Cofund

Deliverable 4.5

Final Demonstration Project Progress Reports

June 2022

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Introduction

This report constitutes Deliverable 4.5 Final Demonstration Progress Report of the SOLAR-ERA.NET Cofund action, with Grant Agreement n° 691664. It presents the synthesis of the individual transnational reports and is based on their publishable summaries prepared by the project coordinators.

Further information on impact and dissemination can be found in the Deliverables 5.2 Impact Assessment Report and 5.3 Final Dissemination and Exploitation and Best Practice Report.

Table 1: List of transnational projects completed

ID	Acronym	Full project title	Topic	Project volume in €	Effective funding in €	Contribution from EC in €
11	PANELPV	Sandwich panels with integrated PV with freedom of size and color.	B	965‘198.04	619‘602.42	165‘870.54
24	MASTERPV	Innovative manufacturing solutions for cost-efficient semitransparent BIPV	B	562'931.16	479'422.19	158'209.32
26	PEarl	PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating	A	867'518.15	589'401.53	194'502.50
28	BI-FACE	High-efficiency bifacial PV Modules and Systems for flat roof applications	B	1'093‘712.00	858‘070.00	283‘163.10
30	Cover Power	Smart Glass Coatings for Innovative BiPV Solutions	B	438'213.10	233'166.30	61'667.10
43	CEFRABID	Clean energy from road acoustic barriers infrastructure development	B	451‘612.71	387‘626.21	127‘916.65
44	NEXT-FOIL	Next generation conductive solar foil for flexible photovoltaics	A	879'781.45	543'772.73	142'484.76
45	HEAVENLY	High-efficiency PERT and IBC cell development focussing on paste and CVD optimization for longterm stability	A	1'456‘964.21	1'119‘889.67	369'563.59
54	1500-SIC	Develop a new photovoltaic inverter with SiC for full power operation at 1500 V	C	1'654'442.67	728‘874.95	160'767.95
58	Erigeneia	Enabling rising penetration and added value of photovoltaic generation by implementation of advanced storage systems	C	655‘570.31	544‘806.81	179‘786.25
60	HyConSys	Hydrogen control in solar thermal parabolic trough heat transfer fluid systems	D	990'727.16	766'029.51	252'789.74
75	ENMESH	ENabling Micro-ConcEntrator PhotovoltaicS with Novel Interconnection MetHods	A	757'284.28	517‘995.13	138'885.02
76	PVtool	Development of tools for effective control of large PV power plants	C	1'228‘537.97	951‘002.59	313‘830.85
77	NELL	Novel encapsulant for long lifetime high voltage PID-resistant PV modules	B	533'675.00	417'834.50	137‘885.39
78	RHINO	Realization of High efficiency Industrial N-type sOlar cells	A	2'232‘954.41	1'377'153.08	454'460.52
91	PROGNOSIS	Intra-hour prediction of solar electricity generation from Photovoltaics	C	283'720.04	245'764.01	81'102.12
	Total			*15'052‘842.66*	*10‘380‘411.63*	*3‘222‘885.40*

PanelPV
Sandwich panels with integrated PV with freedom of size and color

Project duration: from 01.2018 to 12.2020

The project PanelPV aimed at the development of new façade elements with integrated PV. Starting components were sandwich panels made by Panelen Holland and CIGS based PV foil made by Flisom. In the project we have integrated these two into new power generating façade elements. As PV panels generally shows only a dark, almost black color, translucent PV films were developed to allow for color coming from the outside of the sandwich panel. Translucence was achieved by structuring the PV foil with a laser process in such a way as to create a high number of small enough voids. The human eye cannot resolve these individual patterns and perceives only a colored surface. 50% transparency with remaining 40% of the original electrical performance was demonstrated by the use of a new approach developed by TNO. This is an impressive achievement, especially in view of the often observed shunting that can be induced by such laser patterning steps. This translucent approach gives the producer of the sandwich panels full freedom in color or print selection.

Differently colored sandwich panels

During this project the PV foils have been integrated by means of lamination to the outside layer of the sandwich panel. This outer layer as such became the back sheet (BS) of the PV panel. During the project processes such as coatings on the front side of the sandwich panels and adhesion layers between the sandwich panels and the PV foil were tested and optimized. A suitable BS has been identified, and the required lamination process successfully demonstrated. The outer layer with laminated PV was then combined with the insulation and inner protective layer to form full sandwich panels, together with required environmental testing of this final product.

Finally we have fabricated a demo façade at Panelen Holland in which several sandwich panels having two different sizes and with different colors were integrated. Kiwa BDA established a knowledge base related to the product properties, the construction and product regulations.

MasterPV
Innovative manufacturing solutions for cost-efficient semitransparent BIPV

Project duration: from 09.2018 to 07.2021

MasterPV has addressed the development of innovative transparent back contacts in $Cu(In,Ga)Se_2$ (CIGS) solar cells for cost efficient semi-transparent modules. CIGS semi-transparent modules can be achieved with transparency levels up to 30%-40% by selectively removal of part of the absorbers in the devices. However, the optical quality of state of the art devices is strongly compromised by the presence of a Mo back contact that is currently used in the CIGS device architecture.

The project has involved the replacement of the Mo back contact in the traditional CIGS device architecture by chemical vacuum-free based TCO (Transparent Conductive Oxide) electrodes. This will allow achieving a significant improvement in the aesthetic quality of the semi-transparent devices, with the elimination of the back mirror effect that is determined by the remaining Mo regions in the semi-transparent modules. Use of chemical based processes for the fabrication of the back contacts will also allow a reduction of the manufacturing costs, because of the replacement of the expensive vacuum-based Mo sputtering deposition processes by lower cost approaches that are based in vacuum-free chemical processes.

