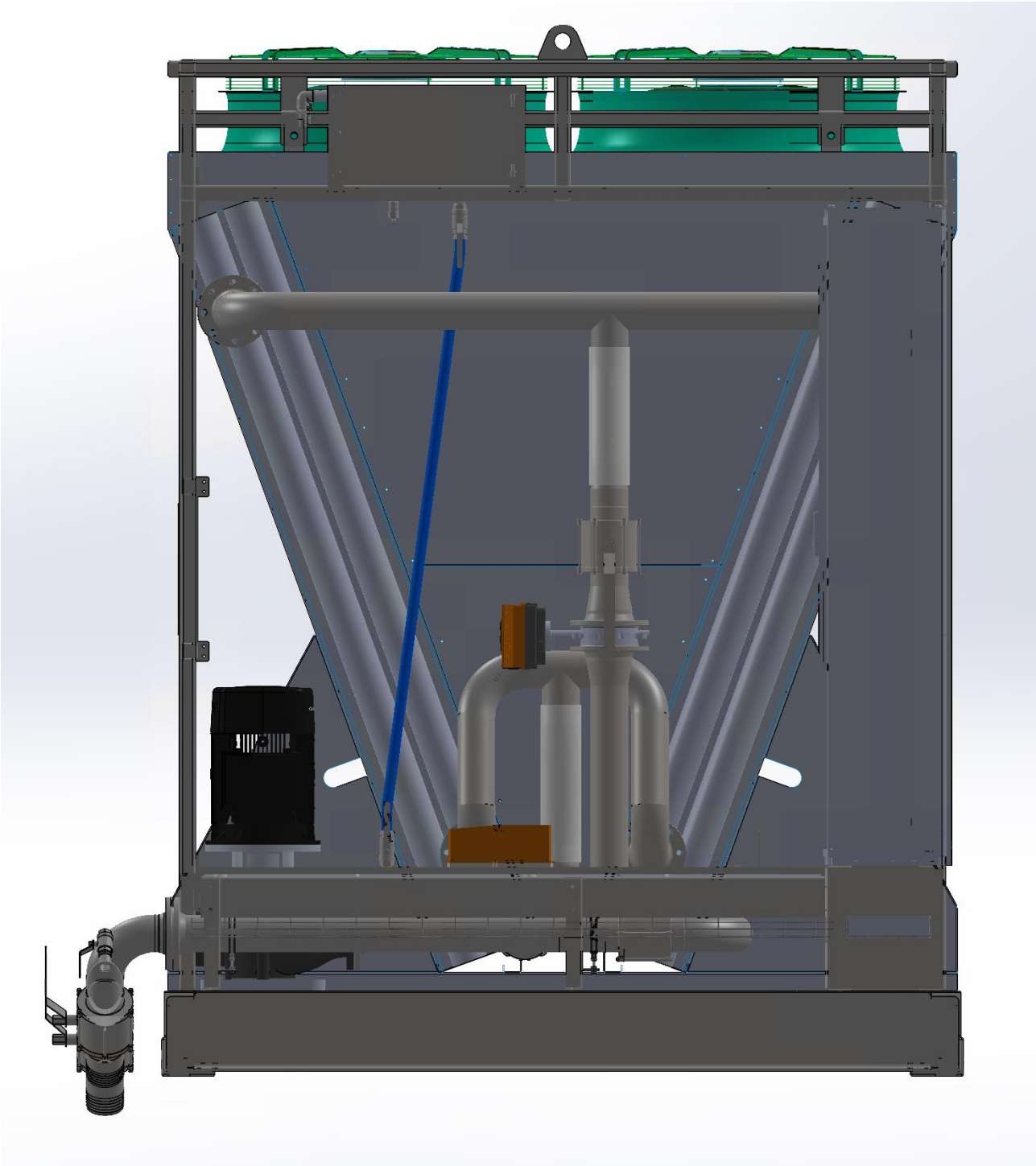


Figure 3 – Section view of the coolant skid, looking from centre towards left.

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Megablock		Electrical Safety Checklist	
Document type	*Author*	*Revision date*	*Revision*
Test Specification	RKN	09-01-2025	3.0.0

10. A1 – Verification that the electrical equipment complies with its technical documentation

EN60204-1 requirements:

a) verification that the electrical equipment complies with its technical documentation;

Figure 4 – EN60204-1:2018, Chapter 18.1

Megablock Component requirements:

Inspection of the electrical equipment and cabinets to ensure congruence between documentation and equipment/cabinet.

Megablock Component validation:

Component	Coolant Skid
Result (pass/fail)	
Date and Initials	

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11. A2 – Verification of continuity of the protective bonding circuit

EN60204-1 requirements:

18.2.2 Test 1 – Verification of the continuity of the protective bonding circuit

The resistance between the PE terminal (see 5.2 and Figure 4) and relevant points that are part of the protective bonding circuit shall be measured with a current between at least 0,2 A and approximately 10 A derived from an electrically separated supply source (for example SELV, see 414 of IEC 60364-4-41:2005) having a maximum no-load voltage of 24 V AC or DC.

The resistance measured shall be in the expected range according to the length, the cross sectional area and the material of the related protective conductors and protective bonding conductor(s).

Earthed PELV supplies can produce misleading results in this test and therefore shall not be used.

Figure 5 – EN60204-1:2018, Chapter 18.2.2

Megablock Component requirements:

The EN60204-1 Chapter 18.2.2, Test #1 specifies a current of 10A.

Megablock Component bonding resistance test is performed with a current of 10A and a test period of 10 seconds.

Megablock Component validation:

The primary earthing point for the coolant skid is the main ground terminal in the control enclosure.

Each component is verified and compared to expected values for the following locations.

ID	Test Point	Expected Value	Recorded Value
1	Control Cabinet Backplate	<100mΩ	
2	Grounding Bar, Below PLC		
3	HT1 Cooling Pipe, From HT1 Cooler		
4	HT1 Manual Valve, HT1 Cooler Outlet		
5	HT1 Coolant Pump, Grounding Connection		
6	HT1 Header Tank, Bolts		
7	HT1 Cooler Frame (Metal)		
8	HT2 Cooling Pipe, From HT1 Cooler		
9	HT2 Manual Valve, HT1 Cooler Outlet		
10	HT2 Coolant Pump, Grounding Connection		

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11	HT2 Header Tank, Bolts		
12	HT2 Cooler Frame (Metal)		

Table 3 – Bonding Resistance Test point and expected resistance values.

When performing the test, ensure the connection between the test leads and the equipment is not contributing to inaccurate measurements.

Notes to test points:

- Point 1-2 is inside the electrical cabinet.
- Point 3-6 is indicated on Figure 6 – Test points for Grounding Test
- Point 7-12 are identical to points 3-6, except mirrored to HT2.

