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Prototypes for demo sites
Second batch

Project Report

ACCIONA, ONYX, FLISOM, CEA, TECNALIA

www.pvsites.eu

Summary

Deliverable D8.5 is a report of the manufacturing works and technical feasibility of the second batch of BIPV and BOS products intended to be installed in the project's demo sites.

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Disclaimer

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1 EXECUTIVE SUMMARY

Deliverable "*D8.5. Prototypes for demo sites - Second batch*" is a report that contains details of the manufacturing and the technical feasibility checking works of the complete batch of BIPV and BOS products, intended to be installed in the project's demo sites. D8.5 includes the second batch of products manufactured, those not reported in "*D8.4. Prototypes for demo sites - First batch*". In this sense, D8.5 can be considered as an update of D8.4.

1.1 Description of the deliverable content and purpose

D8.5 constitutes a complete report documenting the proper development of the manufacturing works and the correct technical feasibility checking of the products. Since, prototypes manufacturing and checking works were not totally completed when D8.4 was finished, D8.5 comes to complete the document with the information concerning the BIPV and BOS products manufactured or checked from the D8.4 delivery date.

Since D8.5 has been conceived as an update of D8.4, the document maintains its structure in every aspect. Thus, each chapter of this document includes the following sections:

- Brief exposure of the technical specifications and final design of the product.
- Description of manufacturing processes.
- Description of quality control actions and validation tests of the manufactured prototypes, aimed to demonstrate the fulfilment of the specific technical requirement established in each case.
- Storing, transport, handling and installation guidelines.
- Results analysis aimed to provide solutions to the problems encountered.

1.2 Relation with other activities in the project

The products and demo-systems design tasks, carried out in previous WPs, included the pre-design, modelling, simulation and final design of the BIPV modules and BOS components conforming the products portfolio of PVSITES project; as well as similar works aimed to achieve the optimum integration of the demo-systems, designed from these products, in the chosen demo-sites.

Table 1.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
Task	**Deliverables**
Task 8.1. Design of demonstration installations	D8.3 Design pack for every demo site
Task 8.2. Manufacturing of prototypes	D8.4 Prototypes for demo sites - First batch
Task 8.3 Installation and commissioning of installations	D8.6 Results of installation and commissioning for every demonstration site

Given that the final designs of some of the BIPV and BOS products have had to be updated, for different reasons, over the last months, manufacturing works have been consequently deferred. This also has occurred due to the fact that some new requirements or correction needs have raised from the experience taken with installation and operation of the first prototypes integrated in the demo-sites. Since there is an obvious dependency between product manufacturing and demo-systems implementation, these last ones have also suffered delays.

1.3 Abbreviation list

- AC: Alternating Current.
- AENOR: Asociación Española de Normalización y Certificación (Spanish association for standardization and certification).
- ANSI: American National Standards Institute.
- BIPV: Building Integrated Photovoltaics.
- BIPVBOOST: Bringing down the cost of multifunctional BIPV systems (Horizon 2020 project).
- BOS: Balance of system (encompasses all components of a photovoltaic system other than the photovoltaic panels).
- c-Si: Crystalline Silicon.
- CSI: Current Source Inverter.
- DIN: Deutsches Institut für Normung (German Institute for Standardization).
- DC: Direct Current.
- DSP: Digital Signal Processor.
- EHG: Ecole Hôtelière de Genève (Catering School of Geneva).
- EMC: Electromagnetic Compatibility.
- EMPA: Eidgenössische Materialprüfungs und Forschungsanstalt (Swiss Federal Laboratories for Materials Science and Technology).
- EKZ: Die Elektrizitätswerke des Kantons Zürich (Power Stations of Zurich Canton).
- EVA: Ethyl Vinyl Acetate.
- FPGA: Field-Programmable Gate Array.
- H2020: EU Research and Innovation framework programme.
- IEC: International Electrotechnical Commission.
- IQNet: International Certification Network.
- ISO: International Organization for Standardization.
- LCD: Liquid Crystal Display.
- LED: Light-Emitting Diode.
- MOSFET: Metal-Oxide-Semiconductor Field-Effect Transistor.
- MPPT: Maximum Power Point Tracking/Tracker.
- PV: Photovoltaics.
- SiC: Silicon Carbide.
- STC: Standard Test Conditions.
- UL: Underwriters Laboratories.

- UNE: Una Norma Española (Spanish standardization association).
- UNE-EN: Una Norma Española - European Norm.
- VDE: Verband der Elektrotechnik, Elektronik und Informationstechnik (Association for Electrical, Electronic & Information Technologies).

2 SOLAR TILE PROTOTYPES BY FLISOM

2.1 Final module design

The solar roof tile is pre-formed by FLISOM's sub-contractor Wittenauer. The lamination of the PV film is done on the already formed tile and this complicates the production significantly. The complexity of the forming did not, however, allow a different procedure. Figure 2.1 shows the final design and a picture of a prototype.

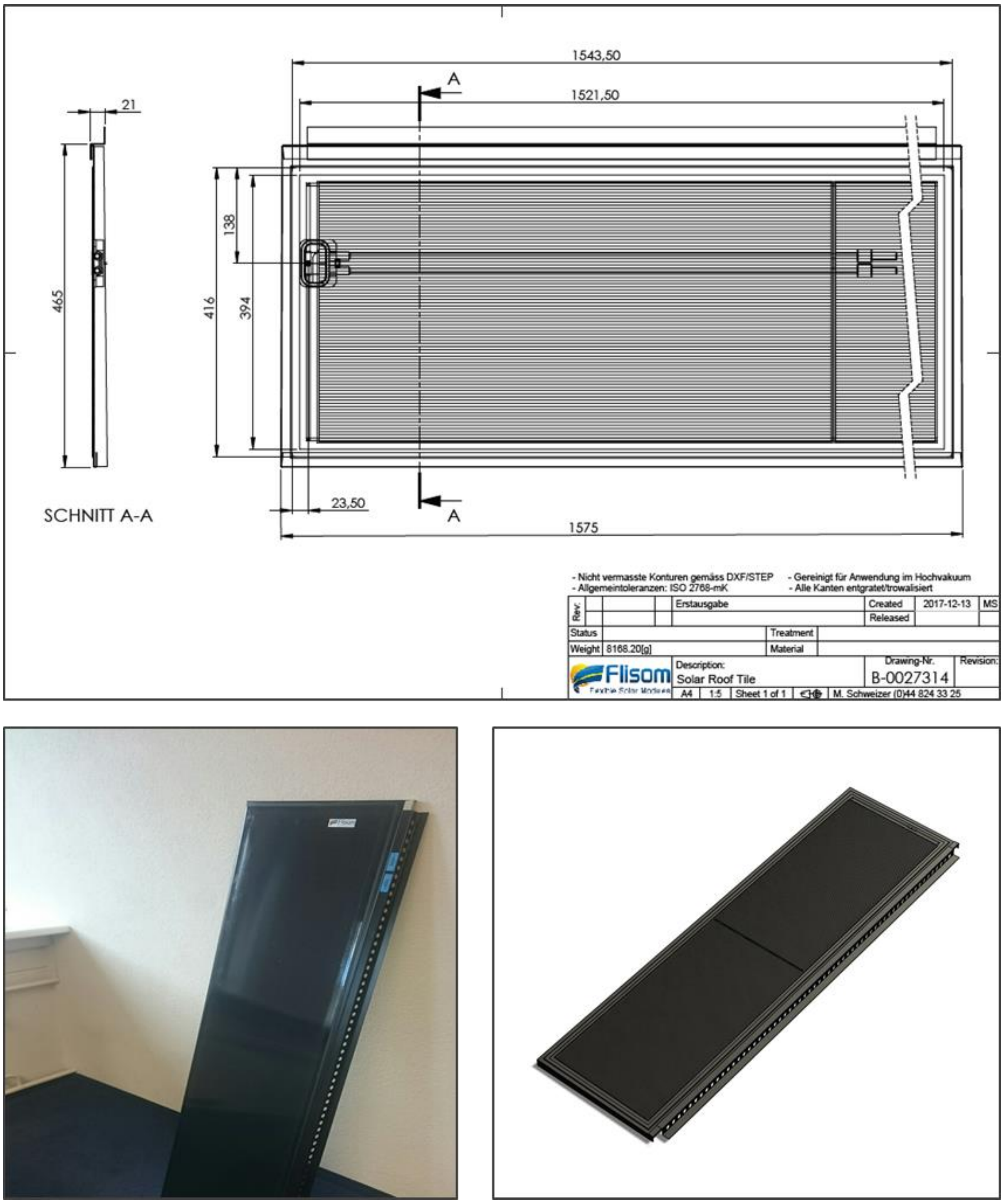


Figure 2.1: FLISOM's Solar tile design

2.2 Manufacturing report

Number of modules to be manufactured: 136.

Table below shows the total number of FLISOM's solar tile prototypes obtained at the end of the manufacturing phase.

Table 2.1 Total number of FLISOM's solar tile prototypes manufactured

Demo Project	Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
Roof-tile Belgium	9.0	136	138	138 (101%)

Figure 2.2 shows one of the first FLISOM's solar tile prototypes, which reached a very high quality.

Figure 2.2: FLISOM's solar tile prototype

2.2.1 Description of manufacturing process

The roof tile is manufactured similarly to the standard eMetal products from FLISOM. Its most specific feature is its thickness. The tile is 20 mm thick, including lamination mats. This has three implications:

- The tiles need to be supported by a matrix, so that they are not deformed in the pressure phase of lamination.

- The matrix and the thickness itself reduce the heat-flow from the baseplate to the module. Therefore, in order to achieve the same temperature, the lamination process must be prolonged. The corresponding recipe was designed by using temperature indicator stickers.

- The thickness allows only a reduced filling of the laminator.

As matrix to fill the tile FLISOM tried three options:

(1) Honeycomb aluminium has proven low thermal mass, acceptable weight for handling. However, the cost for the 6 matrices needed turned out to be too high.

(2) Foam aluminium: this material is easy to handle, but thermal conductivity showed to be very poor.

(3) The Solution that was finally picked was to use square shaped aluminium-tubes connected to a plate was the optimal solution. The corresponding matrix design is sketched in the graph below.

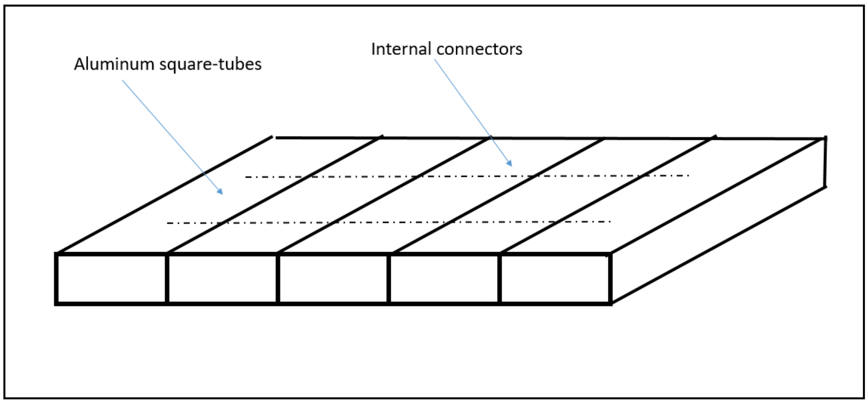


Figure 2.3: Matrix of square shaped aluminium-tubes for the solar tile manufacturing

2.2.2 Quality control and validation tests

With temperature control stickers it was made sure that required lamination temperatures were kept as specified by the material supplier. The modules were inspected for any fault. Adhesion was thoroughly tested and modules underwent 120 h of accelerated lifetime testing.

It was made sure that no important deformation of the tile occurred.

2.3 Lessons learnt for subsequent production

Among the lessons learnt during the manufacturing and validation processes can be mentioned the following ones:

- Only 1 out of 10 painted steel products is suitable for BIPV. The solar standard of 1000 h 85°C at 85% relative humidity is too harsh for most painted steel substrates.

- PVDF coated steel finally passed the test.

- As the product is smaller than usual FLISOM products, it does fit in all processing, testing and storage equipment.
- Handling during manufacturing does not cause problems.
- Implementation of solar devices on steel is difficult with junction box on the backside. Insulation of feed through is not trivial.
- It was found that the increased lamination time and the reduced amount of tiles that can be loaded needs an adaption in the process flow and manufacturing flow.
- The metallic sheet of the tile is a little too narrow, so some slight deformation and ripple was observed.
- Difference of colour, from dark blue to black, between the CIGS film on tiles was detected, not related to difference of power.

3 SOLAR VENTILATED FACADE PROTOTYPES BY FLISOM

3.1 Final modules design

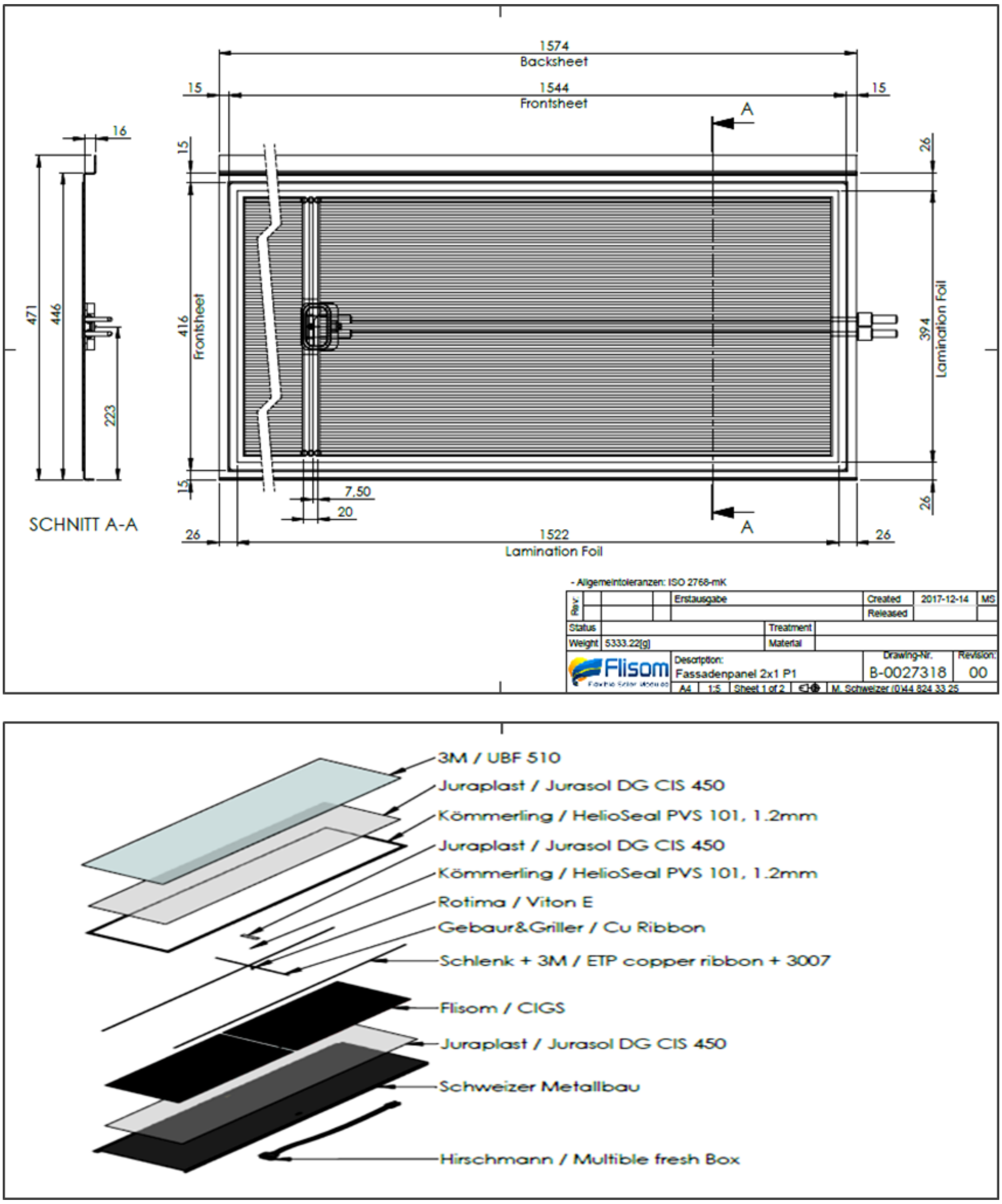
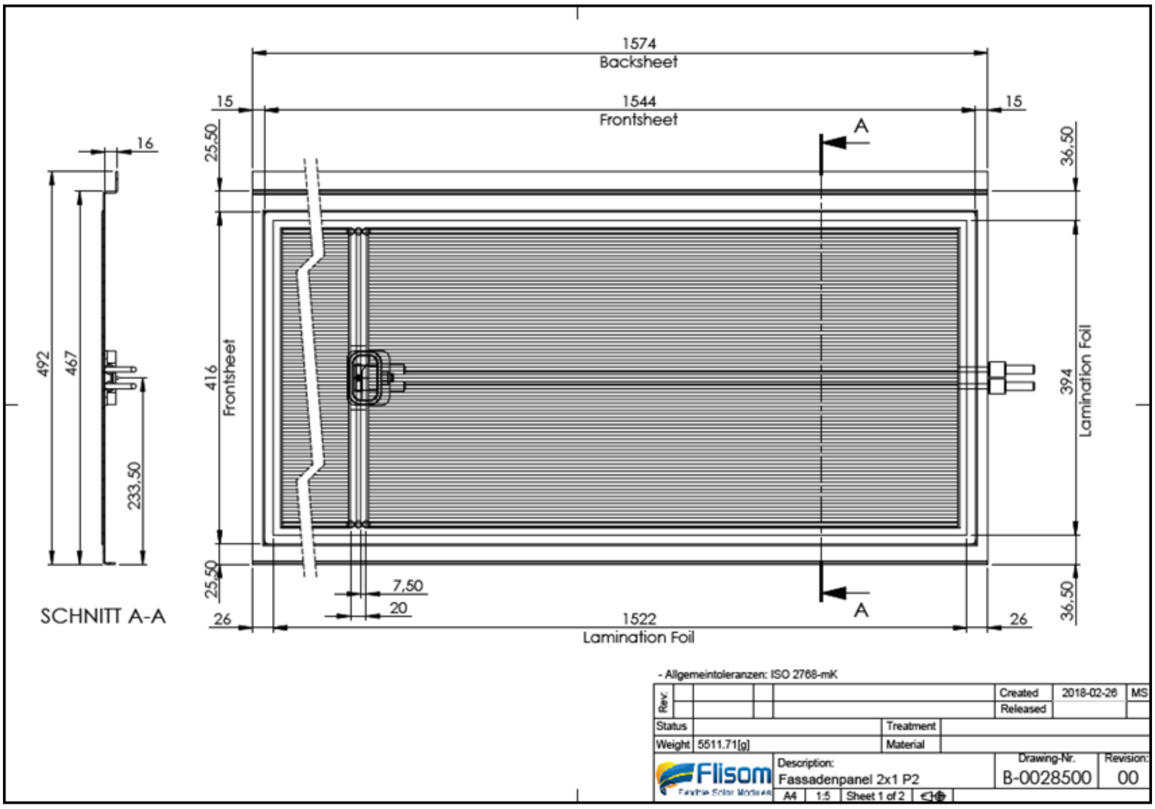