The main scientific challenge achieved in the project is related to the development of optimal transparent back contact configurations allowing for solar cell efficiencies comparable to the high efficiency values that have already been achieved in CIGS technologies with the standard Mo based back contacts. This has required a special effort in the optimization of TCO based contacts suitable for high efficiency devices, which has been based on the development of back contact configurations including nanometric sized functional layers deposited onto the TCO back contact. Optimal back contact configurations identified in the project correspond to the use of chalcogenide ($MoSe_2$, MoS_2) nanometric functional layers and ITO as the TCO. The activities developed in the project have allowed the successful fulfilment of the main scientific and technological Key Performance Indicators (KPIs) defined in MasterPV:

- Demonstration of optimised back contacts leading to device efficiencies ≥ 80% (for vacuum based processes) and ≥ 65% (close to the target of 70%, for chemical based processes), of that achieved with reference Mo-based devices;
- Demonstration of the scalability of processes by the development of 10x10 cm^2 semi-transparent module prototypes with 10%-35% transparency in the visible region.

The main technological challenge is related to the implementation of low cost vacuum-free ink-jet printing processes for the growth of the optimal ITO based transparent back contacts configurations and to the adaptation of these processes for the fabrication of efficient semi-transparent CIGS modules. At commercial level, the improvement of the aesthetic quality of the semi-transparent

modules and the decrease of their cost will contribute to the consolidation of CIGS as one of the main commercial technologies able to answer the increasing demand of cost-efficient and reliable semi-transparent products in the BIPV market. This will allow the development of semi-transparent modules with higher optical quality and combining the high efficiency and high stability characteristic of CIGS solar cells.

PEarl
PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating

Project duration: from 01.2018 to 09.2020

The project focus was set on the exploitation of selective emitter's potential in passivated emitter and rear contact (PERC) silicon solar cells. Compared to PERC solar cells with a homogeneous emitter, those with selective emitter predict a significant increase in conversion efficiency of at least 1.0% absolute and, in consequence, would significantly increase the yield of PV systems, decrease the levelized cost of electricity, and the total cost of ownership. Therefore, Fraunhofer ISE, Meyer Burger, RENA, and Sun Chemical mixed together their complementary competences in the fields of solar cell processing, machine engineering, and material synthesis in order to develop self-aligned process techniques based on the steadily advancing inkjet and plating technology, whereby low Ag consumption has been in focus.

Within PEarl, the Technology Readiness Level (TRL) of PERC solar cells with selective emitter (at Fraunhofer ISE) could be increased from 4 up to 6. Based on specific PEarl processes and materials, especially mask&etch, solar cells with efficiencies of up to 21.7% could be processed in the industrially relevant pilot-lines of Fraunhofer ISE. Moreover, the utilization of innovative inks and machine setups led to a decrease in alignment accuracy inkjet/screen-printing of below ±20 µm. The principal feasibility of the revolutionary self-aligned process technique based on mask&etch, lift-off and plating could be evaluated. Upcoming research will focus an efficiency gain of 0.4%abs. compared to PERC with homogeneous emitter to reach significant competitiveness.

BI-FACE
High-Efficiency Bifacial PV Modules and Systems for Flat Roof Applications

Project duration: from 03.2018 to 09.2020

Initial situation

Although bifacial cells need some additional manufacturing steps, from an economical point of view the production costs are comparable and the yield increase can be between 5 and 30% yield. This depends on the solar cell technology used, the location and system design. Today one of the most effective ways to include PV is the usage of solar panels on manufacturing sites and public buildings, where the generated power is used immediately. In many of these buildings, flat roofs are state of the art. Therefore, the BI-FACE project focused on optimized light weight bifacial PV systems for flat roofs.

The first main challenge at the beginning of the project was optimization of the module itself, e.g. the used components and design rules. Novel materials for i.e. encapsulation and glass / foil had to be evaluated with regards to costs as well as reliability. Furthermore, the manufacturing process was not well analyzed and needed optimization. Besides that, also the characterization of the built modules was still challenging. At that time the characterization of bifacial modules was not well defined, labelling was therefore unprecise and unsatisfactory for customers as well as for manufacturers. Especially there was a big gap between laboratory and manufacturer characterization and measurements.

Parallel to these module aspects the second main challenge was the optimization of the overall system design, where layout and mounting design of the system had to be optimized for energy performance. Energy performance of a system is critically influenced by structure and albedo of the roof surrounding modules and shape of the modules and should be thus evaluated and optimized to achieve maximum performance. The system design needs to take into account different (ballast) load profiles, due to added wind load, which can influence ground reflection and irradiation. Heavy ballast contradicts the requirements of many flat roofs, as many cannot handle heavy weights. This combined optimization of module, system and construction needed to be combined with the economic needs to have high energy yield at low costs.

BI-FACE project aimed the following objectives:
(1) New validated simulation tools for bifacial modules and systems, including simulation of the wind load
(2) Modeled and validated standardization advice for characterization of bifacial modules
(3) New high efficiency bifacial modules and system
(4) Outdoor performance qualification of the bifacial system in different European climate zones and wind and snow load conditions
(5) Guidelines for flash tester upgrade at the module manufacturer's site

Project methods and results

The scope of the project BI-FACE was to develop innovative bifacial modules and systems for flat roofs to exploit the enormous potential of this technology. The results included three novel variations for bifacial modules and systems which were tested in three different climate zones: subtropical (Cyprus), temperate (Austria, 2 sites) and maritime temperate (The Netherlands, 2 sites). The ultimate design of these systems was challenging due to the large number of parameters that influence the energy yield (tilt and distance between modules, reflecting surfaces, shading, cell spacing, materials used and weather conditions).

Within the project five bifacial PV systems were realized and monitored (one system at each site). The setups each featured 3 different types of modules (mono-facial, bifacial n-type (bifaciality ~90%), bifacial p-type (bifaciality ~70%)). So bifacial energy gain on yield could be assessed, as function of module bifaciality, openness of the support structure, as well as the dependence on ground albedo. The monitoring campaign took place over the summer of 2020, putting the extension of the project end-date to good use. The data were evaluated and analyzed with the tools and knowledge developed for bifacial PV within the project.