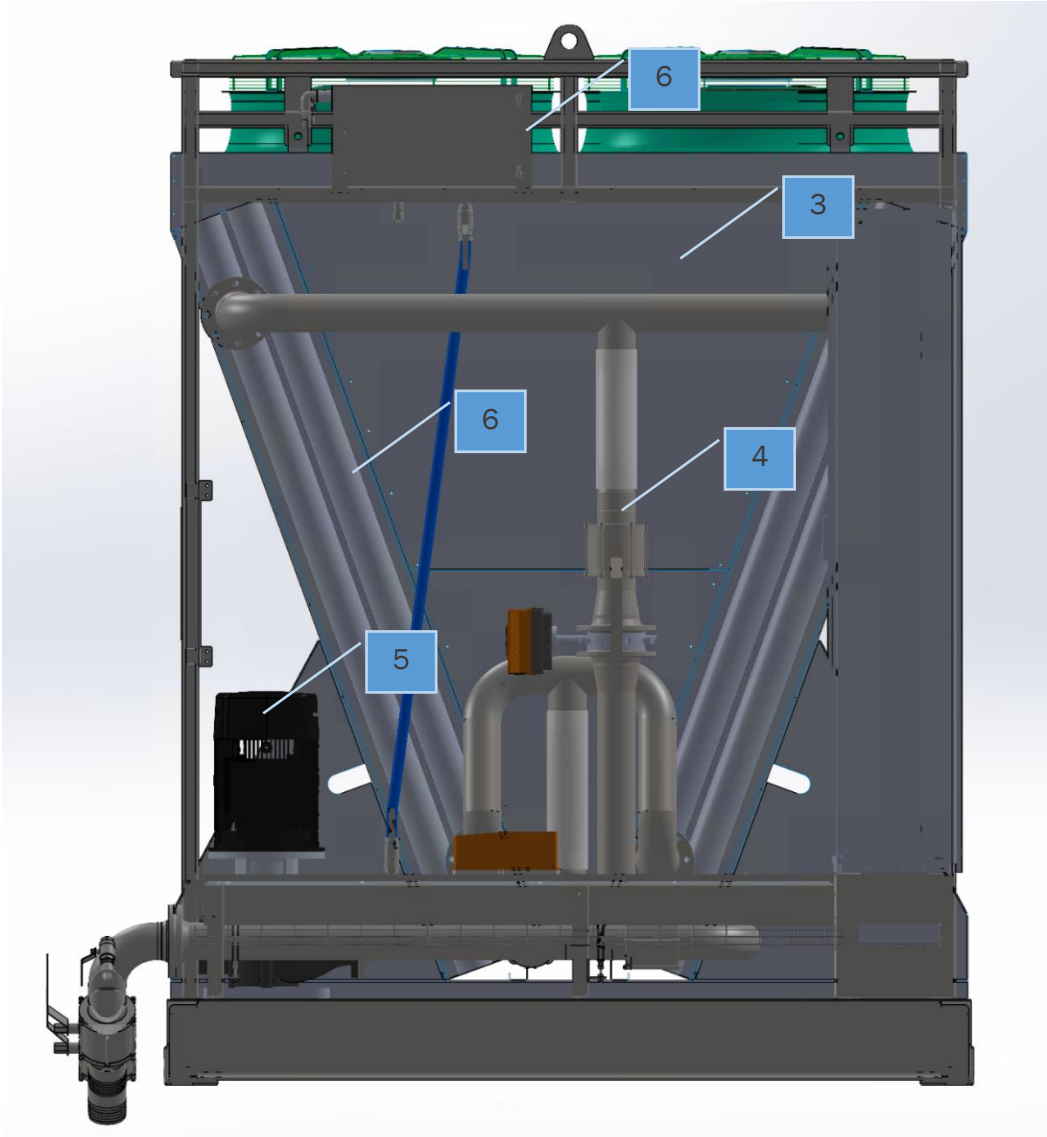


Figure 6 – Test points for Grounding Test

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12. A3 - Verification of conditions for protection by automatic disconnection of supply

EN60204-1 requirements:

18.2 Verification of conditions for protection by automatic disconnection of supply

18.2.1 General

The conditions for automatic disconnection of supply (see 6.3.3) shall be verified by tests.

Test 1 verifies the continuity of the protective bonding circuit.

Figure 7 – EN60204-1:2018, Chapter 18.2

Megablock Component requirements:

As specified in chapter 18.2.1, Test #1 is performed (see section 11). Chapter 18.2.1 further specifies testing of Residual Current Devices (RCD) according to manufacturer specifications. Megablock Component module does not contain any RCD devices.

Megablock Component is not a TN-system, and Test #2 is not relevant.

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13. A4 - Insulation resistance tests

EN60204-1 requirements:

18.3 Insulation resistance tests

When insulation resistance tests are performed, the insulation resistance measured at 500 V DC between the power circuit conductors and the protective bonding circuit shall be not less than 1 MΩ. The test may be made on individual sections of the complete electrical installation.

Figure 8 – EN60204-1:2018, Chapter 18.3

Megablock Component requirements:

The Megablock Component insulation requirements are higher than as specified chapter 18.3. The test is specified in Table 4):

Test point	Pass criteria	Test Voltage [VDC]
UC40-FC04	>1MΩ	500

Table 4 – Megablock Component Power Circuit Insulation Resistance Requirements

Megablock Component validation:

Each component is verified and compared to pass criteria in Table 4.

Component	Coolant Skid
Result – AC Node (value and pass/fail)	
Date and Initials	

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14. A5 – Voltage tests

EN60204-1 requirements:

18.4 Voltage tests

When voltage tests are performed, test equipment in accordance with IEC 61180-2 should be used.

The test voltage shall be at a nominal frequency of 50 Hz or 60 Hz.

The maximum test voltage shall have a value of twice the rated supply voltage of the equipment or 1 000 V, whichever is the greater. The maximum test voltage shall be applied between the power circuit conductors and the protective bonding circuit for at least 1 s. The requirements are satisfied if no disruptive discharge occurs.

Components and devices that are not rated to withstand the test voltage and surge protection devices which are likely to operate during the test shall be disconnected during testing.

Components and devices that have been voltage tested in accordance with their product standards may be disconnected during testing.

Figure 9 – EN60204-1:2018, Chapter 18.4

Megablock Component requirements:

The requirements from EN 60204-1:2018, Chapter 18.4 is compared in Table 5.
AC Voltage for Megablock Components is at most 480V, so twice the supply voltage is 960Vac.

Parameter	EN 60204-1:2018, Chapter 18.4	Megablock Component Testing
Voltage [VAC]	960	2500
Frequency [Hz]	50 or 60	50
Duration [sec]	1	10
Maximum Current [mA]	No arcing	5

Table 5 – Voltage Test Requirements

Megablock Component validation:

Component	Coolant Skid
Voltage Test – L1 (value and pass/fail)	
Voltage Test – L2 (value and pass/fail)	
Voltage Test – L3 (value and pass/fail)	
Date and Initials	

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15. A6 – Protection against residual voltages

EN60204-1 requirements:

18.5 Protection against residual voltages

Where appropriate, tests shall be performed to ensure compliance with 6.2.4.