Figure 3.1: FLISOM's Facade Panel 2x1 P1 design



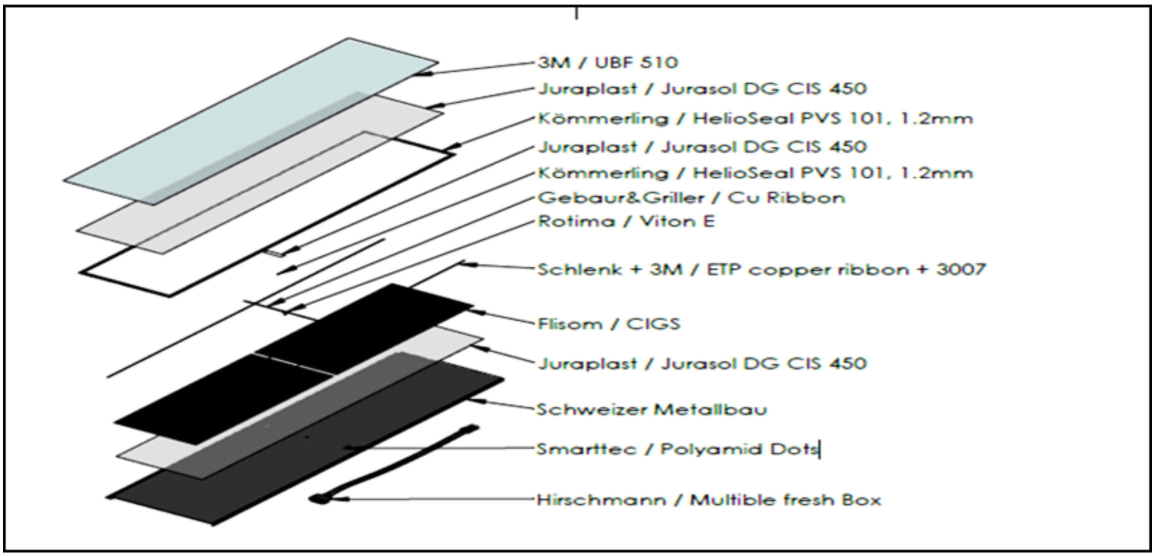


Figure 3.2: FLISOM's Facade Panel 2x1 P2 design

3.2 Manufacturing report

Number of "FLISOM Facade Panel 2x1 P1" modules to be manufactured: 42.

Number of "FLISOM Facade Panel 2x1 P2" modules to be manufactured: 104.

Table below shows the total number of FLISOM's ventilated façade prototypes obtained at the end of the manufacturing phase.

Table 3.1 Total number of FLISOM's ventilated façade prototypes manufactured

Demo Project		Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
EHG	P1	9.0	42	42	42 (100%)
	P2		104	104	104 (100%)

Next figure shows the FLISOM's ventilated façade prototypes ready to be packed.

Figure 3.3: FLISOM's ventilated façade prototypes

3.2.1 Description of manufacturing process

The panel planned for EHG is a 60 W hang-in cassette, as shown in Figure 3.1. The manufacturing has been similar to the roof tile, as also this module is “non-flat”. The material originally planned, powder coated aluminium, turned out to have insufficient adhesion for a façade mounting. The main concern is the delamination caused by water and repeated humidity freeze cycles.

Coated steel turned out to be too heavy for the brick wall. Therefore, elox-aluminium was chosen as optimal solution. Lamination is then less problematic, compared to steel, and adhesion is excellent.

The manufacturing process has been similar to the roof tile.

3.2.2 Quality control and validation tests

The quality control and validations tests were similar to those applied to the roof tile.

3.3 Lessons learnt for subsequent production

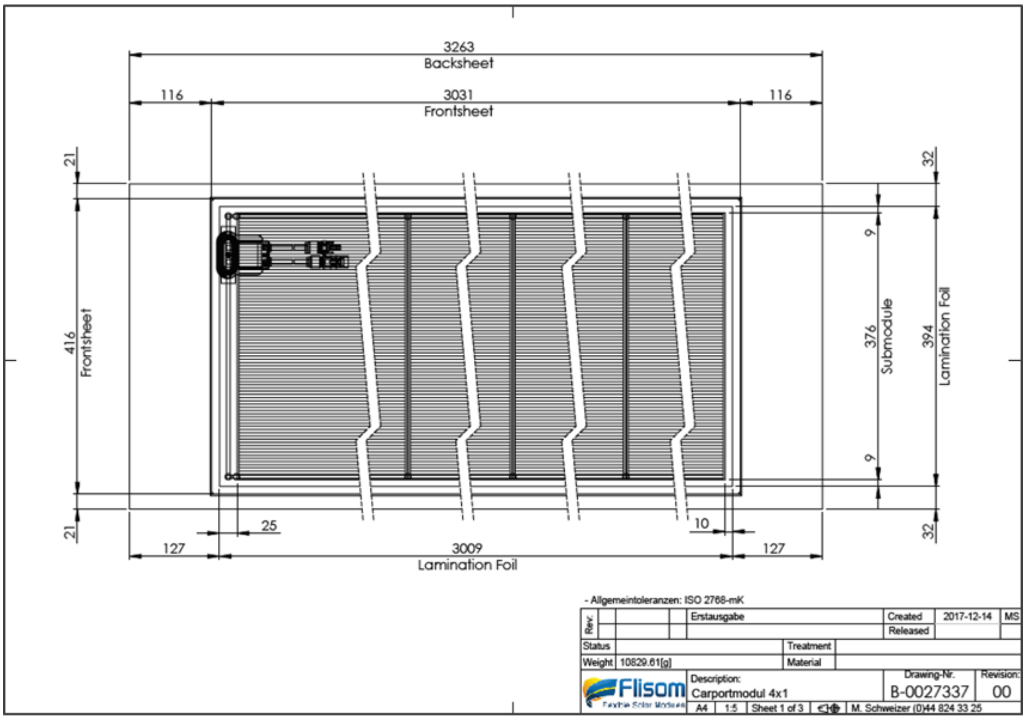
Lessons learnt are, in general terms, common to those reported in the previous chapter; although some key aspects can be highlighted or added:

- The thickness of the metal sheet has a negative impact on the production speed, which is slowed down by 30%, approx., and the lamination has to continue in a separate shift.
- In future, it is therefore preferred to find solutions for flat lamination, followed by the folding of the final piece.
- Handling, packing and protection of Elox Aluminum is tricky. It was required to develop effective procedures, in these regards.

4 SOLAR CARPORT PROTOTYPES BY FLISOM

4.1 Final module design

The carport module had a total length of 5.8 m, longer than the one allowed by the laminator. It was therefore manufactured in 2 pieces and joint later onto 1 large module. Figure 4.1 and Figure 4.2 show the dimensions of the two parts.



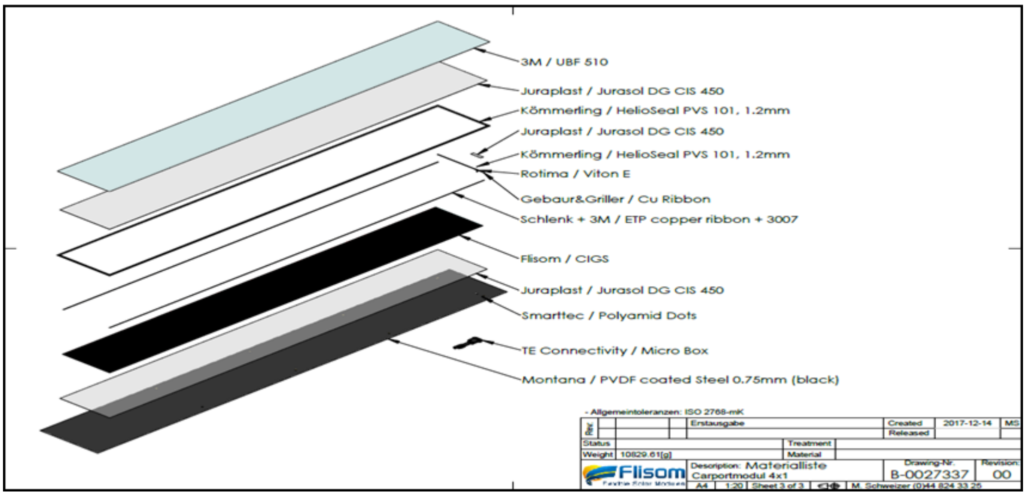


Figure 4.1: FLISOM's Carport Module 4x1 design

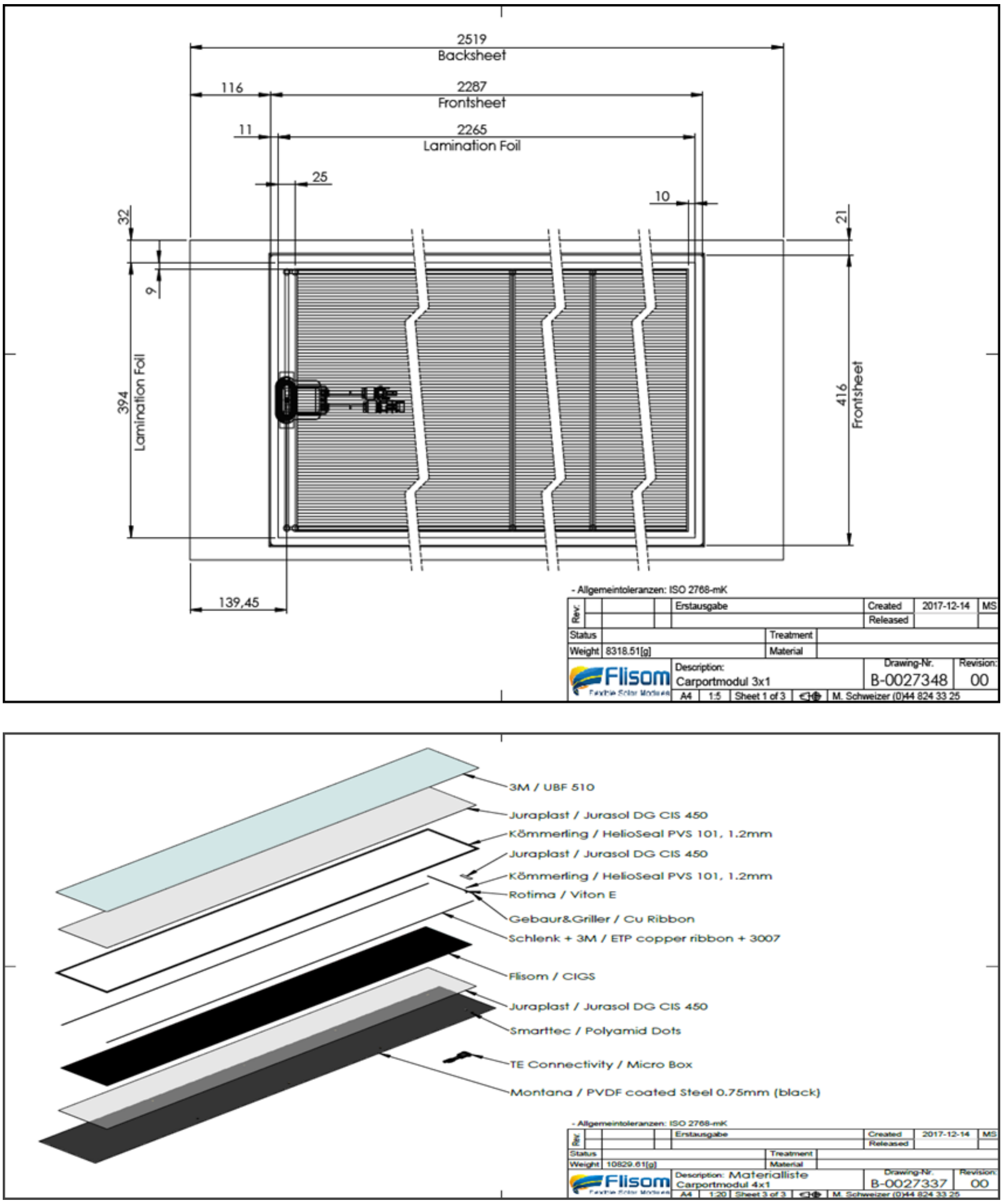


Figure 4.2: FLISOM's Carport Module 3x1 design

4.2 Manufacturing report

Number of "FLISOM Carport Module 4x1" to be manufactured: 37 + 39 = 76.

Number of "FLISOM Carport Module 3x1" to be manufactured: 37 + 39 = 76.

Table below shows the total number of FLISOM's carport prototypes obtained at the end of the manufacturing phase.

Table 4.1 Total number of FLISOM's carport prototypes manufactured

Demo Project		Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
Carport	EKZ	8.2	78	78	78 (100%)
	EMPA	7.8	74	74	74 (100%)

4.2.1 Description of manufacturing process

The modules were difficult to produce due to two reasons: in the first place, due the huge length and weight, which did not allow the modules to be handled by 1 person; therefore, in the future it might be even considered to split the module in 3 parts. The second reason was a relatively high failure rate in the high voltage testing. The long metal back plate made it difficult for the operators to manufacture the module. Also, the low number of modules did not allow the operators to reach a high level of routine.

4.2.2 Quality control and validation tests

The quality control and validations tests were similar to those applied to the roof tile.

The final outcome was excellent, and the aesthetics of the module exceeds FLISOM's expectations. The modules appear, nearly completely, homogenously black and are only 2 mm thin, giving them an elegant appearance. Also, the power on the second carport is significantly higher than planned.

Figure 4.3: Carport modules installed on demo-site EKZ Seuzach

Figure 4.4: Carport modules installed on demo-site EMPA

4.3 Lessons learnt for subsequent production

The lessons learnt during the development and manufacturing phases can be summarized as follows:

- A new lamination recipe was developed to account for thermal mass and geometry.
- A protection foil was purchased and qualified for the safe packing, storing and supplying of the modules. Sharp edges of metal sheets lead to damage.
- It was required to develop an effective packing procedure.
- It was difficult to avoid bubbles in tile manufacturing.
- Adhesion between back sheet and edge seal should be improved.
- The huge size of the panels makes difficult their handling.

5 SOLAR INDUSTRIAL ROOF PROTOTYPES BY FLISOM

5.1 Final module design

The drawings are shown in Figure 5.1; a finished prototype is shown in Figure 5.2.

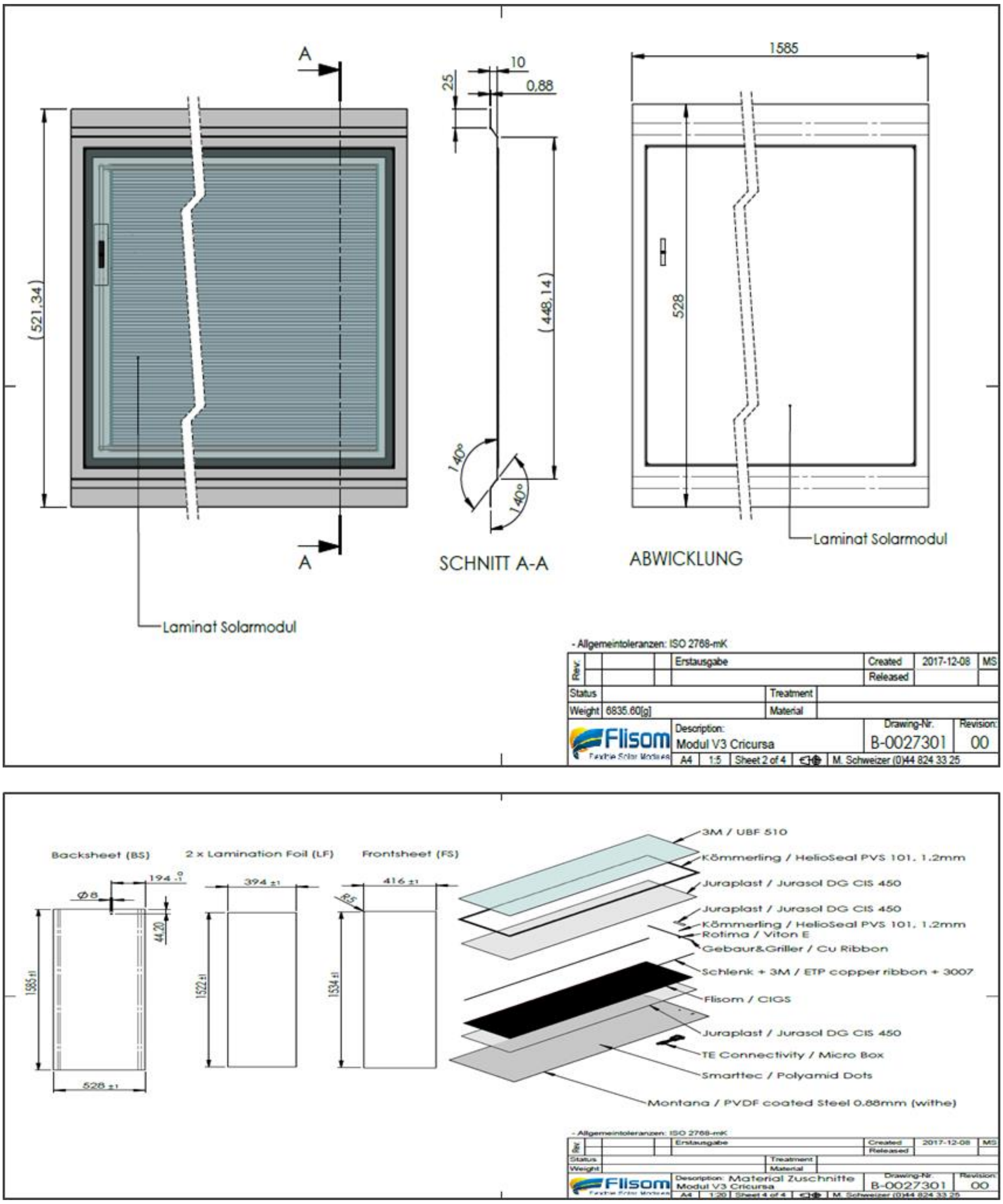


Figure 5.1: FLISOM's Industrial roofing module design

5.2 Manufacturing report

Number of “FLISOM industrial roofing module” to be manufactured: 336.