A holistic approach to energy performance took the aspect of standardization into account. This standardization was not available at the beginning of the project for bifacial modules, hindering rapid market introduction. Therefore, critical efforts were put in to harmonize performance characterization of bifacial PV modules in a factory and laboratory setting and correlate this with the outdoor performance. The results were communicated with the standardization committees.

The layout and mounting design of a bifacial system was critical to obtain the maximum possible performance on flat roofs. The construction demands with respect to wind load, stability, total weight (incl. ballast) and maximum allowed weight on a roof were directly influenced by ballast design and needed to be critically examined in parallel. The intended approach compared theoretical investigations with tests in the laboratory and in the field.

Performance simulations of bifacial modules and systems were developed and compared to laboratory and in field test results. Finally, all innovations were collected, synthesized and validated on a flat roof where the need for lightweight was an additional challenge.

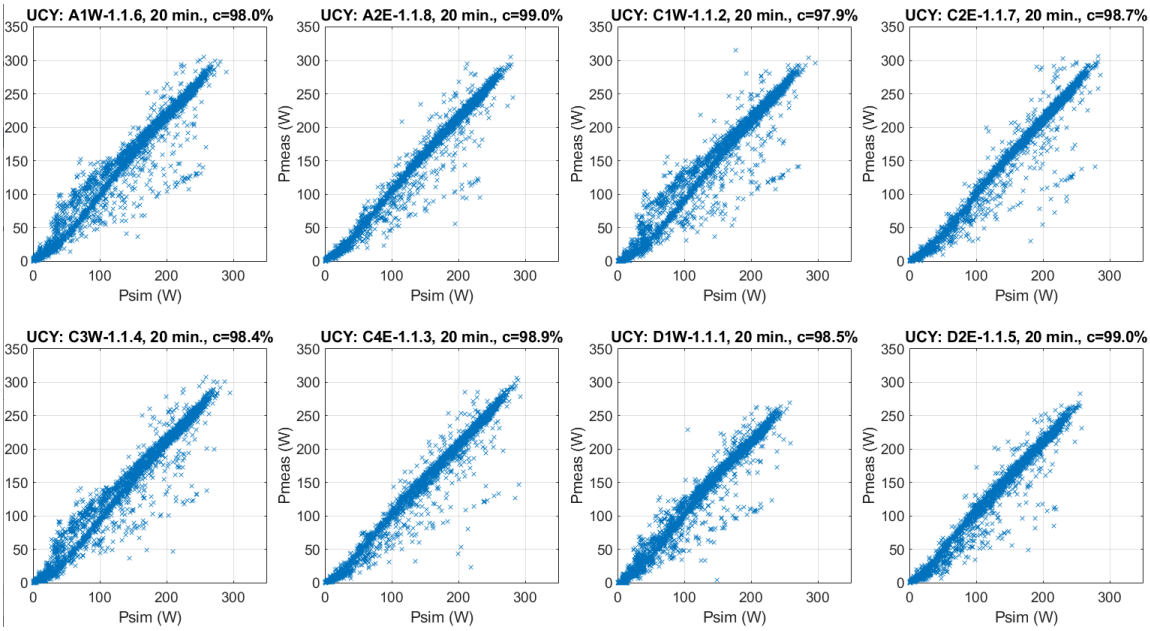
The project BI-FACE aimed to develop technically as well as economically novel bifacial PV systems to exploit the enormous potential of this technology.

Main results achieved

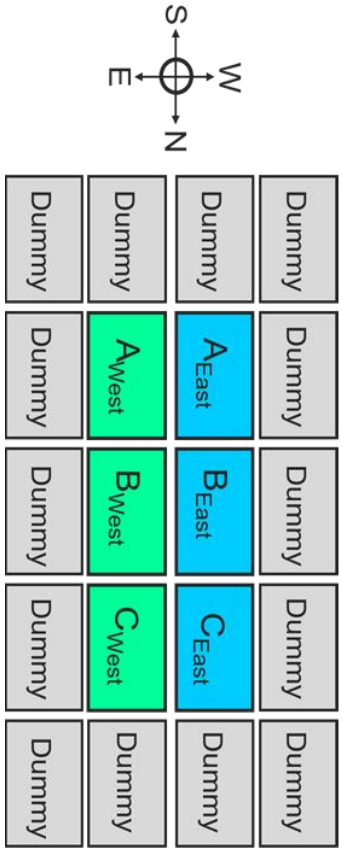
- Novel lightweight bifacial modules and systems for flat roofs for representative climates in Europe
- Innovative, comprehensive models for design and installation of bifacial modules and systems including construction requirements
- Novel manufacturing strategies
- New performance and characterization measurements
- Innovative mounting structures

Highlights of the project

- New validated simulation tools for bifacial modules and systems, including simulation of the wind load (see figure below)
- Modeled and validated standardization advice for characterization of bifacial modules
- New high efficiency bifacial modules and systems. Energy yield increase in comparison to mono-facial systems by up to 20% were achieved according to the results. LCOE decrease of 11.4% were achieved. The decrease is in comparison to LCOE of monofacial modules with black non-transparent backsheet.
- The gain of bifacial PV panels with p-PERC technology and 70 % bifaciality, compared to monofacial ones, were in the range of 15-20 %. Bifacial modules with n-PERT solar cells having a bifaciality of 92% showed an up to 3 % higher yield than bifacial modules with bifacial p-PERC cells. https://doi.org/10.1016/j.renene.2021.02.015 (see figure on next page)
- Outdoor performance qualification of the bifacial system in different European climate zones and wind and snow load conditions
- Guidelines for flash tester upgrade at the module manufacturer's site



Correlation between measured and simulated module powers.



Monitoring site in Austria, with 3 different types of modules

Cover Power
Smart Glass Coatings for Innovative BiPV Solutions

Project duration: from 10.2018 to 09.2021

From many research & development activities on PV module applications it has been found in recent years that the optical appearance of PV modules is mainly determined by the outer side (environmental side) of the cover glass of the modules. In particular, reflections of the incident light on the cover glass surface are essentially responsible for the overall optical perception of the modules. It is precisely this fact that makes it difficult to effectively tune the aesthetics of a photovoltaic module, for example by changing the colour of the solar cells used. In contrast, it is more promising to modify the surface that is mainly responsible for the optical perception to match the design: the outer surface of the cover glass.