Figure 10 – EN60204-1:2018, Chapter 18.5

6.2.4 Protection against residual voltages

Live parts having a residual voltage greater than 60 V when the supply is disconnected shall be discharged to 60 V or less within a time period of 5 s provided that this rate of discharge does not interfere with the proper functioning of the equipment. Exempted from this requirement are components having a stored charge of 60 μC or less. Where this specified rate of discharge would interfere with the proper functioning of the equipment, a durable warning notice drawing attention to the hazard and stating the delay required before the enclosure may be opened shall be displayed at an easily visible location on or immediately adjacent to the enclosure that contains the live parts.

In the case of plugs or similar devices, the withdrawal of which results in the exposure of conductors (for example pins), the discharge time to 60 V shall not exceed 1 s, otherwise such conductors shall be protected to at least IP2X or IPXXB. If neither a discharge time of 1 s nor a protection of at least IP2X or IPXXB can be achieved (for example in the case of removable collectors on conductor wires, conductor bars, or slip-ring assemblies, see 12.7.4), additional switching devices or an appropriate warning, for example a warning sign drawing attention to the hazard and stating the delay required shall be provided. When the equipment is located in places open to all persons, which can include children, warnings are not sufficient and therefore a minimum degree of protection against contact with live parts to IP4X or IPXXD is required.

Figure 11 – EN60204-1:2018, Chapter 6.2.4

Megablock Component requirements:

Identical to EN60204-1 requirements.

Megablock Component validation:

No live parts of the Megablock Component system are accessible without disassembling barriers. All connectors are IP2X or higher in unmated state in applications higher than 60V (power system)

Frequency converters and motor drives are marked with applicable durations before internal capacitors are discharged.

Maintenance procedures for the Megablock Component module include a voltage drawdown process and manual verification before any work on exposed components is permitted.

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16. A7 – Verification that the relevant requirements of 8.2.6 are met

EN60204-1 requirements:

8.2.6 Additional requirements for electrical equipment having earth leakage currents higher than 10 mA

Where electrical equipment has an earth leakage current that is greater than 10 mA AC or DC in any protective conductor, one or more of the following conditions for the integrity of each section of the associated protective bonding circuit that carries the earth leakage current shall be satisfied:

a) the protective conductor is completely enclosed within electrical equipment enclosures or otherwise protected throughout its length against mechanical damage;

b) the protective conductor has a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al;

c) where the protective conductor has a cross-sectional area of less than 10 mm^2 Cu or 16 mm^2 Al, a second protective conductor of at least the same cross-sectional area is provided up to a point where the protective conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al. This can require that the electrical equipment has a separate terminal for a second protective conductor.

d) the supply is automatically disconnected in case of loss of continuity of the protective conductor;

e) where a plug-socket combination is used, an industrial connector in accordance with IEC 60309 series, with adequate strain relief and a minimum protective earthing conductor cross-section of 2,5 mm^2 as part of a multi-conductor power cable is provided.

A statement shall be given in the instructions for installation that the equipment shall be installed as described in this 8.2.6.

Figure 12 – EN60204-1:2018, Chapter 8.2.6

Megablock Component requirements:

The Megablock Component does not have a leakage current higher than 10mA.

Megablock Component validation:

The protection against excessive leakage current is twofold:

- Ground fault detection is in the scope of the 10ft Container (DCAC system)
- Conductivity measurement of internal coolant is a part of the regular maintenance procedures (see N01-003 Service and Maintenance Manual)

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17. Summary Table

The requirements from sections 10 to 16, together with results are summarized below in Table 6:

Requirement headline	EN60204-1 Chapter	Req ID	Pass/Fail?
Verification that the electrical equipment complies with its technical documentation	n/a	A1	
Verification of continuity of the protective bonding circuit (Test 1 of 18.2.2)	18.2.2 – Test #1	A2	
Verification of conditions for protection by automatic disconnection of supply	18.2	A3	
Insulation resistance tests	18.3	A4	
Voltage tests	18.4	A5	
Protection against residual voltages	18.5	A6	
Verification that the relevant requirements of 8.2.6 are met	8.2.6	A7	

Table 6 – Summary Table

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Short Title	Thermographic - Cooling and Ventilation Test Procedure
Full Title	Thermographic - Cooling and Ventilation Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for validating cooling and ventilation are performing correct.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
1	Initial Draft	RKN	01-02-2024
2	Updated	TAN	08-08-2024
3	Updated procedure	RKN	15-11-2024

Checked by: RKN	Date: 15/11-2024
Approved by: RKN	Date: 15/11-2024

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4.3 Measurement locations 6
4.4 Conducting measurements 6
5.0 Appendix 6

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Abrevassion	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module

1.0 Objectives and background

The objectives of this test procedure is to demonstrate the performance of ventilation and cooling on full system solution. The thermographic inspection will be conducted around solution as well as inside where service staff can enter while system stays operational.

- Ensure ventilation system performing as expected.
- Ensure cooling system is performing as expected.
- Validate accessible surface temperatures.

2.0 References

Document	Titel

3.0 Equipment list

Equipment	Purpose
Thermographic imager	Measure temperatures, capture images and create data folder with evidence.

4.0 Test Procedure

4.1 Personal protective equipment

Before commencing the test procedure always analyze the work environment and make sure you take the right precautions.

Suggested PPE depending on solution and work environment:

- Safety shoes
- Goggles
- Hearing protection

4.2 Preparation

- Verify equipment is calibrated and withing valid calibration period.
- Identify how and where to measure the ventilation system.
    - Access to areas that are normally accessible during operation to sweep for hot surfaces.
- Identify how and where to measure the cooling system.
    - It should be possible to view majority of cooling skid to check temperature distribution.
        - If this is not possible, review need for additional equipment during measurements
- Identify possible hot surfaces to be inspected.

4.3 Measurement locations

- Inside solution:
  - Ventilation of components
  - Container ventilation
  - Surface temperatures
  - Cooling circuit
- Outside solution:
  - Container ventilation
  - Surface temperatures
  - Coolers and cooling circuit

4.4 Conducting measurements

Set the Megablock to full power (1000 kW) and wait until temperatures have stabilised. Monitor the containers and ventilation described in section 4.3 through the thermographic imager and take pictures of all relevant areas with elevated temperatures. File in the pictures in a report.

5.0 Appendix

(intentionally left blank)

Short Title	Cooling Circuit Pressure and Leak Test Procedure
Full Title	Cooling Circuit Pressure and Leak Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for validating cooling circuits are leak free and can withstand normal operating pressure.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
1	Initial Draft	RKN	01-02-2024
2	Updated specification	RKN	15-11-2024

Checked by: RKN	Date: 15/11-2024
Approved by: RKN	Date: 15/112024

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Abrevassion	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module

1.0 Objectives and background

The objective with this test procedure is to generalise how cooling circuits are leak free and pressure tested.

2.0 References

Document	Titel

3.0 Equipment list

Equipment	Purpose
Pressure gauge	Monitor pressure

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4.0 Test Procedure

The main purpose of this test procedure is to ensure that the cooling circuit is leak free and can handle maximum system pressure. Furthermore, it is structured in a way to minimize the chance of having big leaks or lose clamps or fittings.

WARNING: The stress test is with elevated pressure, potentially turning plugs or loose fittings into projectiles.