Table below shows the total number of FLISOM’s industrial roofing prototypes obtained at the end of the manufacturing phase.

Table 5.1 Total number of FLISOM’s industrial roofing prototypes manufactured

Demo Project	Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
CRICURSA	20.2	336	336	336 (100%)

5.2.1 Description of manufacturing process

The industrial tiles were easy to manufacture, as the tile can be laminated flat and the coating allows bending the module after being laminated.

5.2.2 Quality control and validation tests

The quality control and validations tests were similar to those applied to the roof tile. The following picture shows the result obtained.

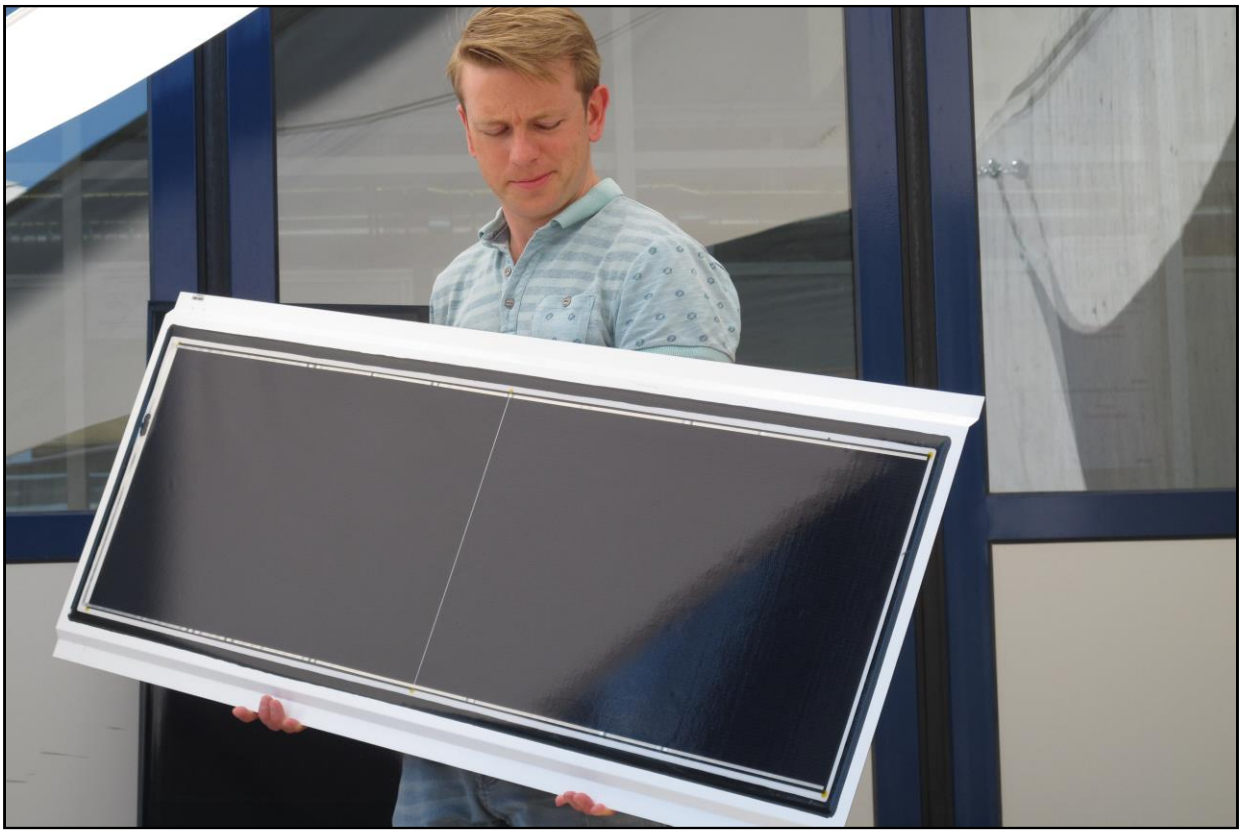


Figure 5.2: Roofing tile for industrial buildings

The weight of only 6.5 kg and the 1.6 m length allowed easy handling for 1 person. In order to not damage the PV module after lamination forming, a special protection foil was identified, qualified and tested. Also, the application of the foil was tested in detail. The modules underwent a full reliability testing after the forming process to make sure that there was no hidden damage. The manufacturing and testing went smooth, and no major unexpected issue occurred.

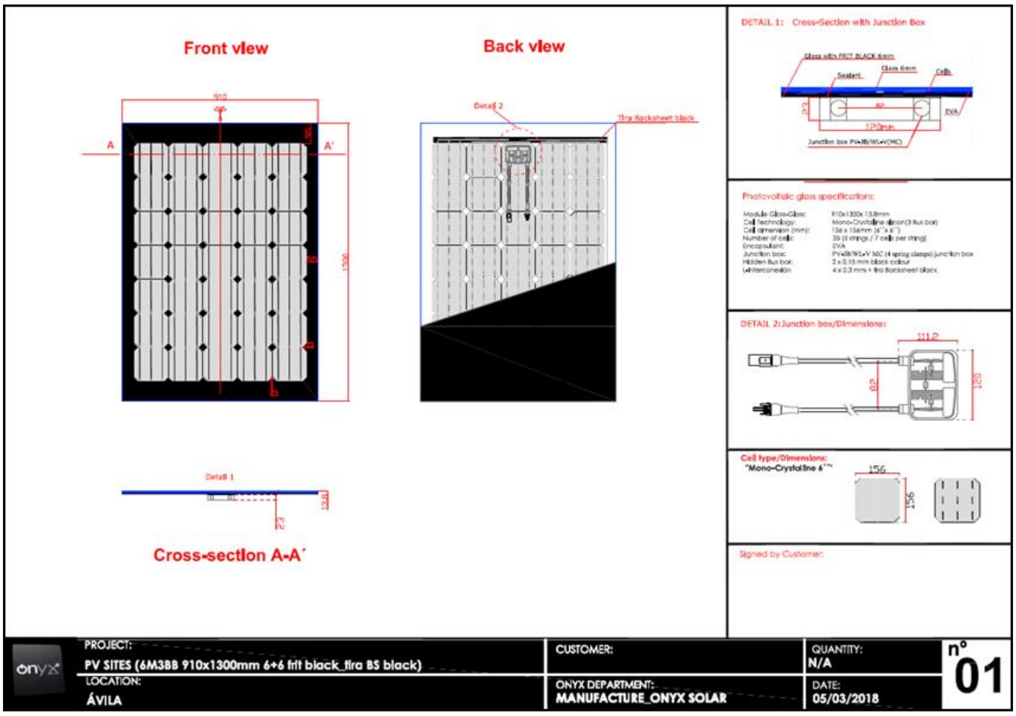
5.3 Lessons learnt for subsequent production

The manufacturing of the industrial tiles turned out to be the “easiest” of all PVSITES products made by FLISOM. This is a welcome fact, as the amount of prototypes to be produced was the highest. In this case, main conclusions were the following:

- Bending solar modules is possible without damaging the device.
- A module length of 1.5 m is an optimal size, as it can be easily handled by just one person.
- There were some logistical challenges related to the shipping of the modules for folding and for the final customer abroad. Payment of taxes was required, even for returning empty containers.

6 OPAQUE SOLAR VENTILATED FAÇADE PROTOTYPES BY ONYX

6.1 Final module design



PHOTOVOLTAIC GLASS	1300 x 910 6" Mono Crystalline	
Electrical data test conditions (STC)		
Nominal peak power	151	P_{mpp} (Wp)
Open-circuit voltage	22.22	V_{oc} (V)
Short-circuit current	9.05	I_{sc} (A)
Voltage at nominal power	18.34	V_{mpp} (V)
Current at nominal power	8.26	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	1300	mm
Width	910	mm
Thickness	13.8	mm
Surface area	1.18	sqm
Weight	35.49	Kgs
Cell type	6" Mono	Crystalline
No PV cells / Transparency degree	35	0% (Opaque)
Front Glass	6 mm	PPI Black connections
Rear Glass	6 mm	Tempered Glass+Black frit
Thickness encapsulation	1,80 mm	EVA Foils
Category / Colour code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or	4,0 mm²
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40…+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

Figure 6.1: ONYX's solar ventilated facade module design

6.2 Manufacturing report

Number of “ONYX solar ventilated facade module” for the multi-storey building in France: 18 x 14 = 112 modules (plus 2 spare units).

Table below shows the total number of ONYX’s solar ventilated facade prototypes obtained at the end of the manufacturing phase.

Table 6.1 Total number of ONYX’s solar ventilated facade prototypes for the French demo-site

Demo Project	Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
Apartments building	17 kWp	112	33 (indoor testing)	114 (102%)

6.2.1 Description of manufacturing process

The process followed for the manufacturing of the modules intended for demonstration has been similar to any other ONYX commercial project.

The process begins with the signing of the manufacturing drawings by the client.

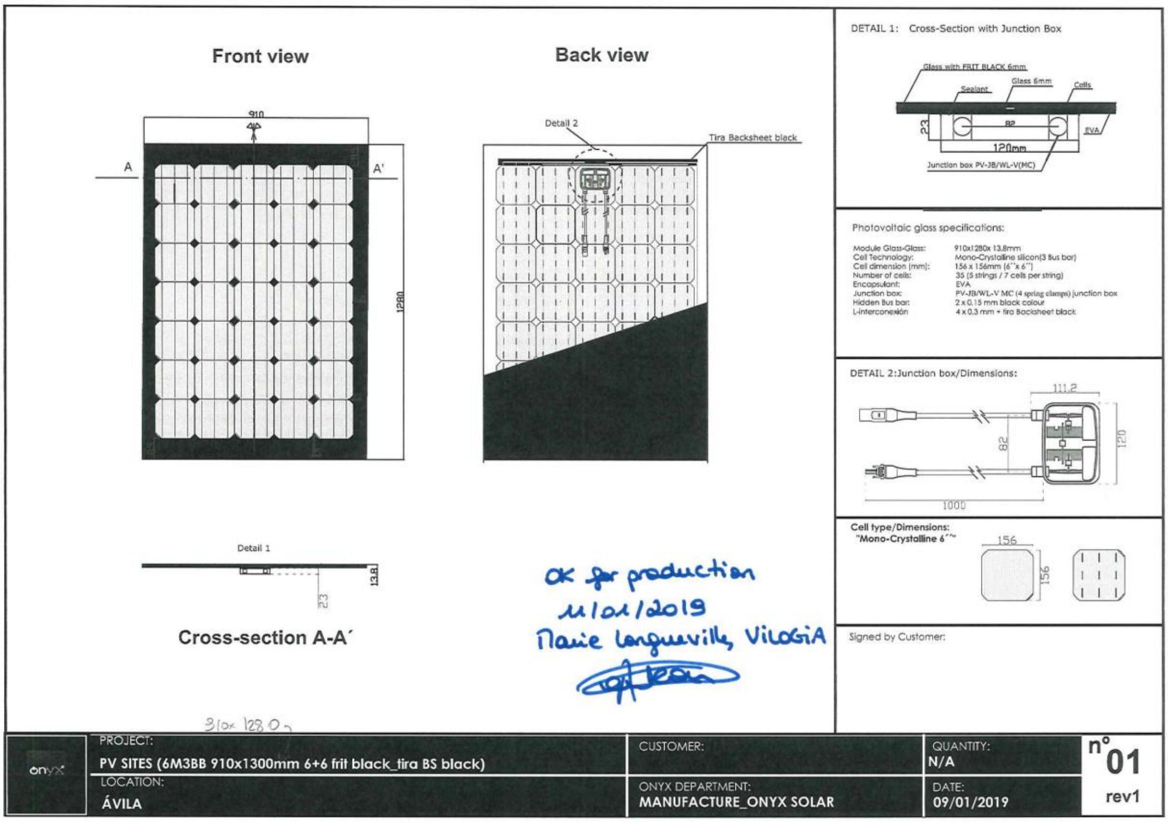


Figure 6.2: ONYX’s solar manufacturing drawings signed by VILOGIA (X5 product)

It is needed to point out that ONYX Solar glass is manufactured under the following standards:

- IEC standard “Crystalline Silicon Terrestrial Photovoltaic (PV) Modules - Design Qualification and Type Approval”, and IEC61730 2011:1&2 standard “Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction & Part 2: Requirements for testing” (factory and crystalline glass certified by TÜV NORD laboratories)
- IEC61701, 2nd ed. 2011-12: Salt mist corrosion testing of photovoltaic (PV) modules.
- UNE-EN 12600:2003 standard (impact resistance).
- UNE-EN 356:2001 standard (Tests for resistance to manual attack).
- UNE-EN ISO 12543-4:2011 standard (resistance to extreme climatic conditions).
- EN 61215 standard “Crystalline silicon terrestrial photovoltaic (PV) Modules - Design qualification and type approval” and EN 61646 “Thin-film terrestrial photovoltaic (PV) Modules - Design qualification and type approval”.
- EN 61730-1 and EN 61730-2: “PV module safety qualification”.
- ANSI Z97.1-2015 (Boil test and impact test according), for safety glazing materials used in buildings - safety performance specifications and methods of test, American National Standard.
- UL-1703 & ULC/ORD-C1703 listed for crystalline and amorphous Silicon glass (“Standard for Flat-Plate Photovoltaic Modules and Panels” standard).
- New standard EN 50583 final content.

Once the drawings were signed, the manufacturing process started.

The first step in the manufacturing process of modules is to classify the cells by power: cells with similar power are used to manufacture the same PV glass, as it is necessary that the cells have similar electrical parameters in order to have the same production in all of them. The colour homogeneity generates an aesthetically balanced panel, as well as similar electrical values in cells provide a similar electrical response in all of them and in the final product.

Once the cells are selected and after passing through mechanical and electrical inspections, they are welded together forming strings by means of an infrared welding process. Cells are joined together by a Sn/Ag/Cu thread or Cu core connections with, Sn / Pb coating and black finish (Sun wire Deco 1.30 x 15-25 mic 0.22 segmented black coating).

Figure 6.3: Detail of strings of cells

The strings are placed on a tempered extra clear glass covered by a sheet of EVA. Then strings are interconnected by L-interconnection (Sun 6 x 0.3mm wire Deco 20-30 mic continuous black coating). The thread formed by Sn/Ag/Cu or the Cu core and the black finished Sn/Pb coating work as evacuator of the power generated in the set.

In order to provide isolation and resistance, another layer of encapsulant material (EVA) is used. The Ethyl Vinyl Acetate (EVA) is an excellent transmitter of solar radiation, ultraviolet radiation does not degrade it, it acts as a protection from vibrations and impacts and it is used as an adhesive between the front and back covers of the module. Finally, and as an outer sheet, a black vitrified tempered glass is used in order to achieve the pre-set aesthetical appearance. Tempering gives mechanical strength to the module.

Once the system is assembled, the laminating process starts. During this process, the system is subjected to pressure and temperature in a furnace with the aim of removing air and to get the cells completely isolated. The encapsulant inside the oven reaches a high degree of compaction and adherence. The excess of encapsulant material (EVA) is removed as soon as the glass is cured. The manufacturing process of PV glass concludes with the connection box assembly and the placing of terminals therein. The final technical parameters of the product are obtained by a solar testing simulator based on a Xenon flash lamp and an electric charge with a multi-meter, simulating STC conditions.

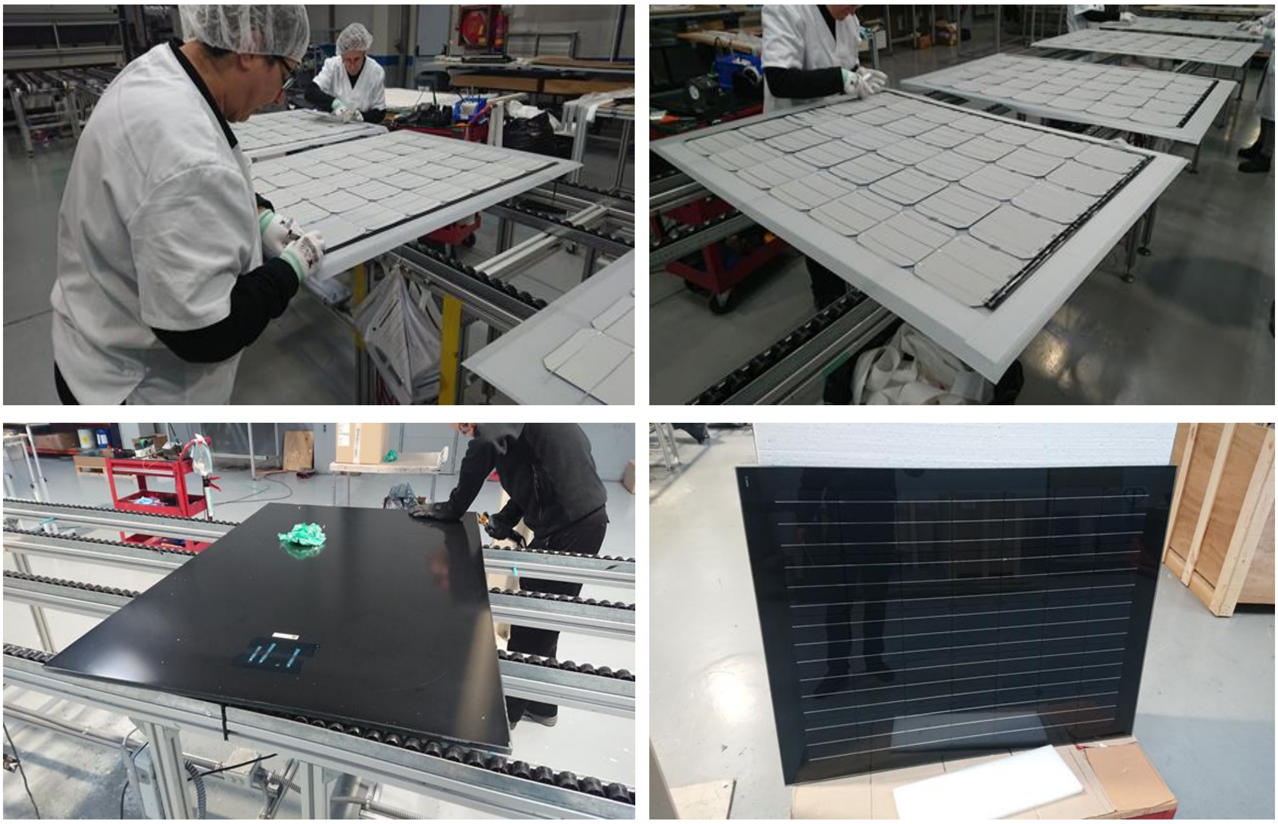


Figure 6.4: Detail of different steps of the PV module manufacturing process

Figure 6.4 shows several steps of the manufacturing process, from manual L-interconnection works to final module production.