The project Cover Power addressed exactly this challenge. By combining different kinds of glass coating technologies, the project results allow for new degrees of freedom for the design of PV modules for BiPV solutions.

In detail, the coatings, applied were characterized optically and their chemical and physical stability was investigated. The durability of these coatings was further evaluated by performing environmental simulations and accelerated aging tests were performed on test modules to assess their performance stability.

The results show an efficient coluring of BiPV modules and also address a problem that in the past has proven to be an obstacle for some facade-integrated BiPV projects: glare. As outcome of the project prototypes of BiPV modules were developed, that are based on the typical glass-glass PV module technology in combination with Si solar cells by applying novel glass coatings to the outer side of their cover glasses. These module prototypes feature the following properties:

- Flexible and innovative design in terms of colour and surface texture
- Minimum glare (less than 0.1% of specular reflection)
- At least 150 W/m² (STC) by exploiting back reflected light in bi-facial cells
- Aging and adhesion of surface coatings are reliable for at least 30 years

A further outcome was the realization of a BiPV installation in a façade (see picture below) and a roof to demonstrate the feasibility of the developed module prototypes. This installation will be operated by echoch2 beyond the end of the project.

Photo of the test façade with grey screen-printed modules

In addition, ertex-solar as well as Joanneum Research are planning further activities as follow-up to the project Cover Power: The screen printing technology in particular has proven itself in use under real life conditions. Here, ertex-solar plans to continue the concept of screen printing with a special ink that incorporates colouring particles for a more vivid colour impression and higher module efficiency. In addition, this ink allows for a homogeneous overall appearance for a facade or roof installation.

Joanneum Research is planning further cooperative research activities in the field of sol-gel coating. The focus will be primarily set on increasing the stability of the coating with respect to weathering and to develop an industrially applicable and automated coating process together with an industrial partner.

CEFRABID
Clean energy from road acoustic barriers infrastructure development

Project duration: from 09.2018 to 11.2020

The CEFRABID project concentrated on advanced photovoltaic (PV) product applications in road and rail (r&r) transport infrastructure. It also focused on related grid integration with noise barriers and passenger stop shelters along local r&r infrastructure for needs of powering this infrastructure, e.g. for signaling, lighting of neuralgic sections of roads and rail platforms, including r&r crossings and, last but not least, warming or cooling passenger stop shelters of special innovatory design.

The focus was on innovative manufacturing of end solutions for r&r infrastructure integrated PV systems. The following issues were addressed and goals pursued:

- Dimensional and outlook flexibility with customised sizes, shapes and colours, freeform module technology, and bifacial (especially for N-S oriented r&r) solar cells and modules, electrical design for energy output optimization: shadows, various tilt and orientation angles, safety issues, all of which had been part of extended preliminary tests at specialized Partner's facilities of their different configurations, including both laboratory tests, as well as outdoor tests on partially movable platforms (PMPs).
- Holistic approach for the energy performance, enabling accumulation of energy for night or worsening weather conditions periods, assuming also backup power supplies from conventional electric grid in emergency states.
- Easiness of installation/application based on modular designs of largely independent and self-sufficient Hybrid PV Noise Road (Rail) Barriers' (HPVNRBs) modular sections, which may be easily prolonged and included in the grid (in series when independent, and in parallel layout for mutual replacement needs).

The traditional road transport infrastructure will be supplemented with the help of these new solutions for HPVNRBs and other surfaces of r&r infrastructure, using innovative and reinforced PV products.

NEXT-FOIL
Next generation conductive solar foil for flexible photovoltaics

Project duration: from 03.2018 to 12.2020

Photovoltaics (PV), based on organic, inorganic or perovskite absorbers, can be fabricated as lightweight and flexible modules, making them attractive for integration in building façades and consumer products. These PV technologies rely on substrates coated with a transparent electrode of high transparency and low sheet resistance. ITO (indium-tin-oxide) is by far the most common electrode, despite its high cost, poor mechanical stability and low figure-of-merit when applied on flexible substrates like PET.

NEXT-FOIL developed an alternative to ITO-coated PET, based on dielectric/metal/dielectric (DMD) multilayers, sputtered at rates compatible to high-throughput, industrial production. As dielectrics, compounds based on MoO_x and TiO_x, were used, with electronic properties that allow their use either as anodes or as cathodes in different solar cell architectures. Optimized DMD electrodes offer: (i) better performance/cost figure than ITO, (ii) sheet resistance <10 Ω/sq, without substrate heating during deposition, (iii) unsurpassed stability of the resistance against bending and (iv) adaptability to specific device energetics.

The industrial applicability of the DMD electrodes was demonstrated by their deposition in a fast, roll-to-roll process and by their implementation for the fabrication of perovskite solar cells, with performance similar to that achieved for ITO-coated substrates.

The consortium consisted of the AIT Austrian Institute of Technology, tackling the simulation and experimental realization of the DMDs, Plansee (Austria) that developed the new oxide compound sputter targets and Solaronix (Switzerland) that implemented the developed electrodes in efficient perovskite cells, together with AIT.

The proof-of-concept of continuous manufacturing and the functional validation of the DMD coated polymer substrates opens the doors for industrial applications of flexible PV devices, printed electronics, or flexible OLED displays.

HEAVENLY
High-efficiency PERT and IBC cell development focussing on paste and CVD optimization for long term stability

Project duration: from 01.2018 to 03.2021

The aim of the project was to move mature silicon based photovoltaic technology into the realms of low cost/high efficiency systems. Focussing on the development of silver pastes for screen printed contacts, atmospheric pressure chemical vapour deposited (APCVD) passivation layers for p+ or n+ doped regions, and long-term solar cell stability, the project facilitates the transfer of lab proven passivated emitter, rear totally diffused (PERT) solar cell technology to an industrial environment.