Minimum safety precautions:

- Hose clamps and fittings
- Wear safety goggles
- When dealing with glycol wear gloves
- Check service manual for maximum system pressure.

4.1 Pre-conditioning

- Check and make sure valves in the cooling circuit are in the correct position.
- For pressure testing with coolant in the cooling circuit, make sure the system is fully bleed. Air in the system can act as a spring and can obscure results.
- To achieve stable temperature let system soak for 12 hours. Alternative watch data from temperature sensors in the full system to ensure stable temperature conditions.

4.2 Leak test with air

- Maximum system pressure on Megablock is 1.5barg.
- No temperature pre-conditioning needed; this is not a sign off test.
- Find compressor and leak test kit.
- Adjust pressure reduction valve to minimum (no pressure after reduction valve)
- Attach leak test kit to cooling circuit (not applying pressure to circuit)
- Open valve from compressed air
- Slowly increase pressure from reduction valve to 20% of maximum system pressure (0.3barg)
- Close valve from compressed air
    - If pressure is not maintained
        - Open valve from compressed air again and look for leaks (where surface material is suitable soapy water spray can be used for leak detection)
        - Fix leak and repeat step.
    - If pressure is maintained
        - Continue to next step.
- Open valve from compressed air
- Slowly increase pressure from reduction valve to 80% of maximum system pressure (1.2barg)
- Close valve from compressed air
    - If pressure is not maintained
        - Open valve from compressed air again and look for leaks (where surface material is suitable soapy water spray can be used for leak detection)
        - Fix leak and repeat step.
    - If pressure is maintained
        - Continue to next step.
- Open valve from compressed air
- Slowly increase pressure from reduction valve to 100% of maximum system pressure (1.5barg)
- Close valve from compressed air
    - If pressure is not maintained
        - Open valve from compressed air again and look for leaks (where surface material is suitable soapy water spray can be used for leak detection)
        - Fix leak and repeat step.
    - If pressure is maintained – test completed and passed.

4.3 Leak test with air setup

Compressor and adaptor hose to be connected. Close valve to expansion tank so that pressure can build in cooling circuit. Find test setup image in appendix.

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4.4 Pressure decay test with coolant

- Maximum system pressure on Megablock is 1.5 barg.
- Make sure cooling circuit have been filled and bled before starting this test.
- Make sure pre-conditioning have been done.
- Find coolant pressure test kit.
- Attach test kit to cooling circuit (not applying pressure to circuit)
- Slowly increase pressure 50% of maximum system pressure (0.75barg)
- Close valve from test kit.
    - Quick inspection of cooling circuit for any coolant leaks.
    - If pressure is not maintained
        - Further inspection of test setup and cooling circuit
            - If there is still air in the system if can cause spring effect and drop in pressure
        - Found and fixed issue, repeat step.
    - If pressure is maintained
        - Continue to next step.
- Open valve from test kit
- Slowly increase pressure to 100% of maximum system pressure (1.5barg)
- Close valve from test kit
    - Quick inspection of cooling circuit for any coolant leaks.
    - If pressure is not maintained
        - Further inspection of test setup and cooling circuit
            - If there is still air in the system if can cause spring effect and drop in pressure
        - Found and fixed issue, repeat step.
    - If pressure is maintained
        - Continue to next step.
- Wait 30 minutes if pressure have dropped re-apply pressure to reach 100% system pressure again.
- Wait 2 hours and check pressure again.
    - If pressure have dropped more than 0.1bar
        - Repeat test
    - If pressure have dropped less than 0.1bar after 2 hours – test completed and passed.

4.5 Pressure decay test with coolant setup

Pressure pump and adaptor hose to be connected. Close valve to expansion tank so that pressure can build in cooling circuit. Find test setup image in appendix.

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5.0 Results and discussion

6.0 Appendix

6.1 Cooling leakage HT1 (Suggested section for FAT or SAT document)

6.1.1 Test

Follow designated test procedure for inspection and verification of a leak-free HT1 coolant circuit.

6.1.2 Relevant Standard / document

- SPC ID 0103 Cooling Circuit Pressure and Leak Test Procedure

6.1.3 Brief Test Plan

- Follow test procedure.

6.1.4 Pass/Fail criteria.

- Allow system to maintain pressure, after 2 hours pressure must not drop more than 0,1 bar.

6.1.5 Test Result

Table 1: Cooling leakage HT1 - Test Result

Date tested	Item	Result	Pass/Fail	Notes
	HT 1			

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6.2 Pressure decay test with coolant

Pressure pump and adaptor hose to connect and pressurise.



6.3 Leak test with air

Compressor and pressure test adaptor hose.



Short Title	H2 Leak Test Procedure
Full Title	H2 Leak Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for validating H2 circuits are within allowed limits and can withstand normal operating pressure.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
-	Initial Draft	RKN	13-05-2024
001	Release		
002	Procedure update	TAN	28-08-2024

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1.0 Definitions

Abbreviation	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module
SME	Subject Matter Expert
PPE	Personal Protective Equipment
DUT	Device under test

2.0 Objectives and Background

The purpose of this test procedure is to generalise how Ballard Product Solutions secure that the fabricated hydrogen systems are not leaking more than the specified limits and the circuits will withstand maximum operation pressure. Furthermore, this procedure is intended to be used on full systems and/or sub assemblies. This test procedure is based on *IEC 62282-3-1 section 5.4 Leakage tests and 5.4.1 Gas leakage tests* with regards to system tests. For hydrogen pipework testing, the IEC 62282-3-1 references *ISO 15649:2001 "Petroleum and natural gas industries – Piping* which states that piping shall be tested according to *ASME B31.12 Hydrogen piping and pipelines.* Hence, the described procedure for component/pipework inspection and leakage test is based on this standard.

3.0 References

Document	Titel
IEC 62282-3-1:2019	Fuel cell technologies - Part 3-1: Stationary fuel cell power systems - Safety
ASME B31.12-2023	Hydrogen piping and pipelines
SPC ID 0202	Snooper mini H2 sniffing procedure
SPC ID 0203	Pipework inspection and leakage test check sheet template
SPC ID 0204	System pressure decay test template

4.0 Equipment list

Equipment	Type	Purpose
H2 sniffer	Sewerin Snooper Mini H2	Detection instrument to snif/locate source of potential leaks
Pressure sensor	Fluke 700RG07 500PSIG	Measuring device to accurately adjust and monitor gas pressure during leakage test
Test gas	Formier gas 5% hydrogen	Test gas for pressurizing pipework where the 5% hydrogen acts as tracer agent for sniffing.
Sniffer test station	Sewerin SPE-HG	Test instrument the emits a reference gas to check the correct function of the Snooper Mini H2 sniffer
Pressure regulator		Test gas pressure regulator for pressurizing the DUT
Pressure relief valve		Safety valve to ensure safe pipework pressurization during test.

5.0 Test Procedures

Any system is comprised of several subassemblies and/or components. Any of these subsystems must be individually inspected and leakage tested before assembly into the complete system. For systems fabricated or assembled by Ballard Product Solutions, testing per section 5.4 applies. Externally delivered systems/modules as well as Ballard standard products must be tested in accordance with *IEC 62282-3-1:2019* or similar industry relevant standards.