Figure 6.5 shows ONYX’s c-Si manufacturing line, starting from automatic laser machine for welding solar cells and ending in the PV glass laminator.

Figure 6.5: General view of ONYX's c-Si manufacturing line. Source: ONYX

6.2.2 Quality control and validation tests

Quality control applied to the manufacturing processes was carried out according to the following certifications and standards:

1. ONYX SOLAR ENERGY, S.L. is certified by IQNet and AENOR for the following field of activities:
   - Design and production of PV glass in thin film and crystalline technologies.
   - Design and development of projects including PV glass solutions for architectural integration.
2. ONYX has implemented and maintains a Quality Management System which fulfills the requirements of the following standards:
   - ISO 9001:2015.
   - ISO 14001:2015.
3. CE marked glass is used.

Once the prototypes are manufactured, the following validation tests are applied to each unit:

- Visual inspection of each unit in order to discard bubbles, cells breakage, rows displacement, etc.
- Validation of the technical parameters by a solar testing simulator based on a Xenon flash lamp and an electric charge with a multimeter, simulating STC conditions.

Additionally, X5 prototypes were tested under different standards within PVSITES WP3. Results can be consulted in D3.9.

Table 6.2 Performed tests for X5 prototype

Product name	Test field	Standard and test	Comments
X5 - C-Si glazed products with hidden bus bars and L interconnections	Photovoltaic standards	IEC 61215: severe dielectric rigidity test, thermal cycling, damp heat	Fire tests of ETAG 034 have been performed using X5 glazing, thus the results can be used for X5 and X8 products
	Construction standards	ISO 12543-4: radiation, humidity, high temperature EN 12600: impact resistance EN 356: manual attack EN 13823: Reaction to fire EN 11925-2: Reaction to fire - Single-flame source EN 410: Optical properties	
	Photovoltaic standards	IEC 61215: severe dielectric rigidity test, thermal cycling, damp heat	-

6.2.3 Measures applied for storing, transport and handling of prototypes

The final units were stored in full closed crates until the shipping to the VILOGIA demo site. The rejected units were stored in trestles for glass in order to have a balance between a secured storage and flexible handling.

Figure 6.6: Storage of X5 final units in crates before shipping to VILOGIA demo site

6.2.4 Prototype Registration

Tables below show the register of manufactured and validated prototypes.

onyx	CONTROL SHEET			
TECHNOLOGY	CRYSTALLINE		GLASS-GLASS	
PROJECT			PV SITES X5	
PRODUCTION				
	SERIAL NUMBER	DATA	ELECTRICAL TESTING	COMMENTS
1	010319AKW6M44001	04/03/2019	OK	M01
2	010319AKW6M66002	04/03/2019	OK	M01
3	010319AKW6M66003	04/03/2019	OK	M01
4	010319AKW6M66006	04/03/2019	OK	M01
5	040319AKW6M66004	04/03/2019	OK	M01
6	040319AKW6M66005	04/03/2019	OK	M01
7	040319AKW6M66006	04/03/2019	OK	M01
8	040319AKW6M66007	04/03/2019	OK	M01
9	040319AKW6M66008	04/03/2019	OK	M01
10	040319AKW6M66009	04/03/2019	OK	M01
11	040319AKW6M66010	04/03/2019	OK	M01
12	040319AKW6M66011	04/03/2019	OK	M01
13	040319AKW6M66012	04/03/2019	OK	M01
14	040319AKW6M66013	04/03/2019	OK	M01
15	040319AKW6M66014	04/03/2019	OK	M01
16	040319AKW6M66015	04/03/2019	OK	M01
17	040319AKW6M66016	05/03/2019	OK	M01
18	040319AKW6M66017	05/03/2019	OK	M01
19	040319AKW6M66018	05/03/2019	OK	M01
20	040319AKW6M66019	05/03/2019	OK	M01
21	040319AKW6M66020	05/03/2019	OK	M01
22	040319AKW6M66021	04/03/2019	OK	M01
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43	040319AKW6M66042	05/03/2019	OK	M01
44	040319AKW6M66043	05/03/2019	OK	M01
45	040319AKW6M66044	05/03/2019	OK	M01
46	040319AKW6M66045	05/03/2019	OK	M01
47	040319AKW6M66046	05/03/2019	OK	M01
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85	050319AKW6M66084	06/03/2019	OK	M01
86	050319AKW6M66085	06/03/2019	OK	M01
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92	050319AKW6M66091	07/03/2019	OK	M01
93	050319AKW6M66092	07/03/2019	OK	M01
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112	050319AKW6M66112	06/03/2019	OK	M01
113	050319AKW6M66113	06/03/2019	OK	M01
114	050319AKW6M66114	07/03/2019	OK	M01

6.3 Lessons learnt for subsequent production.

The problems detected are based on the difficulty of hiding the interconnections between the cells with the black ribbon solution.

Onyx carried out an intensive search for solutions available in the market that allowed hiding the interconnections by using black conductive ribbons or integrating different fully plastic sheets compatible with the lamination, masking the ribbon once the series were manufactured.

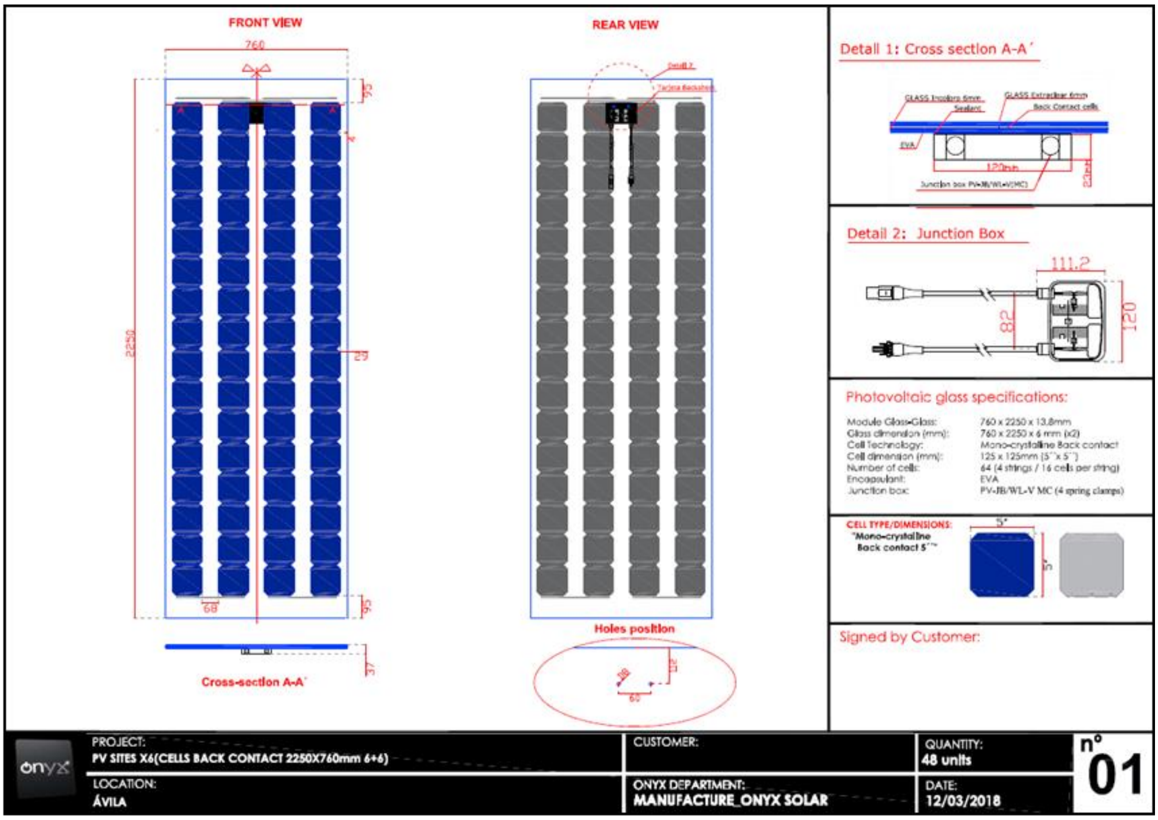
The results were not as expected and the use of this kind of solutions presents problems related to the aesthetics during the manufacturing process.

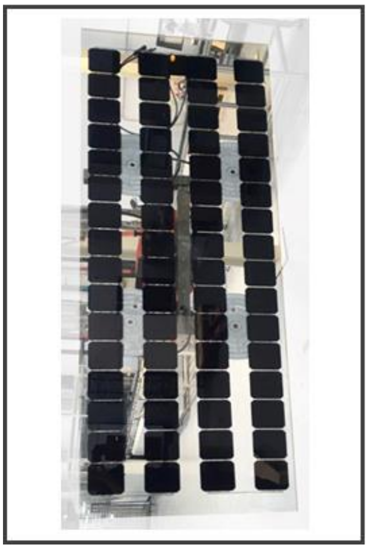
With the solution based on the black ribbon, the problem was located on the appearing of spots in the welding areas between the ribbon and the cells. Due to the heat applied during the welding process, the black coating of the ribbon disappears.

On the other hand, the use of a plastic sheet to hide the connections is not functional because during the lamination process the tape suffers deviations in the position, making visible the ribbon.

7 BACK-CONTACT CELL VENTILATED FAÇADE PROTOTYPES BY ONYX

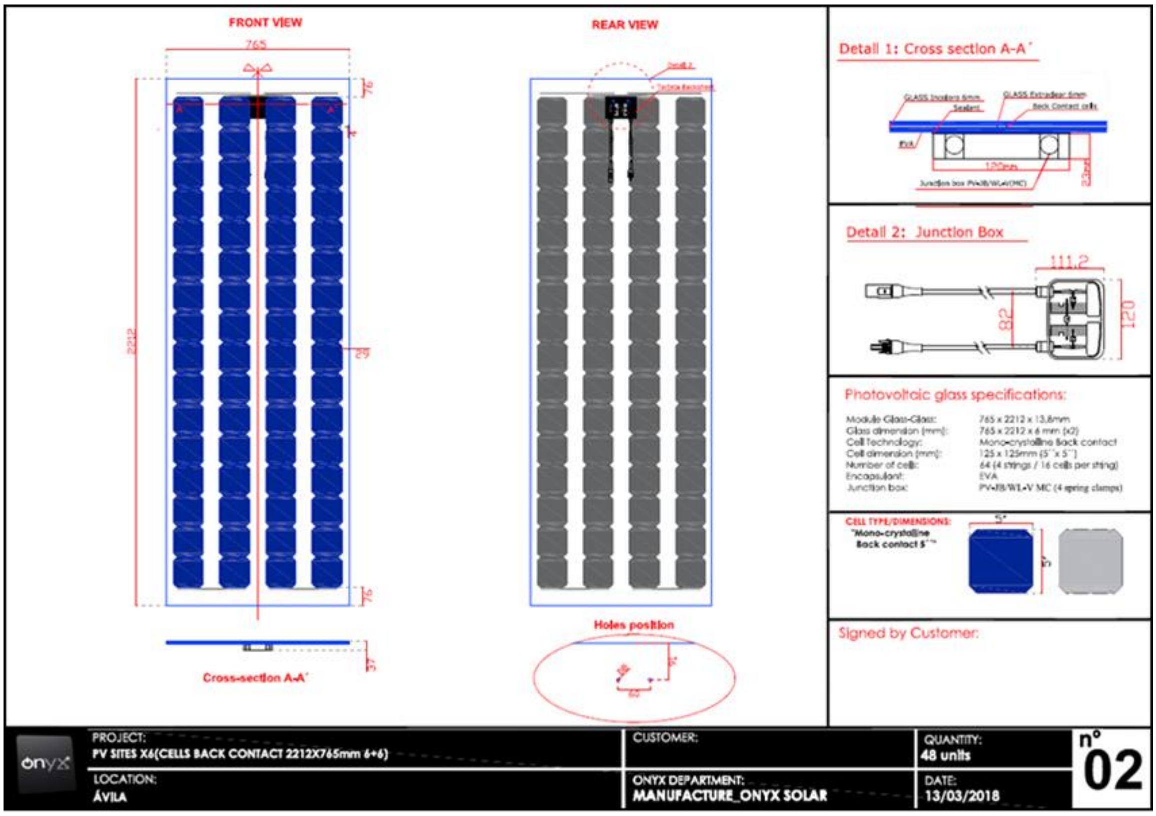
7.1 Final module design

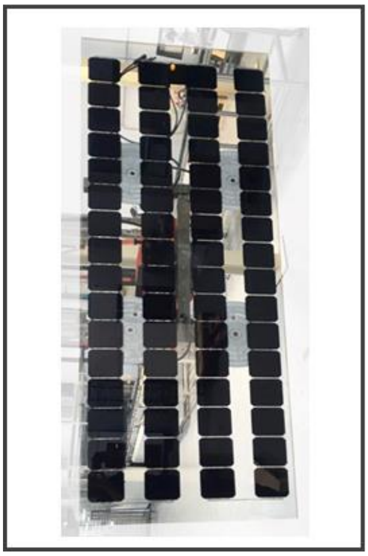




PHOTOVOLTAIC GLASS	2250 x 760	
	5" Mono	Crystalline Back Contact
Electrical data test conditions (STC)		
Nominal peak power	191.5	P_{mpp} (Wp)
Open-circuit voltage	41.60	V_{oc} (V)
Short-circuit current	5.70	I_{sc} (A)
Voltage at nominal power	34.88	V_{mpp} (V)
Current at nominal power	5.49	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	2250	mm
Width	760	mm
Thickness	13.8	mm
Surface area	1.71	sqm
Weight	51.30	Kgs
Cell type	5" Mono	Crystalline Back Contact
No PV cells / Transparency degree	64	39%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Thickness encapsulation	1.80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2.5 mm² or	4.0 mm²
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40…+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0.30	%/°C
Temperature Coefficient of Voc	-1.74	mV/°C
Temperature Coefficient of Isc	3.50	mA/°C

Figure 7.1: ONYX's ventilated façade module, size 1





PHOTOVOLTAIC GLASS	2212 x 765 5" Mono	Crystalline Back Contact
Electrical data test conditions (STC)		
Nominal peak power	191.5	P_{mpp} (Wp)
Open-circuit voltage	41.60	V_{oc} (V)
Short-circuit current	5.70	I_{sc} (A)
Voltage at nominal power	34.88	V_{mpp} (V)
Current at nominal power	5.49	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25ºC, stabilized module state.		
Mechanical description		
Length	2212	mm
Width	765	mm
Thickness	13.8	mm
Surface area	1.69	sqm
Weight	50.77	Kgs
Cell type	5" Mono	Crystalline Back Contact
No PV cells / Transparency degree	64	39%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2.5 mm² or	4.0 mm²
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	ºC
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0.30	%/ºC
Temperature Coefficient of Voc	-1.74	mV/ºC
Temperature Coefficient of Isc	3.50	mA/ºC

Figure 7.2: ONYX's solar ventilated façade module, size 2

7.2 Manufacturing report

Number of modules to be manufactured: 48 modules size 1 (2.250 mm x 760 mm).

Number of modules to be manufactured: 48 (plus 2 spare units) modules size 2 (2.212 mm x 765 mm).

Table below shows the total number of ONYX's solar ventilated facade prototypes obtained at the end of the manufacturing phase.

Table 7.1 Total number of ONYX's solar ventilated facade prototypes for the Spanish demo-site

Demo Project		Power (kW) requested	Number of modules	Prototypes produced	Modules delivered
Office building	2.250 mm x 760 mm	9.2 kWp	48	20 (for indoor testing)	48 (100%)
	2.212 mm x 765 mm	9.2 kWp	48		49 (102%)

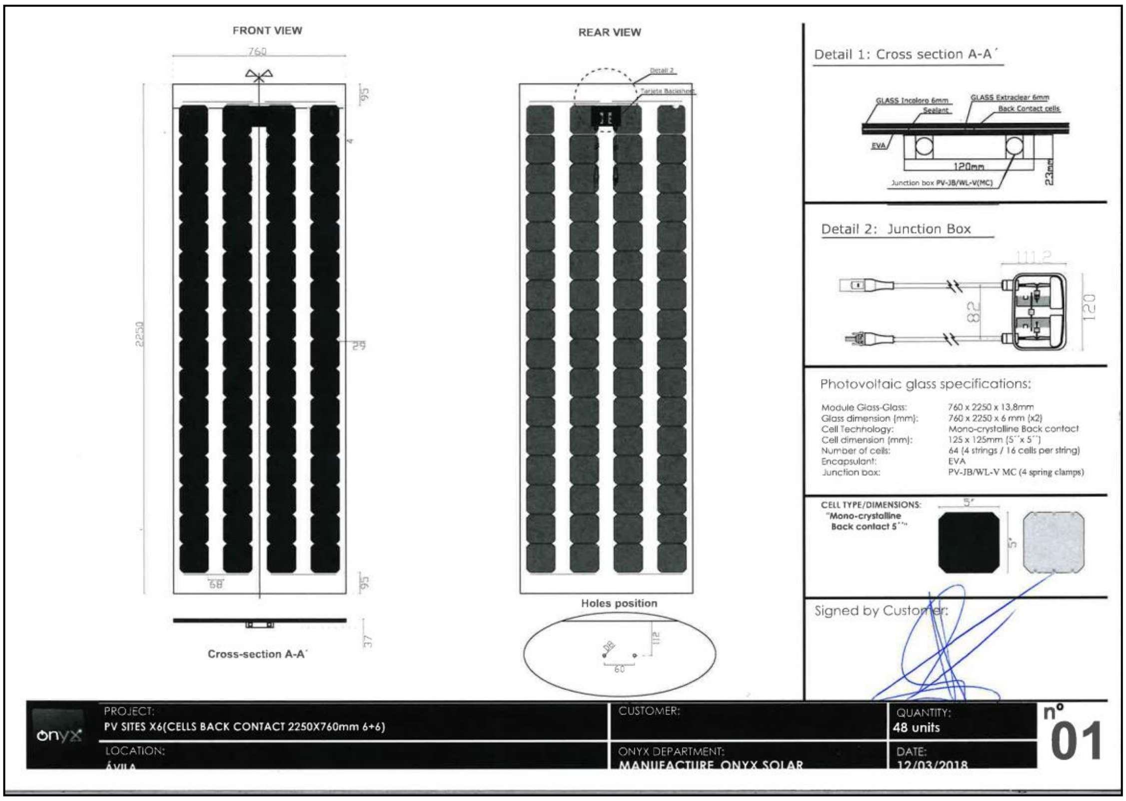
7.2.1 Description of manufacturing process.

The process followed for the manufacturing of the modules intended for demonstration has been similar to any other ONYX commercial project. The process begins with the signing of the manufacturing drawings by the client.