The research carried out in this project has led to a contact formation model for silver metallisation pastes on APCVD passivated silicon solar cells. The in-depth study of the etchant composition and its impact on the SiNx etching process has allowed us to tailor the paste composition to the n- and p-PERT cell architectures. APCVD processes were developed, enabling passivation qualities that allow for >22.5% solar cell efficiency with n-PERT architectures. Long-term stability was tested, ensuring the readiness level of the pastes and APCVD films.

UKN will continue to exploit the project results through follow-up projects with industrial partners. The use of APCVD technology will be further developed within the framework of ongoing research projects.

JM is currently involved in a new project with UKN exploring the use of these new silver metallisation pastes in new solar cell architectures, namely TOPCON. We are actively pursuing IP licencing opportunities and commercial partners. We are also exploring where it is appropriate to publish various findings in academic literature. The knowledge gained on tailoring the inorganic / organic component interactions with a high-solid content paste and the surface they were printed on is being applied across a variety of business units at JM, i.e. the production of hydrogen via green methods. Through analysing these samples, the Advanced Characterisation department at the JM technology centre is now able to apply this improved skill set to other research areas being carried out at the technology centre and across the business units.

1500-SiC
Develop a new photovoltaic inverter with SiC for full power operation at 1500V

Project duration: from 03.2018 to 06.2020

Photovoltaic (PV) energy is experiencing significant cost reduction over the last years. Lately, the bias voltage of photovoltaic panels has risen from 1000 V to 1500 V, leading to a significant reduction of the Balance of Plant cost. In order to improve the Levelized Cost of Energy (LCoE), manufacturers are increasing the installed DC (Direct Current) power of PV panels for a given nominal AC (Alternating Current) power of the inverter (so-called capacity factor) from 1.2-1.3 to higher values. This results in a larger voltage at the maximum power point of the PV panel. As a consequence, conventional power electronics solutions rated at 1700 V maximum voltage are not suitable. This is because they are typically designed to deliver nominal power below approximately 1300 V, but increasing the capacity factor leads to higher maximum power point voltage. Therefore, new solutions are required in order to deliver rated power near 1500 V.

The aim of 1500-SIC is to develop enabling power electronics solutions capable of delivering nominal power at 1500 V with very high efficiency and high volumetric power density at competitive cost. The consortium includes Gamesa Electric from Spain, worldwide supplier of PV inverters; Infineon Technologies Austria, worldwide supplier of semiconductors for power electronics; and ETH Zurich Advanced Power Semiconductor Laboratory from Switzerland, a world-class research centre focused on semiconductor devices and power modules. Specifically, the consortium has worked together to develop a novel Silicon-Carbide diode and a MW-class inverter optimized to deliver nominal power at voltage levels up to 1500 V. The developed technologies have been built and tested at full scale through a comprehensive testing campaign.

The consortium includes key industrial actors in the supply chain of power electronics for PV solutions and a research centre. This maximizes the impact of the R&D outcomes of this program into the European Renewable Energy Industry.

Main outcomes of the project

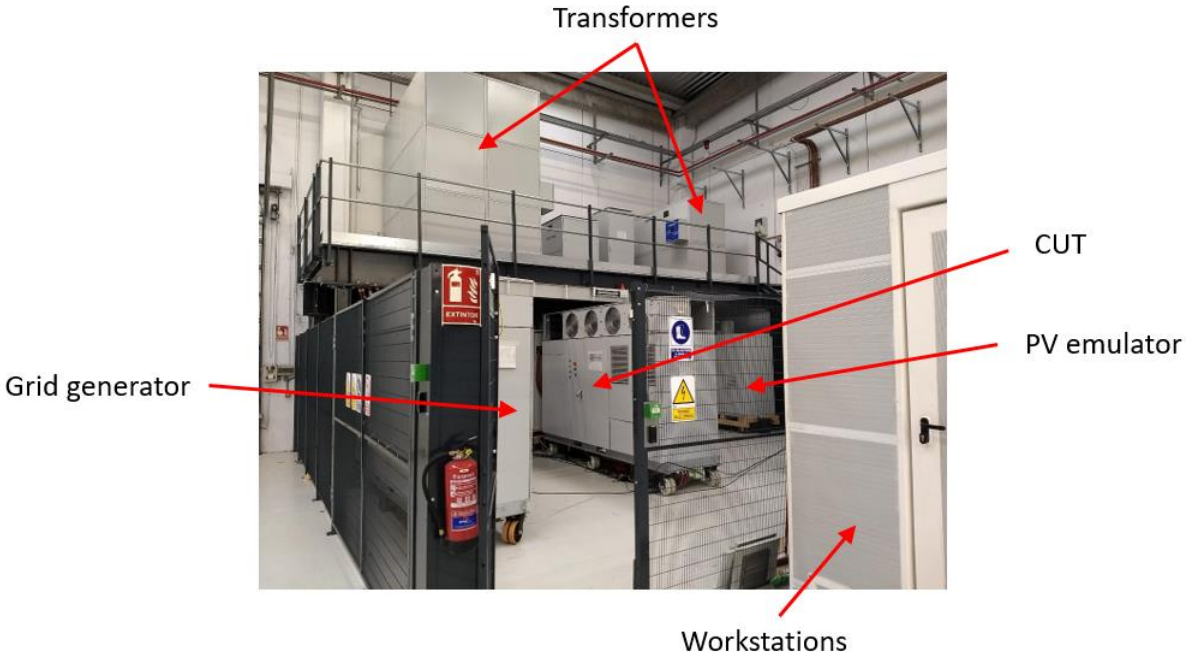
<u>New installation assets</u>

It has been developed two different test rigs to validate the core new designs. These test rigs are:

- Double-pulse test rig. Valid to measure the semiconductor losses during on and switching states. It has been compared standard silicon solutions with novel SiC solutions.