Attention: All test personnel, including external witness should be informed about risks associated with the test and instructed to use proper PPE prior to conducting the test.

WARNING: Pressure testing can potentially turn plugs or loose fittings into projectiles.

Minimum safety precautions:

- The test must be carried out by trained personnel.
- Prior to test start make sure that the work has been HSE risk assessed according to Ballard internal procedures.
- All connection and mechanical assemblies shall be checked before applying pressure.
- All personnel attending the test shall use appropriate PPE.

5.1 Installations and connections

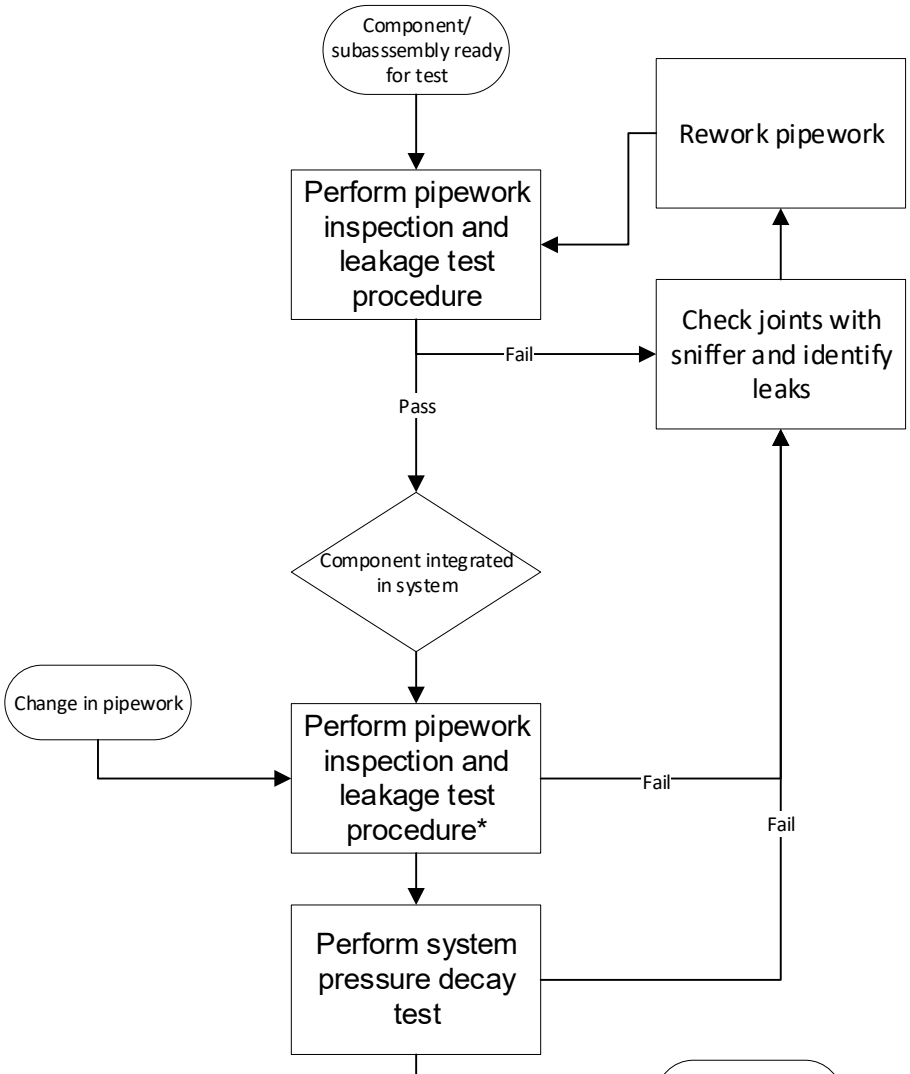
Make sure that all parts of the hydrogen system have been correctly assembled and according to assembly guides and build manuals.

5.2 Review test setup.

Before proceeding to testing, the test setup should be reviewed by a SME. The SME should also determine the pressure of which the system under test will be tested to. Once a setup has been reviewed and approved re-testing can proceed on same approval if the setup remains unchanged. If a diagram of the system under test does not exist create a diagram like the one in appendix. The results from the test should be added on the diagram and saved as part of the test report. During the review a risk assessment should be done and shared with all staff involved with testing and working in proximity to an ongoing test. Make sure that relevant measurement instruments, used during the test all have valid calibration certificates if applicable. Furthermore, ensure that manufacturers procedures are followed for maintaining the equipment accuracy and dependability.

5.3 System test sequence

On any system the following test sequence must be followed during first assembly or reassembly of a system.



* Only for changed/interfacing joints

5.4 Pipework inspection and leakage test

The pipework inspection and leakage test are performed to ensure proper assembly quality is achieved during fabrication and assembly of components/subassemblies. The test is designed to be performed upon work completion in the assembly plant/workshop before release to system assembly.

The test is performed in accordance with or exceeding requirements in *ASME B31.12 Hydrogen piping and pipelines*.

The associated template for documenting the test must be used: *SPC ID 0203 Pipework inspection and leakage test check sheet* template

5.4.1 Test setup

The assembled component or subassembly pipe ends are appropriately sealed off and the pressure regulator with formier gas supply is connected, together with a pressure gauge and appropriate pressure relief valve.

Use of the H2 sniffer instrument must be performed in accordance with *SPC ID 0202 Snooper mini H2 sniffing procedure.*

5.4.2 Test sequence

1. Check for proper functionality of the sniffing tool by using the sniffer test station
2. Inspect the pipework visually for any damage or loose parts
    a. For ferrule fittings, check every fitting with appropriate gap inspection gauge to ensure sufficient tightening is achieved
3. Pressurize pipework to between 1.0-1.2 barg with formier gas and listen for leaks
4. Increase pressure to 50% of test pressure by adjusting the pressure regulator
5. Maintain the pressure for 10 minutes.
6. Listen for leaks and use H2 sniffer to inspect all joints. If leaks are identified record all positions and values in the check sheet, abort test by proceeding to item 10 and file the pipework for rework.
7. If no leaks are detected, proceed to increase pressure to “test pressure” by adjusting the pressure regulator.
8. Maintain the pressure for minimum 10 minutes.
9. Listen for leaks and use the H2 sniffer to inspect all joints. Record all leak positions and values in the check sheet.
10. Blow down system, disconnect test gas supply and secure pipe ends.
11. Check for proper functionality of the sniffing tool by using the sniffer test station.
12. For identified leaks file the pipework for rework.
13. For joints that pass the procedure, a suitable marking must be applied to identify that the joint is verified.
14. If all joints are accepted, sign and file the check sheet.

If leaks are identified during the procedure, the test sequence must be performed again on reworked pipework.