The description of standards applicable to glass-glass products by ONYX provided in section 7 also applies to this product. The first steps in the manufacturing process are parallel to those described in section 7: cell classification, inspections, welding and module layout.

The first step in the manufacturing process of modules is to classify the cells by power: cells with similar power are used to manufacture the same PV GLASS, as it is necessary that the cells have similar electrical parameters in order to have the same production in all of them. The colour homogeneity generates an aesthetically balanced panel; as well as, similar electrical values in cells provide a similar electrical response in all of them and in the final product, in turn.

Once the cells are selected and after passing through mechanical and electrical inspections, they are welded together forming strings by means of an infrared welding process. Cells are joined by specific tabs of back contact solar cells. This allows creating a junction where the stresses and strains are absorbed by the interconnector. This type of cell eliminates front interconnector wire (the positive and negative terminals on the lower side) and thus generates an increase in active area. The strings are placed on a tempered glass extra-clear covered by a sheet of EVA.



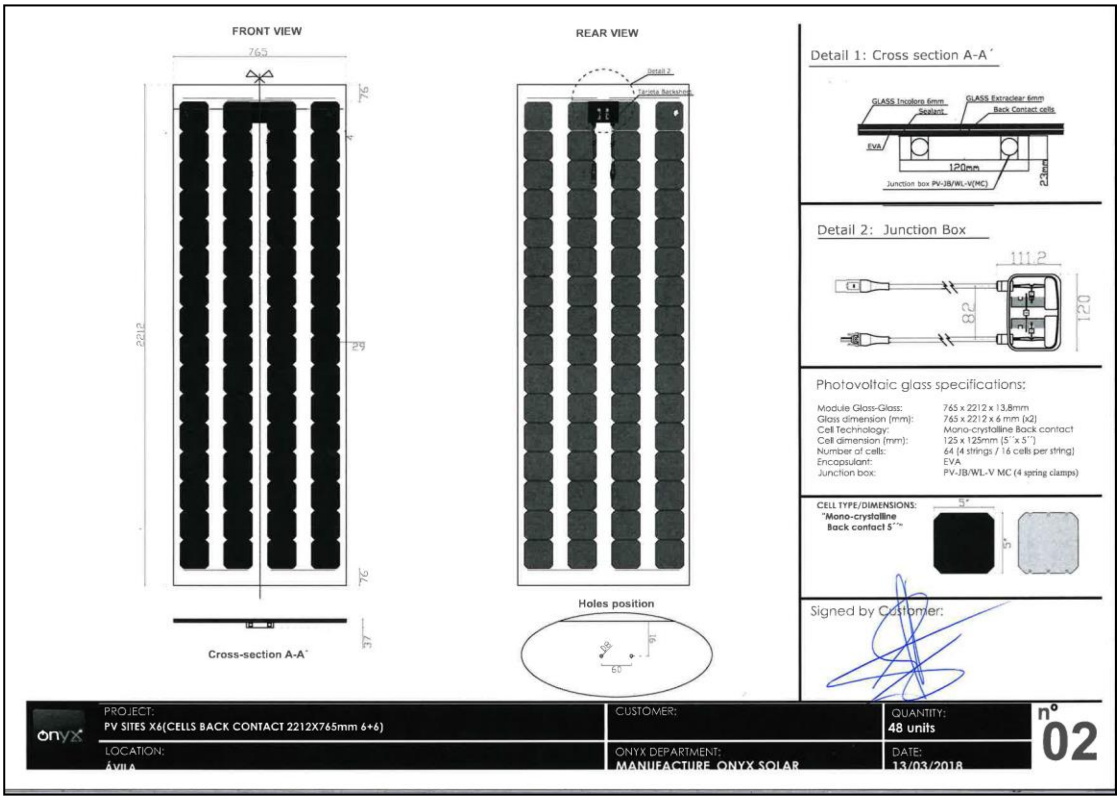


Figure 7.3: ONYX's Solar manufacturing drawings signed by TECNALIA (X6 product)

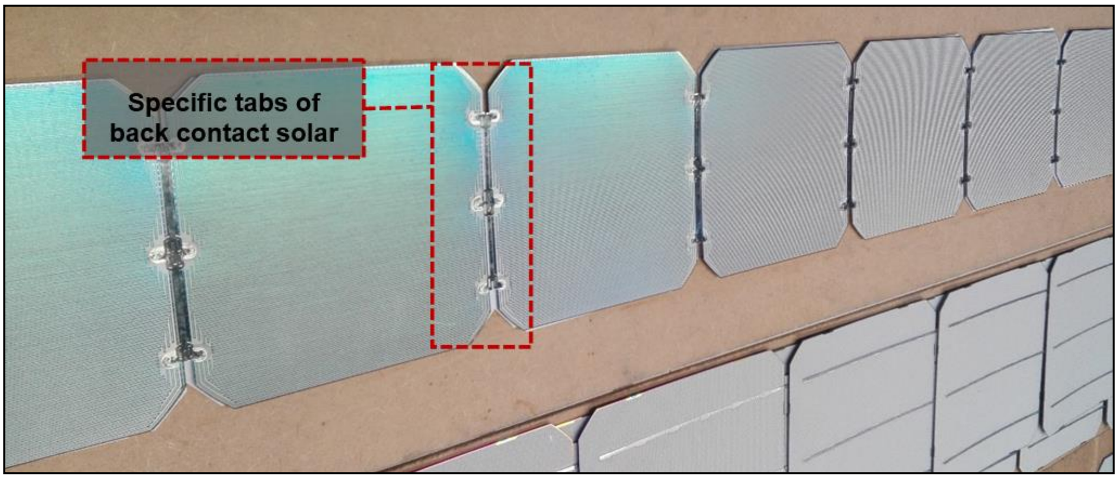


Figure 7.4: Detail of specific tabs of back contact solar cells

During the manufacturing process, a high rejection rate was detected on the cells in the different welding processes. Due to this, a process of exhaustive verification of the voltage was carried out after each phase, completing this verification process with photoluminescence tests on the cells.

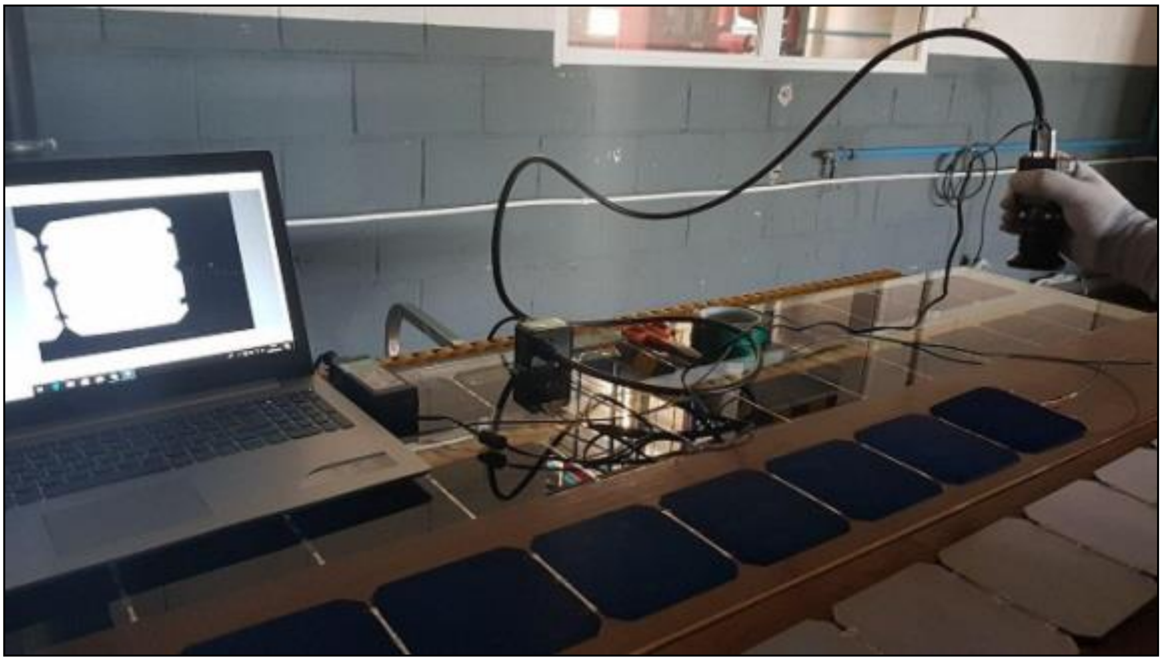


Figure 7.5: Verification process carried out

In order to provide isolation and resistance, another layer of encapsulant material (EVA) is used. The Ethyl Vinyl Acetate (EVA) is an excellent transmitter of solar radiation, ultraviolet radiation does not degrade it, it also acts as a protector of any possible vibrations and impacts and it is used as an adhesive between the front and back covers of the module.

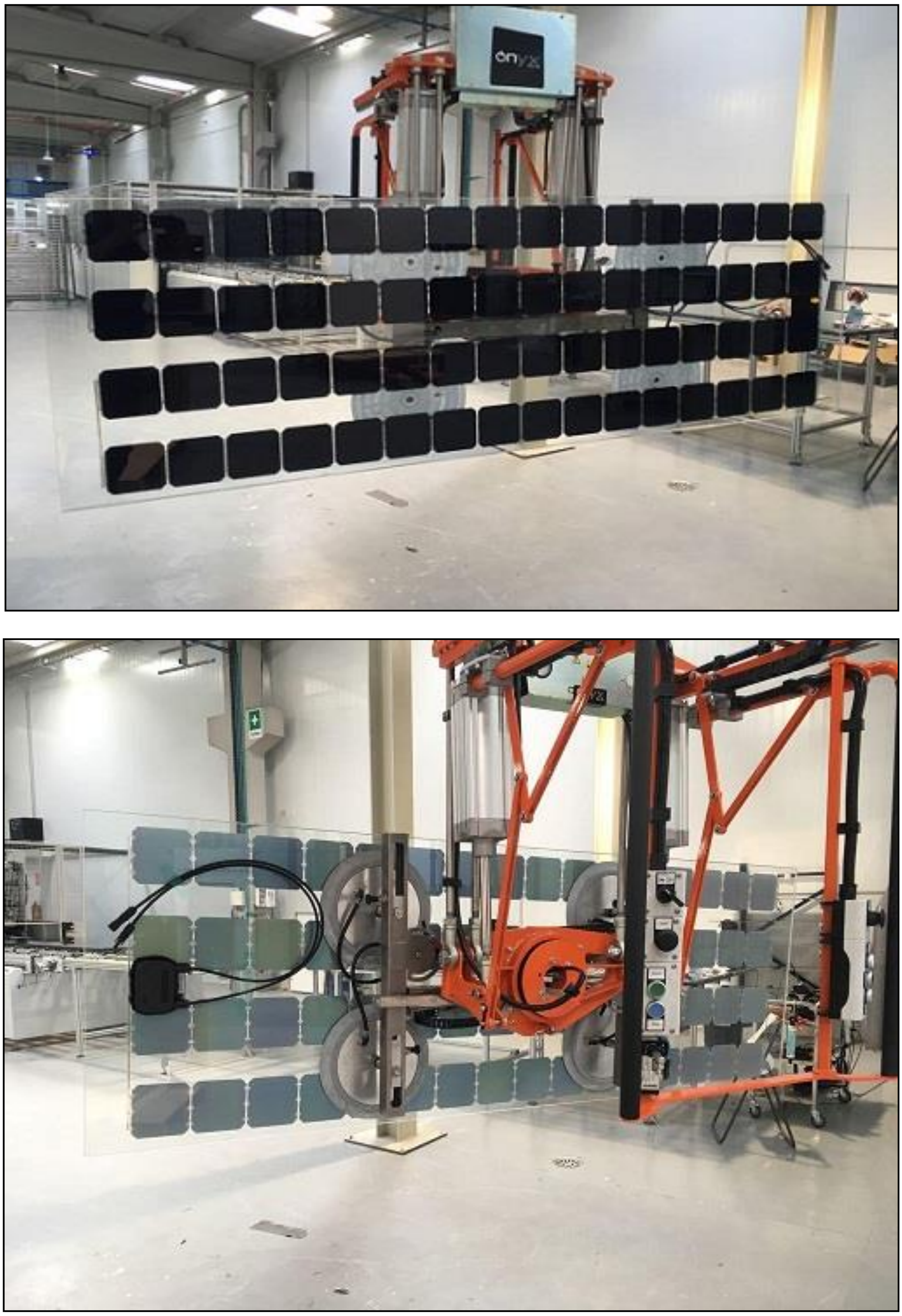


Figure 7.6: Example of one of the prototypes manufactured

Once the system is assembled, the laminating process starts. During this process, the system is subjected to pressure and temperature in a furnace with the aim of removing air and to get the cells completely isolated. The encapsulant inside the oven reaches a high degree of compaction and adherence. The excess of encapsulant material (EVA) is removed as soon as the glass is cured. Manufacturing process of PV Glass concludes with the connection box assembly and placing terminals therein. The final technical parameters of the product are obtained by a solar testing simulator based on a Xenon flash lamp and an electric charge with a multi-meter, simulating STC conditions.

7.2.2 Quality control and validation tests

Quality control applied to the manufacturing processes was similar than explained in section 7.2.2.

Validation tests applied to the manufactured prototypes were similar than explained in section 7.2.3.

X6 prototype was tested under different standards within WP3. Results can be reviewed in D3.9.

Table 7.2 Performed tests for X6 prototype

Product name	Test field	Standard and test	Comments
X6 - Glass-glass products with back contact c-Si cells	Construction standards	ISO 12543-4: radiation, humidity, high temperature EN 410: Optical properties	
	Photovoltaic standards	IEC 61215: severe dielectric rigidity test, thermal cycling, damp heat	-

7.2.3 Measures applied for storing, transport, handling and installation of prototypes.

The final units were stored in full closed crates waiting for the shipping order from TECNALIA. The rejected units were stored in trestles for glass in order to have a balance between a secured storage and flexible handling.

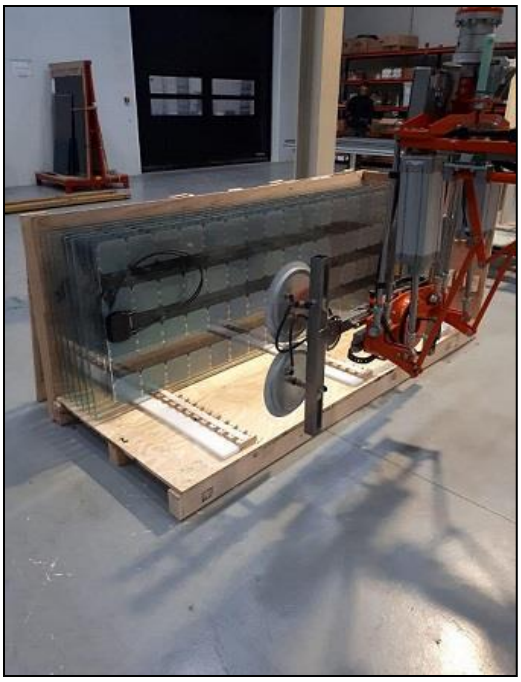


Figure 7.7: X6 c-Si back contact modules stored in crates and ready to be shipped

Figure 7.8: Discarded X6 c-Si back contact modules stored in trestles

7.2.4 Prototype Registration

Tables below show the register of manufactured and validated prototypes.

	CONTROL SHEET		
TECHNOLOGY	CRYSTALLINE (Back Contact)	GLASS-GLASS	
PROJECT		PV SITES X6	

PRODUCTION				
	SERIAL NUMBER	DATA	ELECTRICAL TESTING	COMMENTS
1	280518SUN5M66001	28/05/2018	OK	M01
2	280518SUN5M66002	28/05/2018	OK	M01
3	280518SUN5M66004	28/05/2018	OK	M01
4	280518SUN5M66006	28/05/2018	OK	M01
5	280518SUN5M66007	28/05/2018	OK	M01
6	280518SUN5M66008	28/05/2018	OK	M01
7	280518SUN5M66009	28/05/2018	OK	M01
8	280518SUN5M66010	28/05/2018	OK	M01
9	040618SUN5M66015	05/06/2018	OK	M01
10	040618SUN5M66016	05/06/2018	OK	M01
11	040618SUN5M66017	05/06/2018	OK	M01
12	040618SUN5M66018	05/06/2018	OK	M01
13	040618SUN5M66020	05/06/2018	OK	M01
14	060618SUN5M66021	06/06/2018	OK	M01
15	060618SUN5M66022	06/06/2018	OK	M01
16	060618SUN5M66023	06/06/2018	OK	M01
17	060618SUN5M66025	06/06/2018	OK	M01
18	060618SUN5M66026	06/06/2018	OK	M01
19	060618SUN5M66027	06/06/2018	OK	M01
20	060618SUN5M66030	06/06/2018	OK	M01
21	070618SUN5M66032	07/06/2018	OK	M01
22	070618SUN5M66033	07/06/2018	OK	M01
23	070618SUN5M66034	07/06/2018	OK	M01
24	070618SUN5M66035	07/06/2018	OK	M01
25	070618SUN5M66036	07/06/2018	OK	M01
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28	070618SUN5M66041	07/06/2018	OK	M01
29	080618SUN5M66042	08/06/2018	OK	M01
30	080618SUN5M66043	08/06/2018	OK	M01

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35	080618SUN5M66049	11/06/2018	OK	M01
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39	080618SUN5M66057	11/06/2018	OK	M02
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43	110618SUN5M66061	12/06/2018	OK	M02
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47	110618SUN5M66067	12/06/2018	OK	M02
48	110618SUN5M66068	12/06/2018	OK	M02
49	110618SUN5M66069	12/06/2018	OK	M02
50	120618SUN5M66072	13/06/2018	OK	M02
51	130618SUN5M66073	13/06/2018	OK	M02
52	130618SUN5M66075	13/06/2018	OK	M02
53	130618SUN5M66076	13/06/2018	OK	M02
54	130618SUN5M66077	13/06/2018	OK	M02
55	130618SUN5M66079	13/06/2018	OK	M02
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60	140618SUN5M66084	14/06/2018	OK	M02
61	140618SUN5M66085	14/06/2018	OK	M02
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63	140618SUN5M66087	14/06/2018	OK	M02
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68	140618SUN5M66092	15/06/2018	OK	M02
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74	150618SUN5M66098	15/06/2018	OK	M02
75	150618SUN5M66099	15/06/2018	OK	M02
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78	150618SUN5M66103	22/06/2018	OK	M02
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83	220618SUN5M66109	25/06/2018	OK	M02
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85	220618SUN5M66112	25/06/2018	OK	M01
86	220618SUN5M66113	25/06/2018	OK	M01
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93	130718SUN5M66127	16/07/2018	OK	M01
94	130718SUN5M66128	16/07/2018	OK	M01
95	160718SUN5M66129	16/07/2018	OK	M01
96	160718SUN5M66130	16/07/2018	OK	M01

7.3 Lessons learnt for subsequent production

The main problems detected are related to the difficulty of working with back-contact cell technology. The fragility of the cells requires constant control of their integrity, both electrical and mechanical, during the different phases of the manufacturing process.