Double pulse test bench

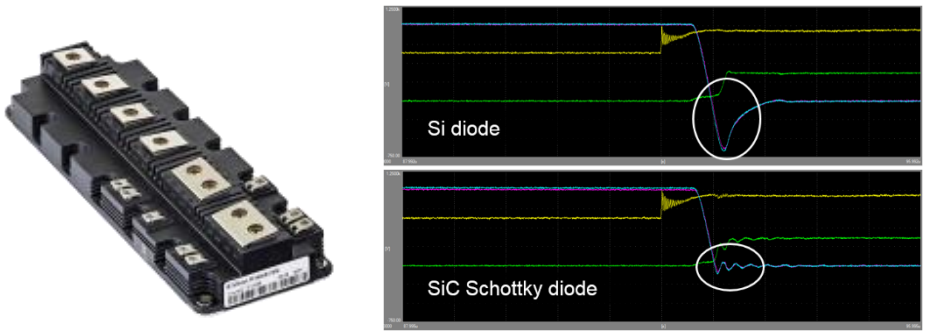
- 5 MW full power test rig. This new test rig has capabilities to test the new PV central inverter at real operating conditions:
  - electrical tests with virtual grid capacity to enable changes in voltage and frequency, including LVRT (Low Voltage Ride Through) and HVRT (High Voltage Ride Through)
  - thermal test, using a climatic chamber that enables measuring the inverter efficiency at different ambient temperature conditions.



Picture of the full power test bench

New product achievements

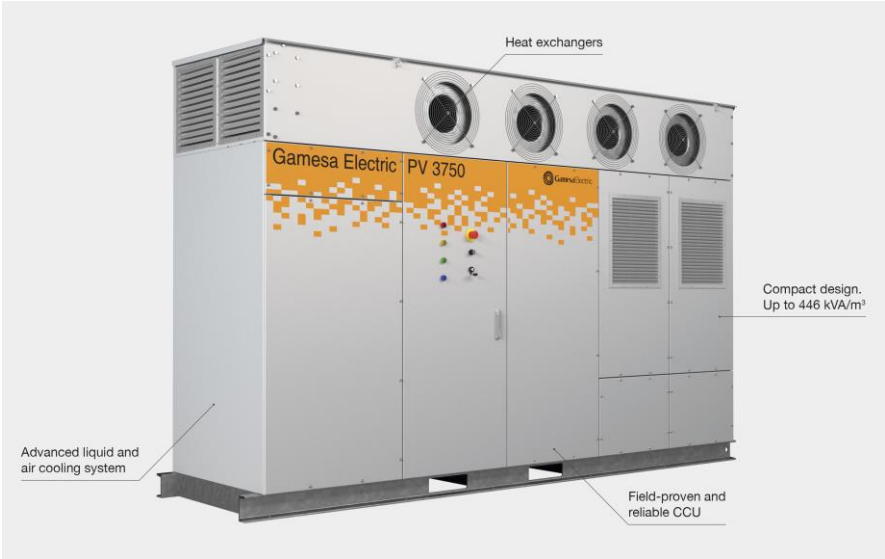
- Validation of a new SiC module for 1500 V PV applications



New power module validated and switch off event comparison

Test results show a 30% less losses with the new SiC module compared to an equivalent Si module. This achievement enables increasing the inverter power density.

- The new Gamesa Electric PV central inverter generation



New 3.75 MW Central PV Inverter equipped with the technology developed with funding support from SOLAR-ERA.NET

Main characteristics improved (compare to existing PV Central Inverter):

- +8% power density with Outdoor characteristics.
- +0.5% CEC (California Energy Commission) effiency increase. The certified CEC efficiency boosts from 98.8% to 99.3%, achieving a world record thanks to the improved semiconductor performance.
- Cosmic ray certified by ETH Zurich, showing the same performance as the Si modules

Further activities and collaboration

Currently, there is development undergoing in a European funded project (TALENT – GA 864459) to incorporate the new 2.0 kV IGBT generation in the PV inverter so the new product is ready for:

- Increase of PV Pdc/Pac (Power DC/Power AC) ratio. Thanks to the continuous reduction of the PV panel cost, it is very convenient to increase the Pdc/Pac ration to sature the inverter capacity. This will imply operation at DC voltages higher than current 1300 VDC.
- Operate batteries at 1500 Vdc. To reduce the LCOE of energy storage assests, battery manufacturers are increasing the maximum voltage of the battery from 1100-1300 Vdc to 1500 Vdc. This voltage change will imply changing the power stack technology and Gamesa Electric is developing a new power stack within TALENT project.

Erigeneia
Enabling rising penetration and added value of photovoltaic generation by implementation of advanced storage systems

Project duration: from 05.2018 to 10.2021

The Erigeneia project targeted to enable the high penetration of PV technology and to utilize its potential value in the energy system by developing a local and central energy management system (EMS) that will combine photovoltaics (PV) with battery energy storage systems (BESS). The project matched the technical requirements imposed by the distribution system operators (DSO) with the upcoming new market regulations, capitalising on the positive effects of PV and BESS combination. In addition, a tool for intra-hour energy forecasting was developed and integrated into the EMS to provide a more accurate and reliable operation plan for the DSO. Finally, a versatile algorithm capable of estimating the optimum size of BESS and PV to meet all the needs of prosumers was also developed. Field trials took place in Cyprus (residential EMS) and Turkey (community EMS) and novel or more effective ancillary services were provided to the network operators (e.g. power smoothing, voltage regulation). Finally, the economic impact of the proposed solutions was quantified.

The proposed work is expected to have significant impact on the further penetration of PV given that the existing grid infrastructure will be utilized in a more efficient way, by increasing the hosting capacity hence deferring grid reinforcement. By promoting grid-friendly self-consumption of PV generation, grid congestion issues will be avoided. Since the EMS will increase the power usage predictability, the current expensive power reserves will be replaced by the local EMS control strategies of the combined PV and BESS EMS. Furthermore, the users will take advantage of the provided flexibility in order to lower their cost of electricity, by gaining from the new upcoming policies of Time of Use (ToU) and dynamic tariffs.

The project was fully in line with the SET plan for effective integration of solar energy technologies in the energy system.

HyConSys
Hydrogen control in solar thermal parabolic through heat transfer fluid systems

Project duration: from 01.2018 to 12.2020

The project aimed at controlling hydrogen (H2) in the heat transfer fluid (HTF) of solar thermal parabolic trough plants within acceptable limits. H2 is slowly formed by the HTF that is currently used in the plants and which is based on aromatic hydrocarbons. The formation rate depends on the operating temperature and the condition of the fluid. Aged qualities reveal higher formation rates. H2 permeates through the steel pipes of the heat collecting elements (receivers). If the gas would accumulate inside the annular gap of the receivers the insulating vacuum would be lost and unacceptable heat losses would result as a consequence.

In order to prevent this condition, getter materials are located inside the annular gap. The getters absorb H2 and therefore maintain the vacuum insulation. If the design conditions in terms of H2 concentration in the HTF are maintained, the getters will be saturated not before the specified lifetime of the receivers. A problem is caused if the H2 concentration is larger than specified at the maximum operating temperatures. This would cause unacceptably low useful lifetimes of the receivers.

The HyConSys project aimed at testing measures against H2 accumulation in the HTF like removal of H2 by nitrogen exchange from the system and by processing steps. This was guided by detailed lab analysis in order to provide in-depth understanding of the relevant processes. Hereby economic measures for H2 removal were identified and optimized.

The results were integrated within a computer model together with cost models to develop a tool for identification of the most economic H2 control strategy for specific CSP systems.

This approach was supported by developing new catalysts for H2 removal and by easy to use techniques for H2 analysis.

It is expected that this combination of analysis, development and improving knowledge will significantly help to overcome the currently upcoming H2 problems in CSP systems.

ENMESH
ENabling Micro-ConcEntrator PhotovoltaicS with Novel Interconnection MetHods

Project duration: from 02.2018 to 12.2020

The Swiss company Insolight is developing a patented PV module which promises a reduction in LCOE for roof-based solar from 0.16€/kWh to 0.011€/kWh. The system uses an array of micro-solar cells with optics and integrated microtracking to produce a low-profile rooftop-compatible solar system with an independently demonstrated efficiency of over 36%, a 100% efficiency gain over cSi. This high efficiency is made possible by the use of advanced multi-junction cells under concentrated light, a technology known as concentrator photocoltaics (CPV). Specifically, this product represents one of the first commercial examples of micro-CPV (µCPV), wherein the cells are 1mm^2 in size or less. µCPV increases performance (due to reduced cell operating temperature, higher optical efficiency and lower series resistance losses) and lowers manufacturing costs. Insolight innovation has further improved the µCPV concept by embedding sun tracking internally in a 50mm-thick panel, enabling roof-top or BIPV installations and avoiding bulky and expensive trackers. An outstanding technological challenge in µCPV is the need to use massive cell interconnection processes due to the large number of micro-cells involved, 5000 cells/m^2 for the Insolight module. The current state of the art is wire bonding, however this inherently serial process is prohibitive for thousands of cells.

The Universidad Politécnica de Madrid, in collaboration with Dycotec Materials Ltd, offer an innovative cell interconnection process involving direct printing of ultra-durable nano-particle coating systems to allow the massively parallel connection of solar cells in a cost-effective high volume roll-to-roll or sheet fed printing process, paving the way for the low-cost manufacture of µCPV.

Under the specifications of the company Insolight solar cell plane and full board prototype containing a total of 143 micro-solar cells was interconnected. The full board is on a glass substrate being semi-transparent for applications with hybrid-PV or agrivoltaics. The final prototype reached equal results as the standard technology using wire-bonding, but with a far cheaper process. TRL6 was achieved for the technology developed in this project.

Finally, the ENMESH project was the transnational team's first collaboration and the seed of the Hiperion project (H2020-LC-SC3-2018-2019-2020).

PVTool
Development of tools for effective control of large PV power plants

Project duration: from 09.2018 to 10.2021

The important proliferation of medium and large size PV power plants in Europe and worldwide is raising the attention to its important role in providing support to the electrical network. Large PV power plants need to ensure a smooth injection of the generated renewable power into the grid where they are connected, while providing the required ancillary services. Depending on the grid nature, such requirements can differ considerably, ranging from frequency or voltage support for PV power plants connected to power systems based on conventional synchronous generators, to grid-forming capability in systems or microgrids where PV is the main generation source.

The project aimed at developing relevant control architectures and control algorithms to ensure optimal performance in different kinds of systems. In relation to control architectures, alternative control architectures where analysed, including decentralized, distributed and hierarchical options. A methodology was presented to select the most appropriate control architecture for each service. As a result, the hierarchical control was highlighted as a relevant alternative to provide frequency support services. Regarding the interaction analysis and control algorithms, detailed small-signal models were developed to analyse the potential interactions derived from more demanding and faster grid support services. The application of different stability analysis methods confirmed the possibility of interactions, specially between the PV inverters and the Power Plant Controller. Also, a control tuning method was suggested to achieve fast grid support services. This method was validated in simulation and in an experimental platform.

In addition, the project aimed at strengthening the relations between the universities and industrial partners. In this direction, a follow-up of research ideas will be addressed by the universities and the industrial partner is planning to test the control tuning methods developed during the project in real-time simulators and eventually real power plants.

NELL
Novel encapsulant for long lifetime high voltage PID-resistant PV modules

Project duration: from 01.2018 to 12.2019

Photovoltaic energy already plays a key role in the global energy market, and it is expected that it will meet 20% of the EU electricity demand in 2030. The PV industry in Europe has lost market share in the last years due to strong competition from Eastern producers. Europe has nevertheless maintained the scientific and technical leadership and should take advantage of this to further increase efficiency and reliability of PV systems, contributing thus to strenghten the competitiveness of the European PV industry and to accelerate PV deployment in Europe.

One solution to decrease system costs which is being demanded by the market is the transition to high voltage systems up to 1500 V and beyond. Higher voltage can yield to system cost savings between 3 and 10% by reducing BOS components and increasing DC yield.

High voltage, however, also implies a higher risk for potential induced degradation (PID) of PV modules. This, in turn, requires the development of new materials for PID-free PV module certification which ensure high reliability and do not increase significantly the module cost. The main goal of the NELL project is precisely to develop a highly PID-resistant encapsulant able to avoid PID even under harsh humidity and temperature conditions in high voltage systems up to 1500 V. The project will thus significantly contribute to the SET-plan goal of reducing the levelised cost of electricity by 20% in 2020, at the same time as ensuring 30 years lifetime with a guaranteed 90% power output.

The NELL consortium has a strong industry participation and is formed by entities with a very long trajectory in PV in Europe. It is led by STR, global leader in encapsulant development for the PV industry, who has strategically partnered with ZSW, technology center who has played a key role in the understanding and measurement of the PID phenomenon in recent years.

RHINO
Realization of High efficiency Industrial N-type sOlar cells

Project duration: from 01.2018 to 03.2021

This project targeted the development of an industrially feasible manufacturing approach for an n-type cell structure that has demonstrated above 25% efficiency in a cleanroom environment. Key elements of the cell structure are an advanced or selective boron-doped emitter and a full area passivated rear contact, fabricated by low-pressure chemical vapour deposition of an in-situ phosphorous doped polysilicon layer on top of a thermally grown interface oxide. For these key elements, production capable processes and high throughput production tools have been developed and implemented in a lean solar cell production process. Both the implementation of the passivating rear contact and reducing the front carrier recombination losses by the development of advanced emitter from BBr3 diffusion increased the efficiency of the developed industrial solar cell from 21% to 22,3% while using screen printed metallization and established production equipment.

The formation of a selective emitter structure, which is realized by laser-doping from the borosilicate glass, which is present on the wafer surface after thermal diffusion, has been intensively studied. A low contact resistance below 2 mΩcm² and a junction depth of > 1 µm could be demonstrated. However, within the project it was not possible to demonstrate an advantage of the laser-doped selective emitter over advanced homogeneous emitters with increased junction depth. High reflection losses at the laser-treated area was identified as one of the main challenges. Instead, advanced homogeneous emitters were developed. These diffusion processes enable recombination parameters of J0e < 15 fA/cm² (textured, Al2O3/SiNx-passivated) at industrially relevant process times of 2 hours. Further optimization of the BBr3-process yielded a junction depth > 1 µm, which effectively reduces metallization induced recombination and these processes were successfully implemented in the solar cell process.

Test modules fabricated from these bifacial cells demonstrated high bifaciality factors of ~85%, still outperforming current passivated emitter and rear (PERC) modules in terms of bifacial properties. Modelling of bifacial module operation enabled a reliable prediction of energy yields depending on system configuration and ambient conditions.

The project contained partners from a research institute, a manufacturer of diffusion and polysilicon deposition furnaces, a laser system specialist and a module manufacturer. They all brought into this project their expertise that enabled to reach almost all the project goals. Based on the project results, follow-up projects were able to further push the development of industrial TOPCon solar cells at Fraunhofer ISE and the industry partners leading to current solar cell efficiencies of up to 23,8% at Fraunhofer ISE. Further exploitation is under way at Fraunhofer ISE with planned industry projects to transfer the developments.

PROGNOSIS
Intra-hour prediction of solar electricity generation from photovoltaics

Project duration: from 04.2018 to 10.2021

The PROGNOSIS project is related to the development of a tool for intra-hour forecasting of solar irradiance over a specific area. The innovative concept of PROGNOSIS is based on the fact that the tool is based on models that do not utilize any meteorological data or specialized equipment but only the power output of a dense grid of connected Photovoltaics (PVs).

The continuous PV input data has been integrated to energy maps over various regions and the attenuation from the normalized power output has been calculated to predict the motion and development of clouds/aerosols in time as these clouds can cause a decrease in the solar irradiance reaching the PV when they cast a shadow over it. Through the development of this dynamic flow map of the power output of the PVs, the solar irradiance can be visualized and predicted, not only for individual PVs, but over entire regions.

Regarding the development of the forecasting model, a machine learning approach was adopted, which can provide accurate predictions based only on the knowledge acquired from historical data. For PROGNOSIS, a model based on the “Recurrent Neural Network” architecture has been built using the historical PV power data. The estimation of clear-sky PV electricity production is also important for determining the attenuation in the energy maps. Thus, a data-driven method was developed for the calculation of the clear-sky signal. The issue of incorporating spatial dependency into our forecasting model was also examined. Results indicate that our model can capture the overall trend and fluctuations of the power output and provide good predictions, not only for PVs in Cyprus and Spain but also in countries with different climates.

PROGNOSIS is essentially a real-time decision-making tool primarily for the energy sector since the resulting forecasting can facilitate the decision-making process for the visualization, management and optimization of microgrids and electricity systems.

The main technological outcomes of the project were the improvement of the algorithms – both in terms of accuracy but also to include spatial variability and the incorporation of real-time data from PV inverters into the developed software. Furthermore, on the business side, the PROGNOSIS tool has potential in a sector that is under a complex transition to becoming more decentralized, with near-zero marginal costs, and especially digitalized. Digital tools that allow automatic and rapid actions will be increasingly important and PROGNOSIS can provide even more value than the one suggested in this report.

For the project continuation, two further projects were the direct outcome of this collaboration: (a) a proposal entitled “Matching complementary EnErgy consumers to boosT the creation of new and optimized Energy Communities”, coordinated by IVE (and CUT being a partner) has been submitted for funding, and (b) Dr Alexandros Charalambides (coordinator of PROGNOSIS) has received a grant under the 2022/23 Fulbright Visiting Scholar Program to visit USA in order to improve PROGNOSIS with data from USA and also to investigate any business opportunities for PROGNOSIS in the USA.

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