5.4.1 Test evaluation

Each joint of the DUT is subject to the following test pass criteria:

Inspection element	Pass criteria
Visual inspection	No visible damage, incorrect assembly or misplacement of the joint. No dirt, lubricants or foreign materials left on the joint No indication of excessive use of force No indication of incorrect use of tools to assemble the joint.
Auditory inspection	No hearable leaks unless allowed by the particular joint.
Gauge inspection (where applicable)	According to gauge tool instruction.
Sniffing	According to acceptable leakage rate of a particular joint + measurement uncertainty of the sniffer (see SPC ID 0202) To be referenced from the ATEX documentation/design manual and recorded in the check sheet.

5.5 System pressure decay test

The system pressure decay test is performed to validate integrity of pipework and instrumentation of the complete H2 system. The test is performed in accordance with *IEC 62282-3-100:2020 section 6.2: Leakage test.*

5.5.1 Test setup

The system pressure decay test may only be performed if all subassemblies have been validated with the procedure described in section 5.4 or equivalent (for externally delivered subassemblies).

The test is performed using the regular fuel supply of the system at test pressure level.

If appropriate, the test may be isolated and divided into appropriate sections to allow for separate validation of individual pipe sections.

To ensure that the validation of the integrity of the pipework is sound, a measurement system analysis must be performed. The accuracy of the equipment, used to measure the necessary variables of the test must contribute to a measuring error of no more than 2% of the allowable leak rate in the system.

The associated template for documenting the test must be used: *SPC ID 0204 System pressure decay test template*

5.5.2 Test parameters

To properly validate the pipework system, the following variables are used. Variables are either universal constants, calculated values, system design values or measured values:

Variable	Name	Unit	Description
P_ops	Max operating pressure	barg	As defined by manufacturer spec
P_d	Design pressure	barg	Highest pressure that may occur under any and all operating modes, including steady state and transient.
P_t	Test pressure	barg	110% of design pressure
P_PRV	Relief pressure of relief valve	barg.	Test setup PRV
L_A	Max evaluated leak rate for pipework system acceptance	Nm^3/h	Maximum allowed pressure decay to pass pressure decay test
L_S	Expected leak rate for pipework system	Nm^3/h	Summarized expected leak rates of all components in the system (per design leak rate). The leak rates may be obtained from component category values or from actual measured leak rates during acceptance testing of the component.
L_C	Max allowed leak rate zone integrity (Critical leak level)	Nm^3/h	Maximum allowed leak rate for a given pipe section, where integrity/operability of the system may be maintained safely

Variable	Name	Unit	Description
L_Mu	Measuring system uncertainty	Nm^3/h	Calculated accuracy of the measuring system, used to perform the test. The MSA must consider the complete signal path of sensors and control system.
L1	Actual leak rate	Nm^3/h	Calculated gas leakage rate from the tested system by performing the pressure decay test
V	Internal space volume	m^3	Calculated Internal space volume within the pressurized section (m^3) (gas volume excepting the internal structure volume) Internal pipework space volume must be obtained from the system design team as a value for any of the relevant sections.
T0	Reference temperature	K	Theoretical reference temperature (288.15K)
T1	internal space temperature start	K	Measured internal space temperature at the beginning of measurement
T2	internal space temperature end	K	Measured internal space temperature at the end of measurement
P0	Absolute reference pressure	kPa	Theoretical reference pressure (1 atm) (101.325 kPa)
P1	Internal space pressure start	kPag	Measured internal space pressure at the beginning of measurement
P2	Internal space pressure end	kPag	Measured space pressure at the end of the measurement
Pa1	Absolute pressure start	kPag	Measured atmospheric pressure at the beginning of the measurement
Pa2	Absolute pressure end	kPag	Measured atmospheric pressure at the end of the measurement (kPa)
t	Test duration	min	Measured test duration (t_end – t_start)

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5.5.3 Sequence

If at any point the system pressure is dropping, investigate leak before continuing testing.

1. Introduce hydrogen to the system by increasing gradually the inlet pressure until test pressure level is reached in the system.
2. Close the relevant inlet valve, isolating pressure supply from the system under test.
3. Let the pressure in the system settle for 2 minutes.
4. Start the pressure decay monitoring by recording
   -start time t_start
   -start internal space pressure P1
   -start atmospheric pressure Pa1
   -start temperature T1
5. Wait for 10 minutes
6. Finish the pressure decay monitoring by recording
   -end time t_end
   -end internal space pressure P2
   -end atmospheric pressure Pa2
   -end temperature T2
7. Calculate the leak rate L1
8. Blow down system or continue operation if test is successful.

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5.5.4 Test evaluation

The actual leakage rate from the system is calculated in accordance with *IEC 62282-3-100:2019. Section 6.2* from the pressure difference in the system, measured over time using the following formula, and with variables as described in section 5.5.2:

$$L_1 = V \times T_0/p_0 \times \{(p_1 + p_{a1})/(T_1) - (p_2 + p_{a2})/(T_2)\} \times 60/t$$

The allowable leakage rate of the system is a function of the allowable leak rates of each component in the system and the uncertainty of the measurement system itself.

The expected leakage rate of components/subassemblies may vary from system to system and may be comprised of a mix of maximum allowed leak rates, obtained from the system's *ATEX zone classification and pipework plan* or expected leakage rates obtained from actual measured values in component acceptance tests.

The measurement system must be evaluated (MSA) to estimate the measurement uncertainty (L_Mu). The measuring system can only be considered sound if the calculated uncertainty amounts to less than 2% of the critical leak rate (L_C).

The test pass criteria threshold is calculated as the allowable/expected leak rate of the system + the measurement uncertainty:

$$L_A = L_S + L_Mu$$

System will pass the pressure decay test under the following criteria:

$$L_1 < L_A$$

6.0 Appendix

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Short Title	Thermographic - Electrical Test Procedure
Full Title	Thermographic - Electrical Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for validating electrical cabinets and installation are performing correct.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
1	Initial Draft	RKN	01-02-2024
2	Updated	TAN	09-08-2024

Checked by: TAN	Date: 9/8-2024
Approved by: TAN	Date: 9/8-2024

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Figure 2 Test pressure set up with principle of attachments. ..... **Error! Bookmark not defined.**

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Abrevassion	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module

1.1 References

Document	Titel

2.0 Objectives and Background

The objectives of this test procedure are to demonstrate the performance of the electrical parts on full system solution. The thermographic inspection will be conducted around solution as well as inside where service staff can enter while system stays operational.

3.0 Test Procedure

3.1 Personal protective equipment

Before commencing the test procedure always analyze the work environment and make sure you take the right precautions.

Suggested PPE depending on solution and work environment:

- Safety shoes
- Goggles
- Hearing protection

3.2 Preparation

- Verify equipment is calibrated and withing valid calibration period.
- Identify how and where to measure the ventilation system.
- Identify how and where to measure the cooling system.
- Identify possible heat surfaces to be inspected.

3.3 Measurement locations

- Inside solution:
  - 40ft container
  - 10ft container
- Outside solution:
  - 40ft container
  - 10ft container
  - Cooling skid

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3.4 Conducting measurements

Set the Megablock to full power (1000 kW) and wait until temperatures have stabilised. Monitor the electrical cabinets and electrical installations described in section 3.3 through the thermographic imager and take pictures of all relevant areas with elevated temperatures. File in the pictures in a report.