Therefore, as described above, the verification processes are carried out in the different manufacturing phases, during which a large rejection rate has been detected (23%), mainly during the welding processes of the series and the subsequent interconnection thereof.

Due to this fact, a new revision protocol linked to this type of technology was incorporated into the manufacturing methodology, based on the verification of the voltages and photoluminescence tests after the different manufacturing stages.

Obviously, it was confirmed that the manual welding process induces high rejections rate and, in order to reduce rejections, a fully automatic welding machine will be preferred. Thus, ONYX is currently working in the development of automatic tabber/welding machine for back-contact solar cells within H2020 project BIPVBOOST.

8 BOS COMPONENTS PROTOTYPES BY CEA

The following sections include the complete characterization of the 5kW 3-phase photovoltaic inverter design and the list of technical requirements fulfilled, as well as a brief explanation of the manufacturing and the tests carried out for the validation of the manufactured prototypes. At the date of writing this report, inverters are not installed in the two demosites (CRICURSA and TECNALIA).

8.1 Final three-phase PV inverter design

Below are listed the technical requirements considered for the equipment design and detailed the main technical data and characteristics of the final product.

The inverter has been designed in order to fulfil the requirements of the European standards concerning PV inverters. Considered standards are listed bellows:

- Grid requirements:
  - IEC 62910: Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements.
  - EN 50438: Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks.
  - IEC 61000-3-2: Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase).
- Safety:
  - IEC 62116: Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures.
  - IEC 62109-1: Safety of power converters for use in photovoltaic power systems - Part 1: General requirements.
  - IEC 62109-2: Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverter.
  - DIN VDE 0126-1-1: Automatic disconnection device between a generator and the public low-voltage grid.
- Efficiency measurement:
  - EN 50530: Overall efficiency of grid connected photovoltaic inverters.

The final specifications of the SiC inverter developed by CEA are provided in the datasheet below.

Table 8.1 Technical specifications of the 5 kW three-phase PV inverter developed by CEA

Functionality description	5 kW, three-phase, photovoltaic inverter
Technology description	Current-source topology (CSI) based on silicon carbide (SiC) semiconductors
Number of PV inputs	1
Number of MPP trackers	1
Nominal AC Power	5 (kVA)
Maximum PV power	5 (kW)
Dimensions	410x160x290 (mm)
Weight	13 (kg)
Enclosure	Metallic box with locked front door
Protection degree	IP65
HMI	Front LCD screen and push buttons
Communication	Modbus RS485
Refrigeration	Natural air-cooling heatsink
Mounting system	Wall mounting with screwed fixture
Operating temperature	80 ºC (heatsink)
General protections	Metallic box preventing electric shocks
Safety procedure	Before any intervention on the inverter (cabinet opening): 1) AC-side electrical separation followed by, 2) PV cable disconnection
PV connectors	MC4 PV connectors
AC connectors	Screw terminal blocks
Communication connectors	RJ45 connector and RS485 terminal
HMI	Front LCD screen
Maximum Efficiency	98%
Overall efficiency (50530)	97.5% (CEC), 97.1% (EU)
Input voltage Range	140V – 500V
MPPT voltage Range	280V - 400V (at full rated power)
Max Input Current	18 A
Power factor (PF)	>0.90 in normal condition
Nominal Output Voltage	230 V_{RMS}

Max Output Current	9 A_{RMS}
Nominal frequency	50 Hz
Stand-by consumption	15 W
Night consumption	0 W
Switching frequency	125 kHz
Residual Current Detector (RCD)	yes
Low Voltage Ride through (LVRT)	yes
Anti-islanding protection	Detection based on active method
PV array insulation resistance detection	yes

8.2 Manufacturing report

Number of prototypes to be manufactured: 4.

The manufactured devices are PV inverters tied to the 3-phase AC grid. The power of the inverter is 5kW. It has been designed to work on the 400V, 50Hz grid, with a DC input voltage range is 280V to 500V.

The inverter is based on 12 silicon carbide MOSFET that are surface-mounted on a printed circuit-board. The thermal management is made with a naturally cooled heatsink. Common-mode and differential-mode filters are built with through-holes mounted passive components. Safety components are also included, such as relays and residual current monitoring unit. Low power electronic for MOSFET driving and monitoring are placed on the power circuit board too. Control is implemented on a FPGA chip, which is placed on a daughter board. A human to machine interface, with push buttons and LCD screen, is assembled through the front door. All components of the inverter are packed in a metallic housing that can be mounted on a wall. Connections for DC and AC cables are available.

8.2.1 Description of manufacturing process

A total of 4 silicon carbide-based inverters of 5kW power have been manufactured to be installed on 2 demonstration sites (TECNALIA and CRICURSA).

Pictures below show the printed-circuit board of the inverter with electronic components mounted; the housing of the whole device and the electrical connections.

Figure 8.1 shows the front-side of the printed circuit board with all the surface mounted component and in particular the two switching cells.

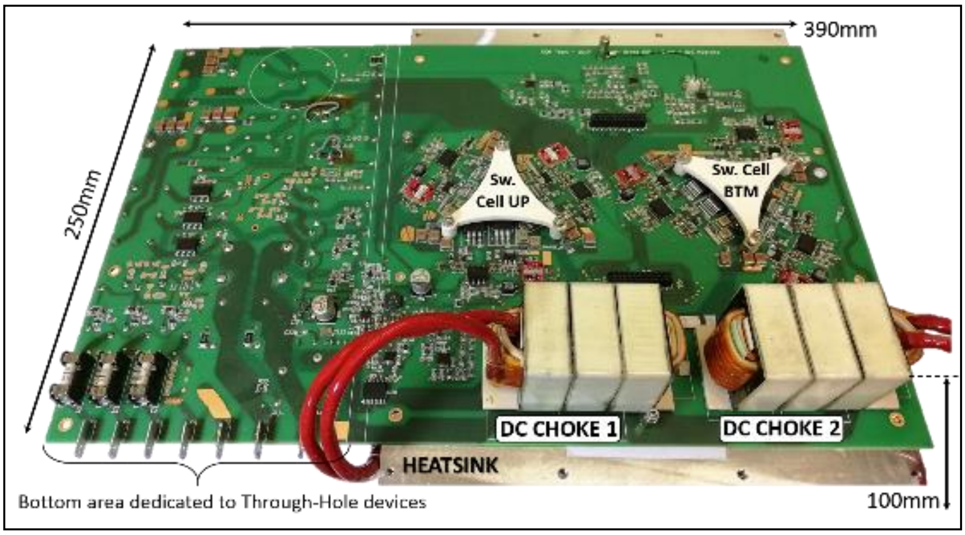

Figure 8.1: CEA's inverter printed circuit-board with surface-mounted electronic components

Figure 8.2 shows the inverter housing, without the circuit board to be screwed to the heatsink at the bottom. On the door, the human to machine interface board.

Figure 8.2: Front view of the inverter housing

Figure 8.3 shows the printed circuit board mounted on the heatsink with through-holes electronic components.

Figure 8.4 shows the backside of the housing of the inverter, the heatsink and the mounting system.

Figure 8.5 shows the front side of the opened inverter, with the printed-circuit board and the inverter.

Figure 8.6 shows the electrical connectors and their assignations.

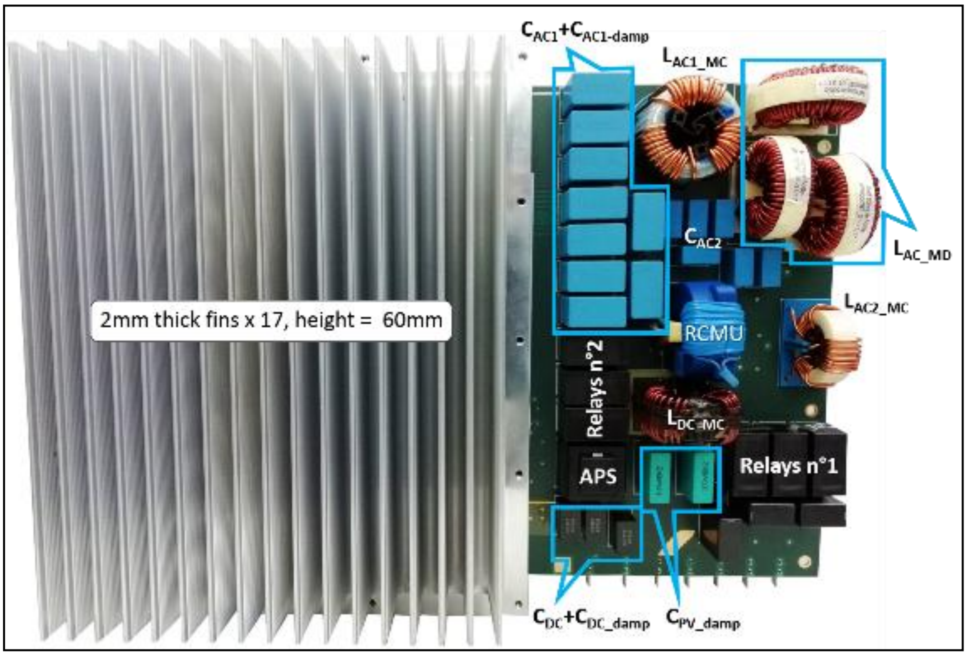

Figure 8.3: Back view of the printed circuit board

Figure 8.4: Back view of the inverter with heatsink and wall mounting system

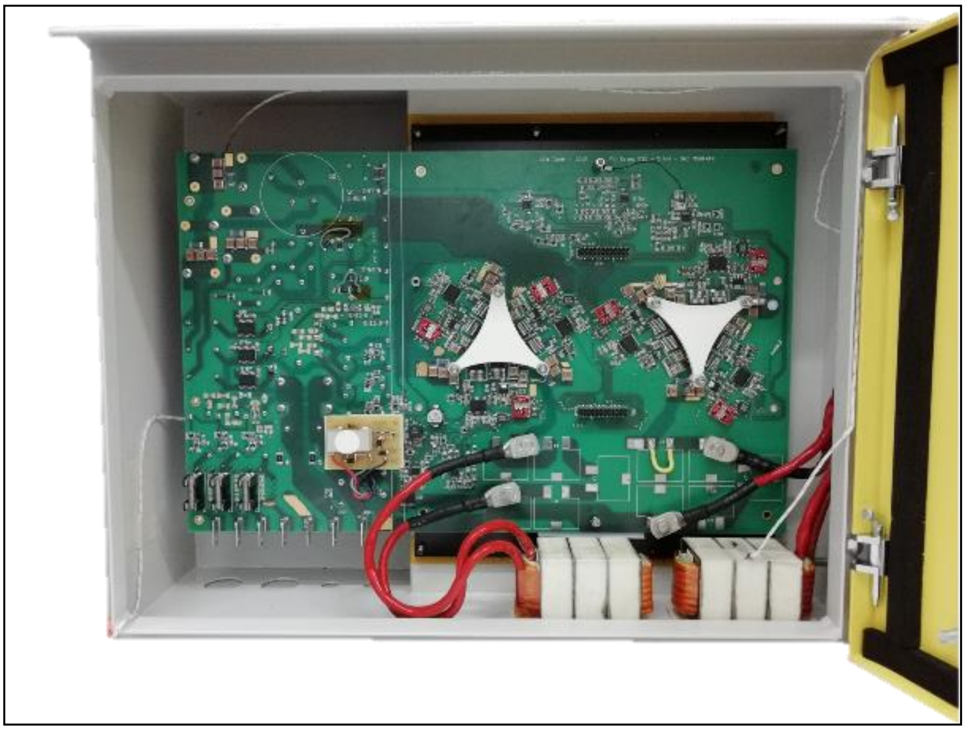

Figure 8.5: Printed circuit-board placed into the housing

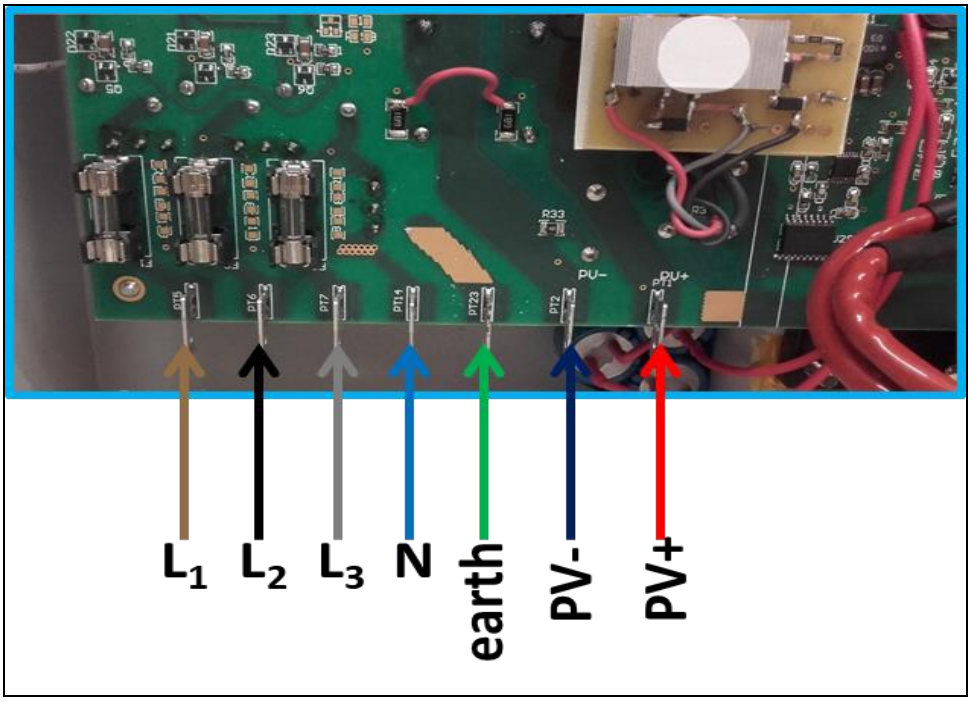

Figure 8.6: Electrical connections

8.2.2 Quality control and validation tests

Functional, electrical operation in normal condition tests have been performed.

The inverter injects the current in the 3-phase grid and work the PV generator at its maximum power point as required.

Waveforms are shown in Figure 8.7:

- DC voltage $V_{PV.}$
- DC current $I_{PV.}$
- AC voltage $V_{AC.}$
- AC current $I_{AC.}$
- Control pattern of the 12 switches.

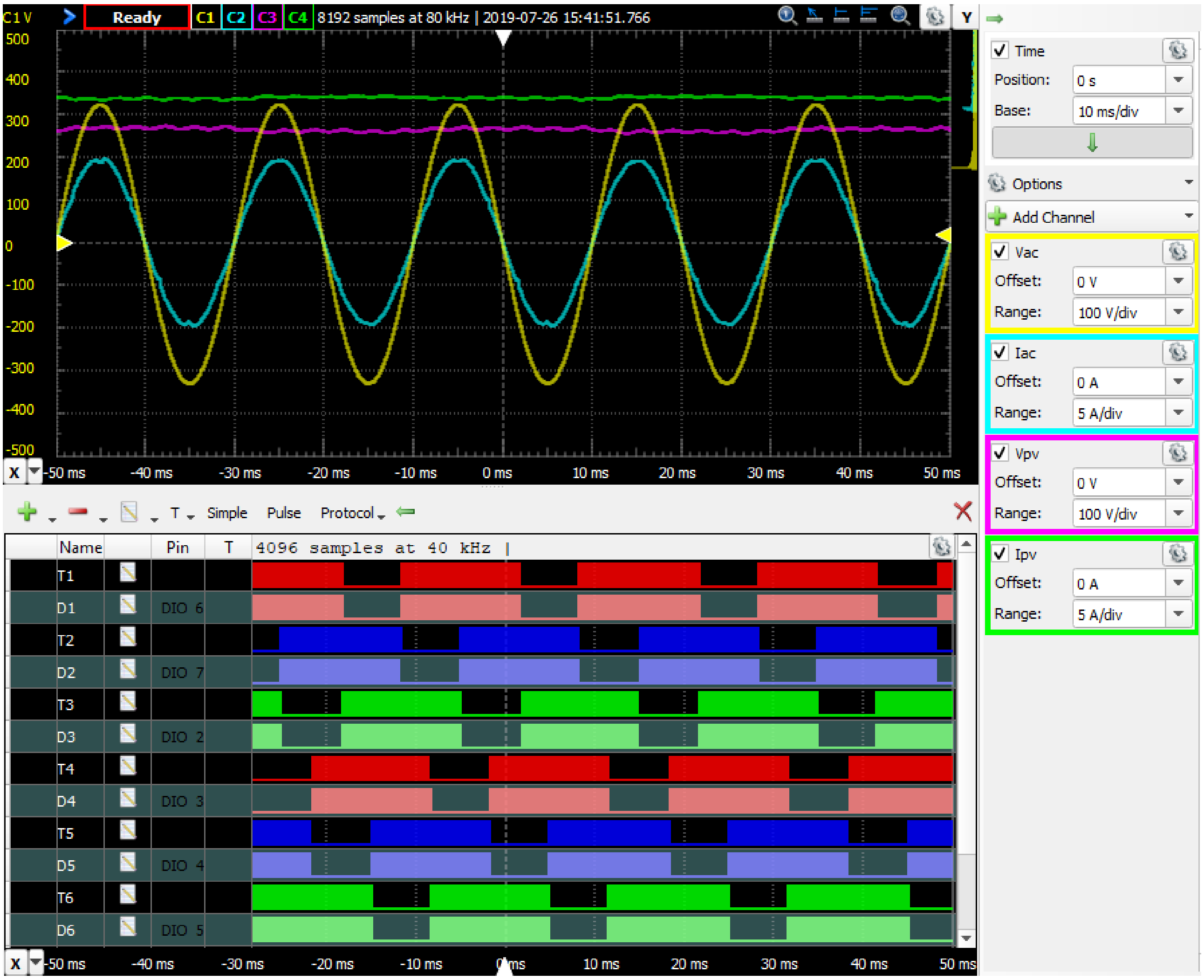

Figure 8.7: Waveform signals measured with oscilloscope

Conversion efficiency has been measured according to the EN50530 standard, resulting in the plotted curves Figure 8.8:

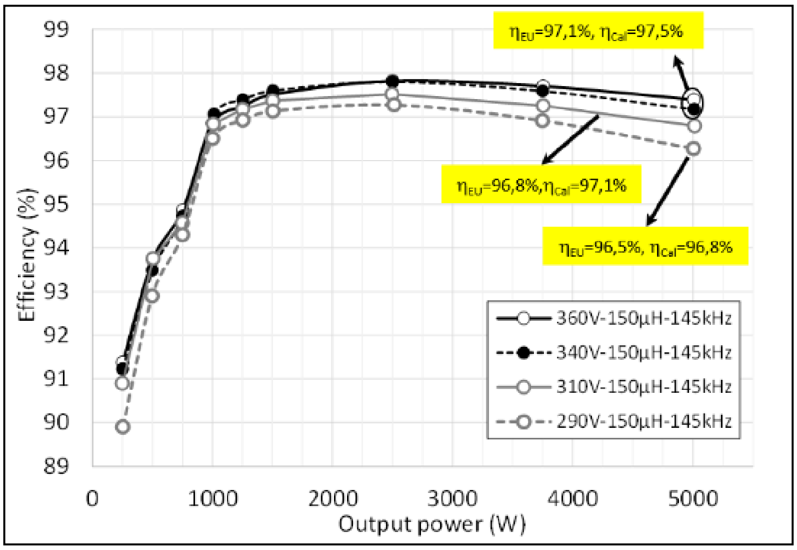

Figure 8.8: Measured conversion efficiencies

Validation tests for which the inverter complies are:

1- **Normal Operating Range**
   a. **Voltage & Frequency Operating Range. (EN50438)**
   b. **Under-frequency response (EN50438)**
   c. **Over-Frequency response (EN50438)**
2- **Interface Protection**
   a. **Under / Over Voltage Test (EN50438)**
   b. **Under / Over Frequency Test (EN50438)**
   c. **Main Loss Detection (Islanding) (IEC 62116)**
   d. **Automatic Reconnection (EN50438**
3- **Safety Protections**
   a. **Residual current detection (IEC 62109:2)**
   b. **PV array insulation resistance detection (IEC 62109:1)**
4- **Power Quality**
   a. **Harmonic & Flicker (61000-3-2, 61000-3-3)**
   b. **DC Current Injection (EN50438)**
5- **Low Voltage Ride Through (IEC 62910)**
6- **Reactive Power Delivery (EN50438)**
7- **MPPT Tests (EN50530)**
8- **Power Conversion Efficiency (EN50530)**

Figure 8.9 shows the profiles required by the Spanish PO12.3 grid-code, the inverter must comply with active power versus grid frequency, active and reactive power versus grid voltage and low-voltage ride through capability.

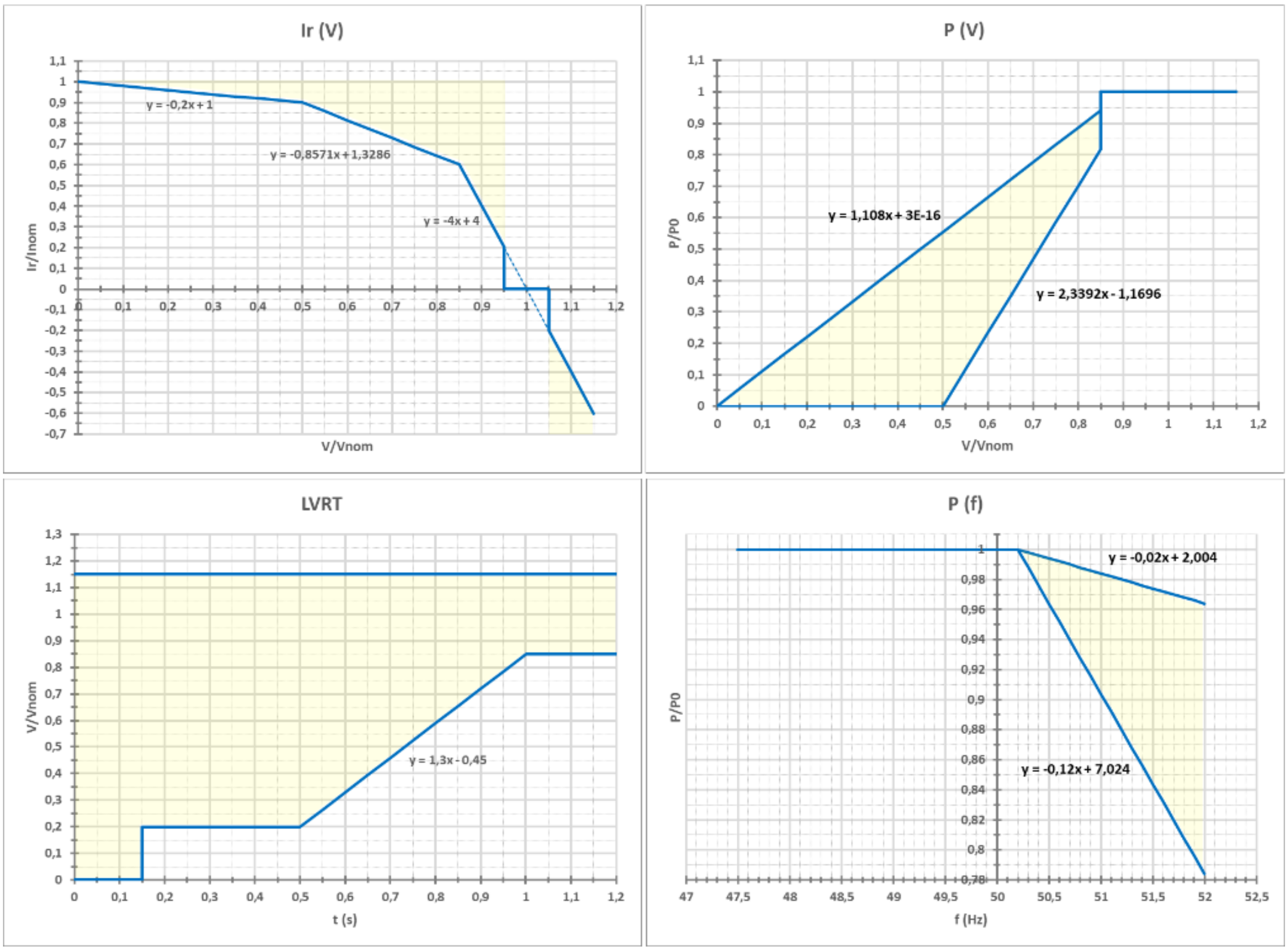

Figure 8.9: Spanish grid-code profiles

8.3 Lessons learnt for subsequent production

Below are listed the lessons learnt, from the first inverter prototype, during the design and implementation of the PVSITES new converter:

- Implementation and driving of specifically packaged 900V silicon carbide MOSFET.
- Use of the synchronous rectification, with anti-serial connected MOSFET, in order to reduce the on-state diode losses.

- Common-mode filter design and tuning for transformer-less grid connected current-source inverter, especially concerning the earth leakage current flowing, due to PV modules parasitic capacitances.
- DC inductor current cancelation procedure, essential in order to allow the inverter stopping, thanks to a software based method.
- Integration and use of PV inverter specific safety subsystems like PV insulation resistance measurement, residual current monitoring and anti-islanding detection.

9 BOS COMPONENTS PROTOTYPES BY TECNALIA

9.1 Final PV-storage converter design

A high efficiency, low cost and flexible 10kW three-phase DC-coupled PV storage inverter has been designed by TECNALIA. The equipment can be easily parallelized to make larger systems up to hundreds of kW and offers a wide DC input range to cope with different BIPV generators (even affected by mismatching effects) and battery packs. It communicates with the BEMS in order to provide monitoring data about PV storage inverter performance and receiving the required commands to implement required energy management strategies. Multilevel symmetrical topology is used for the DC-DC Converter for battery and PV source management. Both converters and the Three-Phase DC-AC Converter are coupled in a high-voltage DC link. The control unit is composed of a DSP controller (TMS320F28335) and FPGA for managing the power transfer inside the converter and provide external communication.

Figure below shows the system and inverter's basic diagrams.

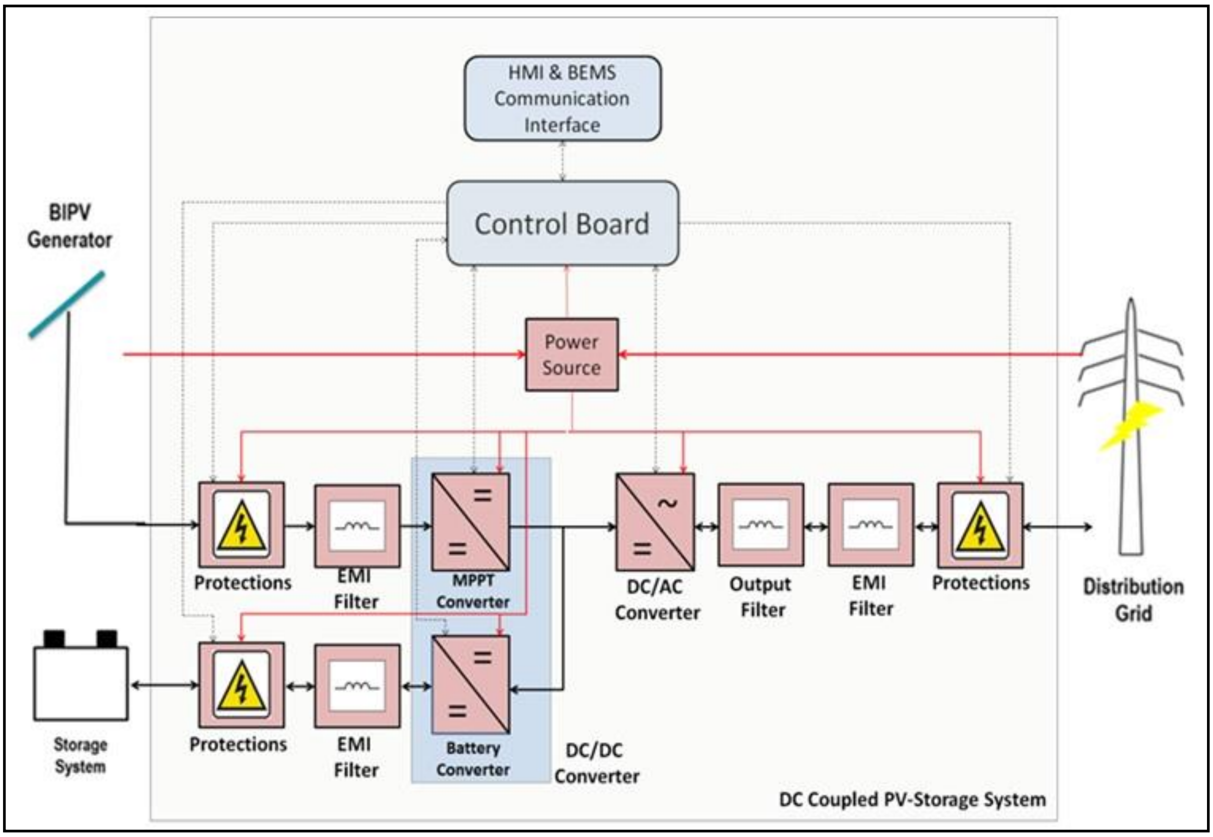

Figure 9.1: Basic diagram of the DC Coupled PV-Storage System

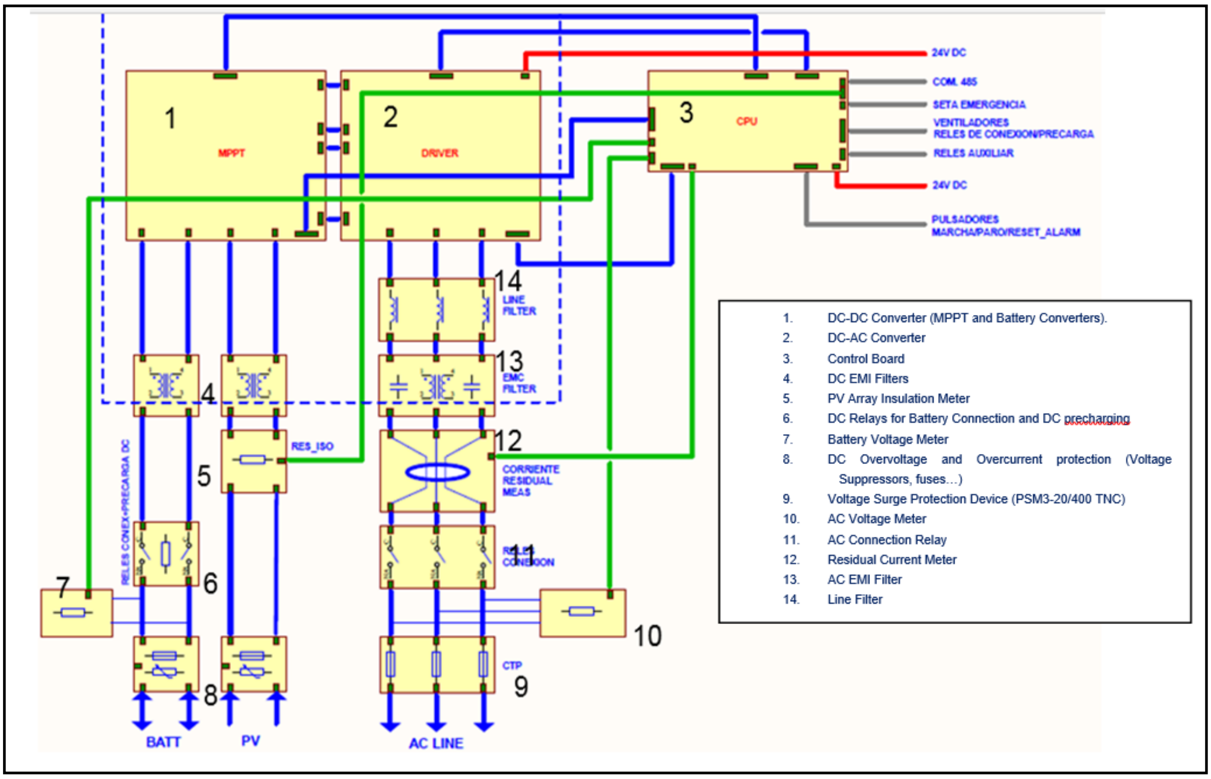

Figure 9.2: Basic diagram of the DC-Coupled PV-Storage Converter

Table below gathers the technical specifications of the PV-storage converter.

Table 9.1 Technical Data / Specifications of the DC-Coupled PV-Storage Converter

Input(DC)	
Number of Inputs	2
PV MPP Trackers	1
Battery Regulators	1
PV MPP Tracker	
Max Input Voltage	1000V
MPP voltage Range / Rated	200-800V / 650V
Min Input Voltage	200
Max Input Power	10kW
Min Input Power	50W
Max Input Current	20A
Battery Regulator	
Max Input Voltage	700V
Min Input Voltage	250V
Max Bat Power	10kW
Min Bat Power	50W
Max Bat Current	20A
Output (AC)	
Max AC Output Power	10kW
Nominal AC Voltage	230V/400V
Max AC Output Current	15.9A / 27.6A
Number of Phases	3
Power factor (PF)	>0.9998 at Rated Power
Power factor Range (PF)	0.95 Overexcited to 0.95 Underexcited
Frequency	50Hz
Efficiency	
PV to Grid Efficiency (Max/European)	96.589% / 95.746%
PV to Bat Efficiency (Max)	0.96249
Bat to Grid Efficiency (Max)	97.23%

Protective devices	
PV Array Insulation Monitoring	YES
Residual Current Detector	YES
DC Reverse Polarity Protection	YES
Galvanically Isolated	NO
Anti Islanding Protection	YES (UNE EN 62116)
LVRT Capability	YES (IEC 62910)
Direct Current Injection Protection	YES
AC Voltage Protection	YES
AC Frequency Protection	YES
General Data	
Dimensions	840x740x280 (mm)
Weight	75kg
Enclosure	Metallic cabinet
Mounting system	Wall mounting
Topology	Transformerless
Cooling	Forced Ventilation
Protection degree (IEC 60529)	IP65
Operating temperature	0 – 40 ºC
Relative humidity	0-90%
Stand-by consumption	15W
Communication	RS485. Modbus RTU
HMI	LEDs for indicating Inverter errors/status
External Switches	Start/Stop Selector
	Supply Switch

9.2 Manufacturing report

Number of prototypes to be manufactured: 3.

9.2.1 Description of manufacturing process

Figure 9.3 shows the 3D design developed by TECNALIA for building the converter envelope. The structure was manufactured in a local company called CISUNOR and the converter was finally mounted by Elson.

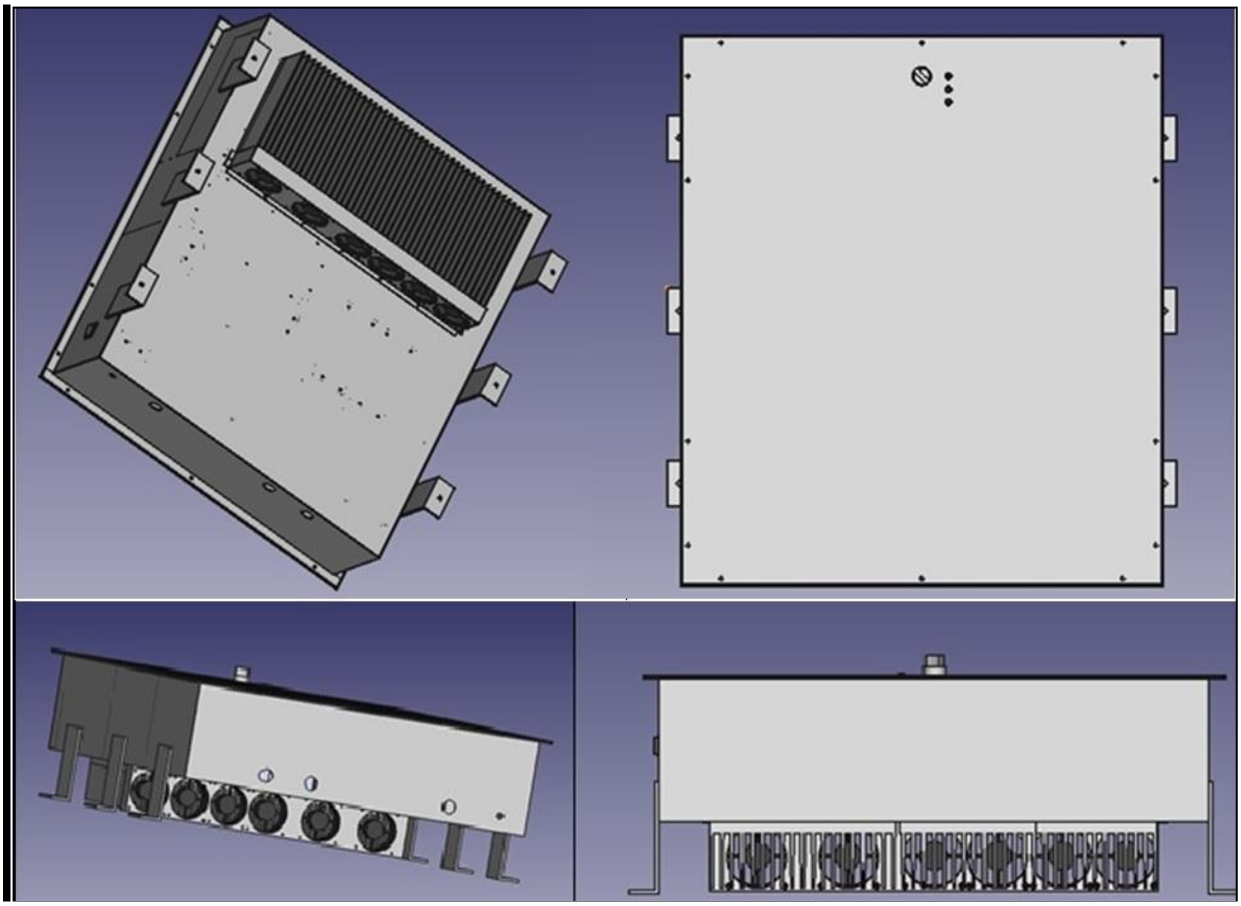

Figure 9.3: TECNALIA's PV-Storage Inverter. 3D Design

The following pictures show the aspect of the first manufactured prototype.

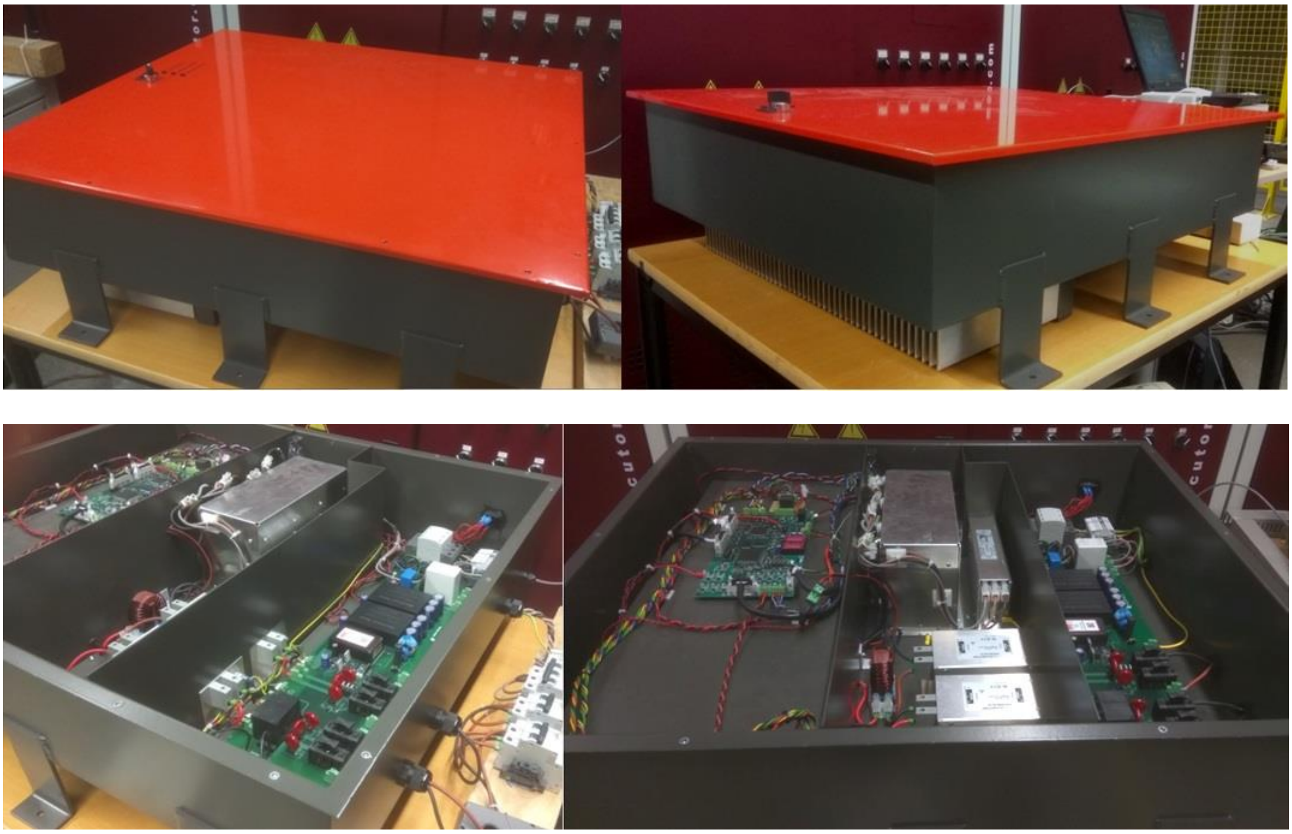

Figure 9.4: TECNALIA's PV-Storage Inverter. Prototype 1

9.2.2 Quality control and validation tests

In order to validate the manufactured prototypes, they must be subjected to a minimum list of tests. The results of these tests must be compared with the data obtained from the reference prototype, which has been completely tested before, including grid code certification tests according to what is documented in deliverable 5.4 The list of tests to be applied to each manufactured prototype can be summarized as follows:

Table 9.2 TECNALIA's PV-Storage Inverter. Prototype Testing

Test	Description	Procedure	Duration
Serial Communication	Serial communication must be tested first so as to check if the inverter is capable of receiving operating parameters or sending monitoring data.	The communication might be done using a Modbus Master Simulator in a PC.	Test read / write of several input and holding registers.
Analog measurements	The correct measurement of the different analog signals (voltages, currents and temperatures) must be checked and	These measurements can be obtained by connecting the DSP emulator or by using inverter communications. Some calibrating parameters can be modified through communications. If any parameter not included in the communication map must be changed, calibration should be completed with FW modification.	

<table>
<tr><th>Test</th><th>Description</th><th>Procedure</th><th>Duration</th></tr>
<tr><td></td><td>calibrated before starting inverter operation.</td><td></td><td></td></tr>
<tr><td>Functional tests</td><td>These initial tests have the objective of checking the correct operation of the different parts comprising the PV-Storage Inverter: Power Converters (Battery, PV and Grid).</td><td>The correct performance of the inverter must be observed for different PV generation levels or grid power references as indicated in the following table:
<table>
<tr><th colspan="4">Functional tests</th></tr>
<tr><th></th><th colspan="3">Power Level</th></tr>
<tr><th>Test nº</th><th>PV</th><th>GRID</th><th>BAT</th></tr>
<tr><td>1</td><td>100%</td><td>100%</td><td>0%</td></tr>
<tr><td>2</td><td>100%</td><td>66%</td><td>33%</td></tr>
<tr><td>3</td><td>100%</td><td>33%</td><td>66%</td></tr>
<tr><td>4</td><td>100%</td><td>0%</td><td>100%</td></tr>
<tr><td>5</td><td>66%</td><td>100%</td><td>-33%</td></tr>
<tr><td>6</td><td>66%</td><td>66%</td><td>0%</td></tr>
<tr><td>7</td><td>66%</td><td>33%</td><td>33%</td></tr>
<tr><td>8</td><td>66%</td><td>0%</td><td>66%</td></tr>
<tr><td>9</td><td>33%</td><td>100%</td><td>-66%</td></tr>
<tr><td>10</td><td>33%</td><td>66%</td><td>-33%</td></tr>
<tr><td>11</td><td>33%</td><td>33%</td><td>0%</td></tr>
<tr><td>12</td><td>33%</td><td>0%</td><td>66%</td></tr>
<tr><td>13</td><td>0%</td><td>100%</td><td>-100%</td></tr>
<tr><td>14</td><td>0%</td><td>66%</td><td>-66%</td></tr>
<tr><td>15</td><td>0%</td><td>33%</td><td>-33%</td></tr>
<tr><td>16</td><td>0%</td><td>0%</td><td>0%</td></tr>
</table>
It is not necessary to stop the converter to change the power level, it can be modified by setting the corresponding references through communications and modifying the PV Simulator.
It is recommendable to check the DC current injection and current harmonic emission for each test case.</td><td>No minimum duration.
It is enough to wait until the inverter becomes stable at the power level set point.</td></tr>
<tr><td>Continuous tests</td><td>The aim of these tests is to check the proper performance of the Inverter when working under expected continuous operation</td><td>In the same manner as seen for the functional tests, continuous operating must be checked for different power levels according to the following table:
<table>
<tr><th colspan="4">Functional tests</th></tr>
<tr><th></th><th colspan="3">Power Level</th></tr>
<tr><th>Test</th><th>PV</th><th>GRID</th><th>BAT</th></tr>
<tr><td>1</td><td>100%</td><td>100%</td><td>0%</td></tr>
<tr><td>2</td><td>100%</td><td>33%</td><td>66%</td></tr>
<tr><td>3</td><td>100%</td><td>0%</td><td>100%</td></tr>
<tr><td>4</td><td>33%</td><td>100%</td><td>-66%</td></tr>
<tr><td>5</td><td>0%</td><td>100%</td><td>-100%</td></tr>
</table>
The power conversion efficiency and converter temperature must be computed and compared with the expected results obtained for the pattern prototype.
The efficiency must be computed with a calibrated wattmeter, while the temperature can be obtained from communications.</td><td>4 hours / test as long as the temperature or power conversion efficiency is considered stable.</td></tr>
<tr><td>Grid Code Compliance Tests</td><td>The prototype must meet with all the connection requirements</td><td>As explained before it is only necessary to repeat some representative grid code tests for each prototype. If the applicable grid code for a certain prototype is equal to the one considered for the</td><td>Complete the required tests.</td></tr>
</table>

Test	Description	Procedure	Duration
	established by the applicable Grid Code. It is not compulsory to check the fulfillment of the complete grid code for each prototype, which has been previously done with the reference prototype, only some specific tests are necessary	previously tested reference, the following tests apply: - Low Voltage Ride Through Capability: Test the most restrictive case (Lower Voltage, Max duration). - Islanding Protection: Test Islanding protection at nominal configuration. - Ground fault protection: Connect the corresponding resistor or capacitance to ground so as to check the proper ground protection. - PV Array Insulation protection: Connect the corresponding limit insulation resistor to ground so as to verify that the inverter does not start operation and reporting the corresponding alarm. - Verify Power Quality: Check the values of harmonic emission and DC Current injection measured in the functional tests. If the applicable grid code is not the same, the differences between both grid codes must be analyzed (different interface protection values, different limits, different test procedure…) to determine which test must be repeated.	

9.2.3 Measures applied for storing, transport, handling and installation of prototypes

The inverter weights 75kg, so the user must be aware of the injury risk in case of lifting the inverter incorrectly or in case of dropping when it is transported. Therefore, it must be carried and lift upright with the help of several people. The Inverter must be mounted following the subsequent specifications:

- Mount the Inverter vertically on the wall or on a solid surface with tilted backwards by maximum 15ºC.
- The mounting location must always be clear and safely accessible without the use of additional aids, such as scaffolding or lifting platforms.
- The ambient temperature should be below 40°C to ensure proper operation. Do not expose the inverter to direct solar irradiation.
- Respect at least the following clearance to the walls or other objects:
  - Floor: 50cm.
  - Sides: 30cm each side.
  - Ceiling: 30cm.
  - Front: 10cm.

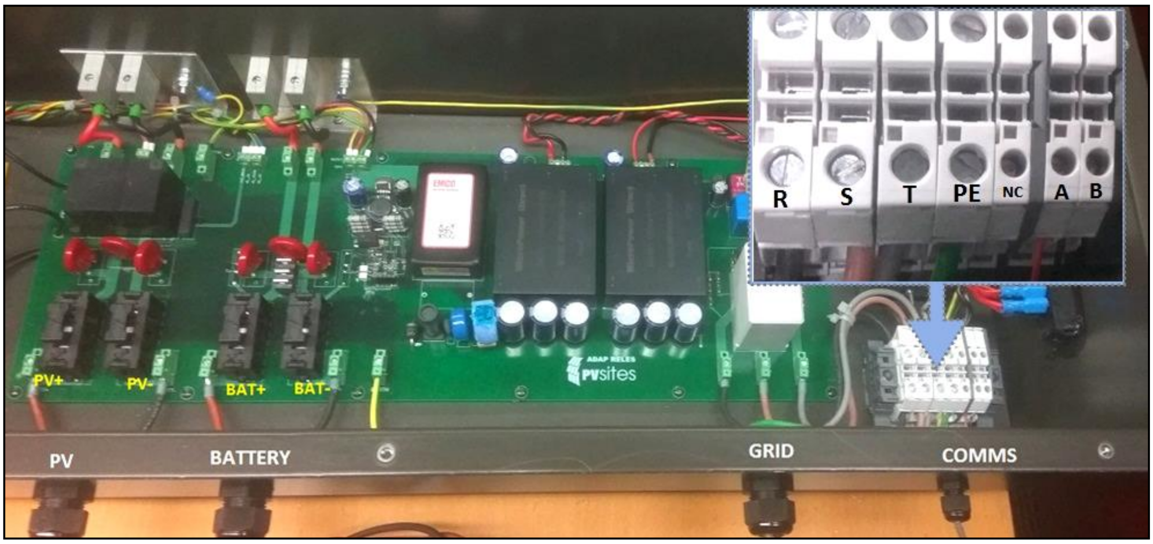

Figure 9.5: TECNALIA's PV-Storage Inverter. Wiring

For wiring the different power sources (Battery, PV and Grid) as well as the communication line, please, remove the front cover carefully disconnecting the cables connected to it. Inverter terminals must be connected as indicated in Figure 9.5. To avoid damaging the inverter and electrical shock hazard, please, disconnect all the power sources and be sure the inverter is not operating and energized (wait at least 5 minutes from switch off) before manipulating the inverter. The correct order for switching off the equipment is:

- Stop Inverter operation through communications or set front selector to off (see below).
- Switch off the supply switch (see below).
- Disconnect all the power sources connected to the Inverter.

Please, follow the reverse order for turning on the inverter. Figure 9.6 shows the different indicators and switches provided by the Inverter, which can be listed as follows:

- Front switch: To enable/disable inverter operation.
- Right side switch: To switch on/off inverter power supply.
- LED Indicators: Three LED Indicators (red, yellow and green) to inform about different inverter status according to what showed in
- Table **9.3**.

Table 9.3 TECNALIA's PV-Storage Inverter: LEDs Code

State		Red	Yellow	Green
Battery SOC	NORMAL	OFF	X	X
	HIGH	ON	X	X
	LOW	Blinking	X	X
ALARM ON		OFF	ON	OFF
Battery Status	CHARGING	X	ON	ON/Blinking
	DISCHARGING	X	Blinking	ON/Blinking
Inverter Operation	Grid_ON + NO_PV	X	X	Blinking
	Grid_ON + PV_ON	X	X	ON

LED indicators can be seen in the front side of the equipment.

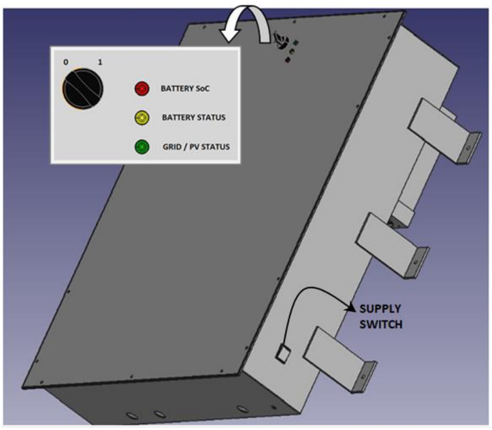

Figure 9.6: TECNALIA's PV-Storage Inverter. LED Indicators and External Switches

9.2.4 Prototype Registration

Table 9.4 assigns a serial number and version to each prototype manufactured.

Table 9.4 TECNALIA's PV-Storage Inverter. Prototype registration.

Prototype	Serial Number	HW Version	FW Version	Installation
Prototype 1	1	v2.1	V3.2	Tecnalia Testing
Prototype 2	2	v2.2	V3.3	Vilogia Demo
Prototype 3	3	v2.2	V3.3	Vilogia Demo
Prototype 4	4	v2.2	V3.4	FormatD^2 Demo

HW release notes:

- v2.1. Changes (from previous version):
  - New Input/output Board version (Power Supply Filtering, Solid State Relays and new ADC circuit for PV Insulation Measurement…).

- EMC Filtering Capacitors at Battery Input.

- v2.2. Changes:
  - PV Connection Relay.

FW release notes:

- v3.2. Changes:
  - Modbus Mapping modification.
  - New BMS interaction.
  - Spain Grid Code.
- v3.3. Changes:
  - France Grid Code.
- v3.4. Changes:
  - Belgium Grid Code.

9.3 Lessons learnt for subsequent production

Until now, only two minor problems, which will be considered for futures HW versions, have been identified for the last prototype. They can be listed as follows:

- LED connectors: The CPU board does not provide terminal connectors for wiring the corresponding signals to the led indicators. In the present version, this has been solved by welding cables directly into the board.

- Pull-up resistors in microcontroller relay signals: A problem regarding unintended relay activation was detected when switching off Inverter power supply. The microcontroller seemed to be switched off before than other parts of the circuit, so relay signal are left in high impedance and then unintended short relay activations occurred. Despite being a very short period activation, high currents can appear at battery and grid terminal. The signals provided by the microcontroller for this purpose are low active, so to avoid this it is necessary to add a pull-up resistor for each one.

- Some problems have been detected when validating the prototypes, which have required some HW changes. They can be listed as follows:

  - Power Supply filtering: Power supply was affected by common mode noise, which jeopardized ADC measurement and RS485 communication. The problem was solved by adding a common mode filter at power supply input.
  - PV Insulation Measurement: Some problems were detected when measuring the PV array insulation resistance. First, it was necessary to replace the high voltage-low power relays used to measure each channel by low power solid state relays. Secondly, it was necessary to modify the ADC circuit to allow the measurement of negative voltages to earth. Moreover, it was necessary to add power connection relay in the PV input in order to disconnect the power converter from the PV array when measuring the insulation resistance.
  - EMC Filtering Capacitors: EMC filter selected for battery input did not include stray capacitors to earth, which was not considered necessary because was not affected by parasitic capacitors. Nevertheless, this was found problematic at some operating modes, creating noise problems inside the inverter and excessive residual current circulation. Proper stray capacitors were included in order to solve this problem.