4.0 Appendix

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Short Title	Noise Level Measurement Test Procedure
Full Title	Noise Level Measurement Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for measuring noise level inside and outside system. To validate work environment but also the noise emitted.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
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Abrevassion	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module

1.0 Objectives and Background

The objective of this test procedure is to determine the noise level generated by a full system solution. The measurements will be conducted around solution as well as inside where service staff can enter while system stays operational.

- Ensure compliance with noise regulations and safety standards.
- Evaluating the impact of the system noise to the surrounding environment.

2.0 References

Document	Titel
ISO 8528	Reciprocating internal combustion engine driven alternating current generating sets – Part 5: Generating sets

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3.0 Equipment list

Equipment	Purpose
Decibel meter	Measure noise level
Anemometer	Measure wind speed
Measuring tape	To measure up to 7 meter

4.0 Test Procedure

4.1 Personal protective equipment

Before commencing the test procedure always analyze the work environment and make sure you take the right precautions.

Suggested PPE depending on solution and work environment:

- Safety shoes
- Goggles
- Hearing protection

4.2 Preparation

- Verify equipment is calibrated and within valid calibration period.
- Identify the main noise sources inside and outside solution.
- Identify at which the operating points the solution will emit the most noise.
- Identify normal operating point for solution.

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4.3 Measurement locations

- Inside solution
  - Multiple measurements to capture the overall sound level within the work environment.
- Outside solution
  - 1-meter grid around solution
  - 7-meter grid around solution

4.4 Conducting measurements

- If decibel meter does have recording function:
  - Inside container measurement:
    - Measure maximum noise level at identified operating point in 5.2 and at location identified in 5.3. Measure for around 30 seconds to ensure a stable reading.
    - Noise level sweep:
      - Container running normal operating condition.
      - Start record noise level and walk from one end of the container to the other end.
      - Sweep should last around 20 seconds.
  - Outside container 1 meter:
    - Mark up the 1-meter perimeter around the container for example with a cone in each corner. If site does not allow 360 degree walk around at 1 meter while running, multiple recordings can be taken and compared to find maximum noise level.
    - System off (with noisy surroundings take a reference log)
    - Start recording the noise level, and slowly walk around the perimeter marked up.
    - Container running at most noise emitting point.
    - Start recording the noise level, and slowly walk around the perimeter marked up.
    - Analyze and find maximum noise level.

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- Outside container 7 meter:
  - Mark up the 7-meter perimeter around the container for example with a cone in each corner. If site does not allow 360-degree walk around at 7 meter while runnin0g, multiple recordings can be taken and compared to find maximum noise level.
  - System off (with noisy surroundings take a reference log)
  - Start recording the noise level, and slowly walk around the perimeter marked up.
  - Container running at most noise emitting point.
  - Start recording the noise level, and slowly walk around the perimeter marked up.
  - Analyze and find maximum noise level.

- If decibel meter does not have recording function:
  - Inside container measurement:
    - Measure maximum noise level. Measure for around 30 seconds to ensure a stable reading.
    - Noise level at 3 points in the container:

      Container running normal operating condition.

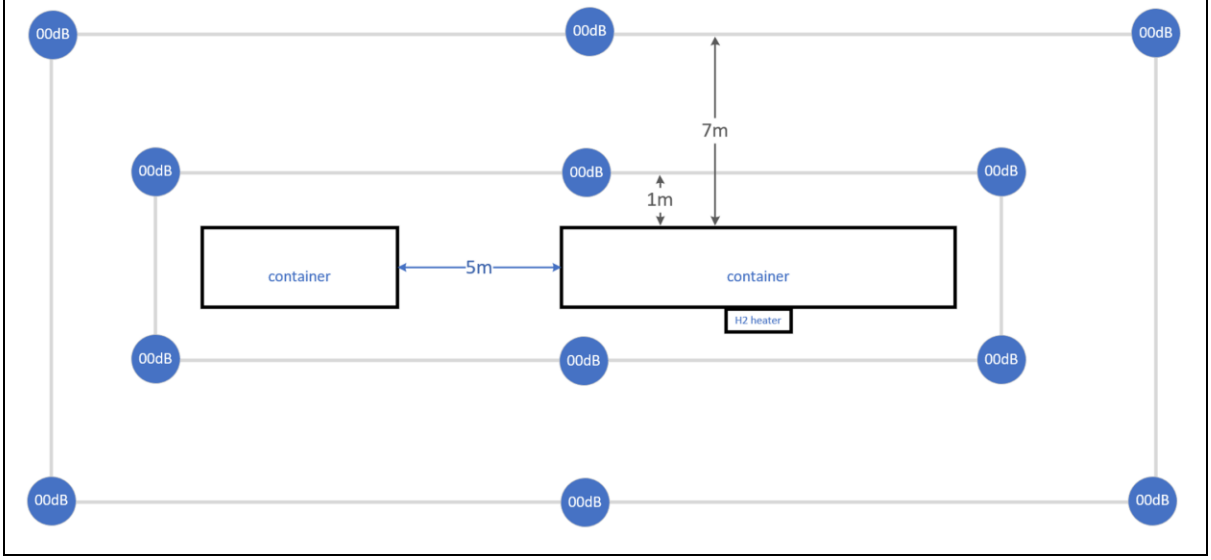
      - Measure noise level 1 meter from the one end of the container.
      - Measure noise in the mid point of the container.
      - Measure noise level 1 meter from the other end of the container.
  - Outside container 1 meter:
    - Mark up the 1-meter perimeter around the container for example with a cone in each corner. (If test setup does not allow full access complete as many points as possible)
    - System off (with noisy surroundings take a reference log)
    - Container running at most noise emitting point.
    - Start measuring the noise level, at each corner and in the mid point. Find reference map in appendix. And note down the noise level.
    - Analyze and find maximum noise level.

- Outside container 7 meter:
  - Mark up the 7-meter perimeter around the container for example with a cone in each corner. (If test setup does not allow access complete as many points as possible)
  - System off (with noisy surroundings take a reference log)
  - Container running at most noise emitting point.
  - Start measuring the noise level, at each corner and in the mid point. Find reference map in appendix. And note down the noise level.
  - Analyze and find maximum noise level.

5.0 Appendix

5.1 Reference map measurement grid

Figure 1: Reference map measurement grid



Short Title	Power Quality Measurement Test Procedure
Full Title	Power Quality Measurement Test Procedure
Abstract	This document describes the background, criteria and specifies the test procedure for validating cooling circuits are leak free and can withstand normal operating pressure.

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
1	Initial Draft	RKN	01-06-2024
2	Update to match testing requirements	PBL/TAN	01-09-2024

Checked by: PBL	Date: August 2024
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Abbreviation	Meaning
FCwave	FCwave 200kW Marine Fuel Cell Module

1.0 Objectives and Background

This test procedure aims to evaluate the power quality performance of Fuel Cell gensets and compare it to conventional diesel gensets G3.

2.0 References

Document	Titel
ISO 8528-5:2022	Reciprocating internal combustion engine driven alternating current generating sets

3.0 Equipment list

Equipment	Purpose
Fluke 1775	Power Quality Analyzer, measures Voltage, Current and Frequency Data

4.0 Test Procedure

4.1 Personal protective equipment

Before commencing the test procedure always analyze the work environment and make sure you take the right precautions.

Suggested PPE depending on solution and work environment:

- Safety shoes
- Goggles
- Hearing protection

4.2 Preparation

Fuel Cell Megablock system is to be connected to a variable power consumer such as a load bank or grid connection.

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4.3 Steady state testing

4.3.1 Apply rated power of the fuel cell Megablock system.

4.3.2 Monitor and record the following parameters for at least 10 minutes:

- Voltage
- Frequency
- THDi
- THDu

4.3.3 Analyse data to make sure recorded values are within the limits.

Fill in the following table:

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤±5% At 400V: +/-20V			
	Frequency	≤0.5% At 50Hz: +/-0.25Hz			
	THDu	<5%			
	THDi	<5%			

4.4 Dynamic testing

4.4.1 Apply the following load step changes of rated power of the system. In systems where these load steps are not possible perform alternative dynamic tests:

- 0% to 35%
- 35% to 70%
- 65% to 100%
- 100% to 50%
- 50% to 0%

If it is not possible to perform these load steps, due to either system design or test setup, alternative load steps shall be used, and these should be confirmed with SME and test engineer.

4.4.2 Monitor and record the following parameters for at least 1 minute after each load change:

- Voltage
- Frequency
- THDi
- THDu

Fill in the following tables:

4.4.3 0% to 35%

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤-15[c]% At 400V: (<60V_{ac} droop)			
	Frequency	≤-/7+δf_{st})[c] % At 50Hz: >45Hz			
	THDu	<5%			
	THDi	<5%			

4.4.4 35% to 70%

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤-15[c]% At 400V: (<60V_{ac} droop)			

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Frequency	≤-/7+δf_{st})^{c} % At 50 Hz: >45Hz			
	THDu	<5%			
	THDi	<5%			

4.4.5 65% to 100%

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤-15^{c}% At 400V: (<60V_{ac} droop)			
	Frequency	≤-/7+δf_{st})^{c} % At 50Hz: >45Hz			
	THDu	<5%			
	THDi	<5%			

4.4.6 100% to 50%

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤+20% At 400V: (<80V_{ac} overshoot)			
	Frequency	≤+10% At 50Hz <55Hz			

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Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	THDu	<5%			
	THDi	<5%			

4.4.7 50% to 0%

Date tested	Parameter	Criteria (ISO8528-5:2022, Table 4)	Result	Pass/Fail	Notes
	Voltage	≤+20% At 400V: (<80V_{ac} overshoot)			
	Frequency	≤+10% At 50Hz: <55Hz			
	THDu	<5%			
	THDi	<5%			

5.0 Appendix

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SPC ID 0204 System Pressure Decay Test Template

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Revision Record

Rev #	Description	Revised By	Date dd-mm-yyyy
-	Initial Draft	TAN	21/08/2024
1	Released	TAN	30/08/2024
2	Updated	TAN	09/09/2024

Purpose	Pressure decay test template for recording tightness and evaluating system pipework integrity
Reference procedure	SPC ID 0104 rev 002 H2 Leak Test Procedure

Checked by	MHA	Date: 09/09-2024
Approved by	MHA	Date: 09/09-2024

Title	
Project	
Test date	
Identification of piping system (photo or P&ID) [✓ or -]	

Test volume	
Test fluid/gas	
Test location	
Test performed by	
Results approved by	
Filing date	

L_S - Expected leak rate for pipework system							
Ferrule fittings tightness tolerance	<		bar				
Bonded seal tightness tolerance	<		bar				
L_S total*	= 0		bar				
L_S total	=	0	NM3/h				
L_Mu - Measuring system uncertainty							
pressure gauge uncertainty							
transmitter FS (full scale)	=		barg				
Linearity	<		% of FS	=	<	0	mbar
Non-repeatability	<		% of FS	=	<	0	mbar
Analogue input	±		microA	=			mbar/10 minutes
Accuracy ±0.25% actual reading	±		microA		=		mbar
Temperature uncertainty (3 Kelvin)				=	±	82	mbar/10 minutes
L_Mu total					=	82,0	mbar
*=All joints and valves are considered to be classified "enhanced tightness". Hence zero allowable leak rate							

Calculation of L_Mu, measuring system uncertainty

	V	T0	T1	T2	P0	P1	P2	Pa1	Pa2	t	L_Mu
	M3	°C	°C	°C	kPa	barg	barg	kPa	kPa	minutes	NM3/h
String 1	3,46E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,68E-03
String 2	3,05E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,48E-03

String 3	2,67E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,29E-03
String 4	2,74E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,33E-03
String 5	3,12E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,52E-03
String 6	3,50E-03	15	15	15	101,325	7,150	7,068	101,325	101,325	10	1,70E-03

Calculation of L_A, max evaluated leak rate for pipework system acceptance

	L_S	L_Mu		L_A
	NM3/h	NM3/h		NM3/h
String 1	0	1,68E-03	=	1,68E-03
String 2	0	1,48E-03	=	1,48E-03
String 3	0	1,29E-03	=	1,29E-03
String 4	0	1,33E-03	=	1,33E-03
String 5	0	1,52E-03	=	1,52E-03
String 6	0	1,70E-03	=	1,70E-03

Procedure

Fill in design pressure = barg
The Test Pressure is 1.1 times design pressure or above = 0 barg
If the system previosly has been leakage tested with formier gas, this test can also use the used gas for operation
To perform the test follow "Sequence" paragraph 5.5.3 in SPC 0104 H2 Leak Test Procedure

Calculation of L1, actual leak rate

	V	T0	T1	T2	P0	P1	P2	Pa1	Pa2	t	L1 (gas leakage rate)
	M3	°C	°C	°C	kPa	barg	barg	kPa	kPa	minutes	NM3/h
String 1		15			101,325						#DIV/0!
String 2		15			101,325						#DIV/0!
String 3		15			101,325						#DIV/0!
String 4		15			101,325						#DIV/0!
String 5		15			101,325						#DIV/0!
String 6		15			101,325						#DIV/0!

Sensor	Sensor placement
Temperature sensor T1 & T2	BT01 Sensor in H2 heater
Pressure sensor P1 & P2	FCwave pressure inlet sensor
Atmospheric pressure Pa1 & Pa2	Data from https://www.dmi.dk/maalinger/show/DK/2620167/Hobro/

Result of test

	L1	<	L_A	Pass (Below acceptance criteria L_A)
	NM3/h		NM3/h	Pass/Fail
String 1	#DIV/0!	<	1,68E-03	
String 2	#DIV/0!	<	1,48E-03	
String 3	#DIV/0!	<	1,29E-03	
String 4	#DIV/0!	<	1,33E-03	
String 5	#DIV/0!	<	1,52E-03	
String 6	#DIV/0!	<	1,70E-03	

Title:
P&ID of Hydrogen Supply system

SPC ID:
Revision:

Printed on: