P-MOB	**Collaborative project** Grant agreement: 260087	COOPERATION

P-MOB

Integrated Enabling Technologies for Efficient Electrical Personal Mobility

Collaborative project

Grant Agreement 260087

ICT – Information and Communication Technology

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Project Coordinator: Pietro Perlo

Deliverable D3.1: Working monolithically integrated module on non-glass substrate

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Dissemination level: Confidential

SUMMARY

1 Scope

This activity will consist on the application of high efficiency solar panels on both horizontal and vertical surfaces by:

- comparing and selecting the most appropriated PV technology (silicon, thin film..)
- defining the architecture to minimize the impact of shadows, spots, dust and isolated cell ruptures
- select the appropriated electronic including MPPT, management of by pass diode and optimal adaptive coupling to the battery.
- integrating in a robust way PV modules into vehicle panels

2 Comparison and selection of the most appropriated PV technology (silicon, thin film)

The activity has been concentrated on the comparison of cost-performance affordable technologies for transportation means.
Five major technological areas have been analyzed:

- Monocristallne silicon
- Multicrystalline silicon
- Thin Film: CIGS, others
- Sphelar cells (Japan)
- Sliver cells (Australia)

The terms adopted for comparison are:

- Efficiency
- Weight
- Manufacture control level in view of the application
- Evolution of production cost
- Constrain on availability

The table summarises the results:

	Efficiency **Of the current production**	**Weight**	**Manufacture**	**Evolution of production cost**	**Constrain on availability**
Mono-crystalline silicon	>23% cells 20% module Very good performance under diffuse light when AR treated. Good operation in horizontal and vertical surfaces.	<2kg /m2 If laminated in polymer sheets	Sandwich lamination with polymer sheets. Special care needed when the solution has back contacts. Good curvature in one direction very limited curvature in two directions. Simplified cell to module assembly expected in short term. Aesthetically pleasant when with back contacts.	Production cost at module level expected at 1€/ W before 2015	Best monocrystalline cells still available only from two suppliers. No constrains on availability before 2015.
Poly-cristalline silicon	19% cell 17% Module Medium performance under diffuse light.	<2kg /m2 If laminated in polymer sheets	Sandwich lamination with polymer sheets. Good curvature in one direction very limited curvature in two directions. Simplified cell to module assembly expected in short term. The needed wiring connection limits the aesthetics impact.	Production cost at module level expected at 0.7-0.8€/ W before 2015	No constrain on availability
Thin film CIGS	up to 15% cell, 13% module very good performance under diffused light	<2kg /m2	Roll to roll in polymer. Needs of construct the module in thicker polymer and with serial connection to increase voltage.	The potential low cost due to the roll to roll lamination is limited by the need to increase the voltage. Production cost at module level expected at 0.5-0.6€/ W before 2015	Constrains on the availability of module with efficiency above 12%. By 2015 CIGS films are expected to be available with no constrain at efficiency above 14%.
Sphelar **Sphere of silicon**	Up to 12% Depends on the desired level of transparency. Operates under all condition of diffused and direction of	3kg/m2	Complex process need to produce the sphere, complex procedure to laminate the sphere in polymers. Aesthetically very pleasant with patterns defined in any shapes.	Not available. Potentially low cost but the level manufacturing complexity may be such that it cannot compete with other thin film technologies.	Difficult to predict when a real large sale production will start. Only samples available under heavy constrains.

	light.				
Sliver **Slices of silicon**	Up to 20% Operates under all condition of diffused and direction of light	<2kg /m2	Complex process need to produce the sphere, complex procedure to laminate the sphere in polymers. Aesthetically pleasant.	Potentially low cost. but the level manufacturing complexity may be such that it cannot compete with other thin film technologies.	Difficult to predict when a real large sale production will start. In the last five years the producer has shown only samples.

CIGS flexible modules have been purchased under agreement and measured with measured efficiency of the order of 11.5%.

Monocrystalline cells have been purchased from Sunpower Corporation and laminated in sandwiched in polymer-polymer modules. The measured efficiency is 20%. The optimisation of the lamination process is still in evolution. Contact have been taken with other laminators to share the experience of using back contact cells.

Experience has started cutting cells into two or three parts to better cover the area of the roof.

The concentration of P-MOB is on monocrystalline cells because the high priority is given to the efficiency. The evolution of the production cost suggests that the dominant cost will not be the production of the cells or light to electricity conversion layer, but rather the packaging of the cells into the module, the integration of the cells-modules with the body panels and control electronics. Combining all these parameters in view of technology evolution the winning technology appears to be monocrystalline silicon for some more years. While the efficiency of monocrystalline silicon production modules is expected to increase up to 22% before 2013, the large scale production of CIGS or other thin film solutions in thin polymer substrates with efficiency above 17% is not expected before 2017. Because the cost of the so called “Balance Of System” BOS is essentially independent from the technology the lower overall €/W is dictated by the efficiency. That is monocrystalline silicon with AR treated surface.

Example of experimented panels are reported on the following figure.

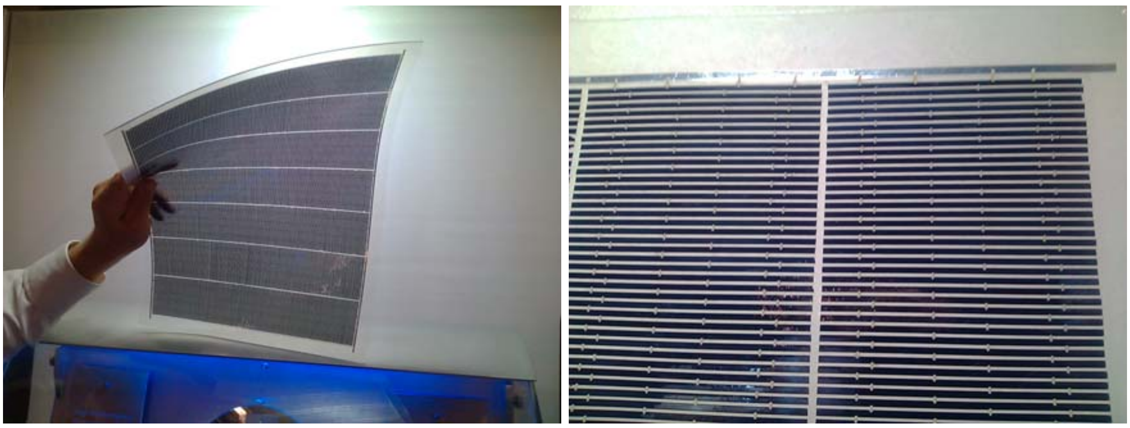


Fig.1. Sliver cells and CIGS globar solar (right)

3 Architecture to minimize the impact of shadows, spots, dust and isolated cell ruptures

The need to work at voltages above the junction level of the conversion element requires a serial connection of the cells (when a roll to roll process is used the film has to be cut in parts to assure serial connection of the parts then a higher output voltage). When connected in series the cells operate limited by the cell that produces less power. In a series of 100 cells one single broken cell opens the circuit. Similarly one single cell under shadow can radically reduced the overall output. The use of by pass diodes is the usual method to limit the problem. This problem is particularly relevant for a moving vehicle having surfaces continuously exposed to different levels of light. The following figures explain the problem.

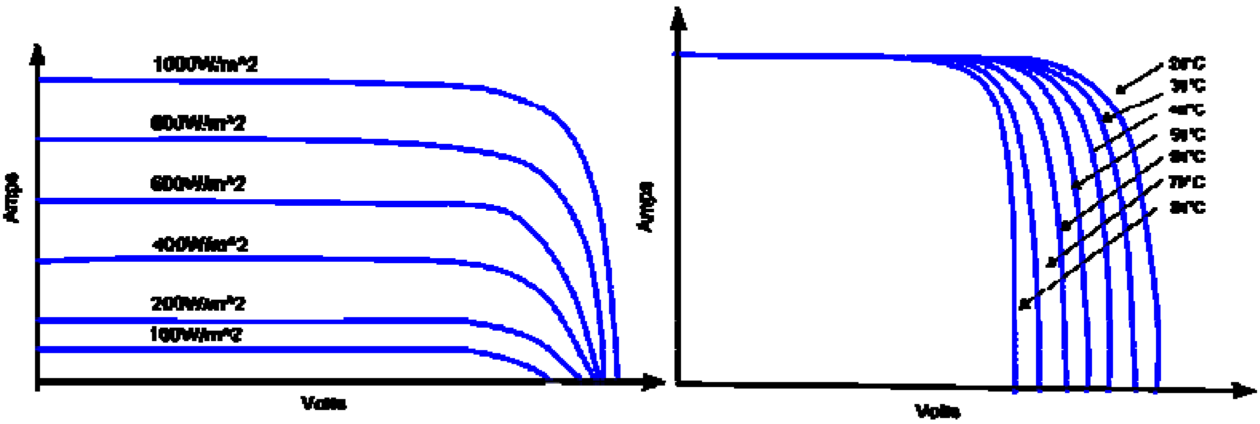


Fig. 2. The output current is proportional to the intensity of solar irradiation to which it is exposed. At higher temperature the Vmp voltage reduces, shifting the entire V-I curve to the left. The module power rating is specified at standard test conditions which consist of homogeneous irradiation of 1000W/sqm at 25°C.

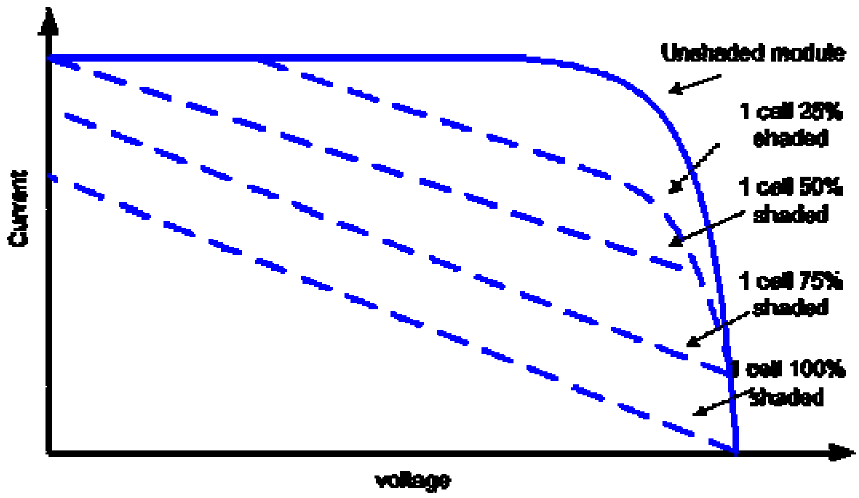


Fig. 3: Effect of shading on one cell of a single crystalline module that has no internal bypass diode. One completely shaded cell will reduce the module output as much as 75%. Curves traced with MPPT not in function.

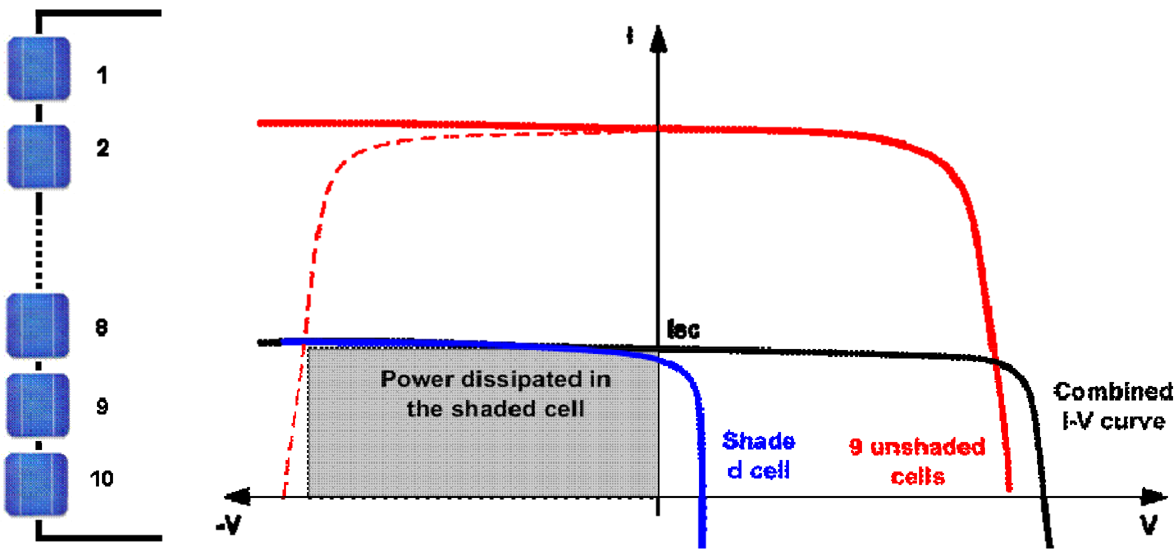


Fig. 4. I-V curve of 10 cells with one cell shaded, without bypass diodes. The shaded cell dominates the behavior of the full module.

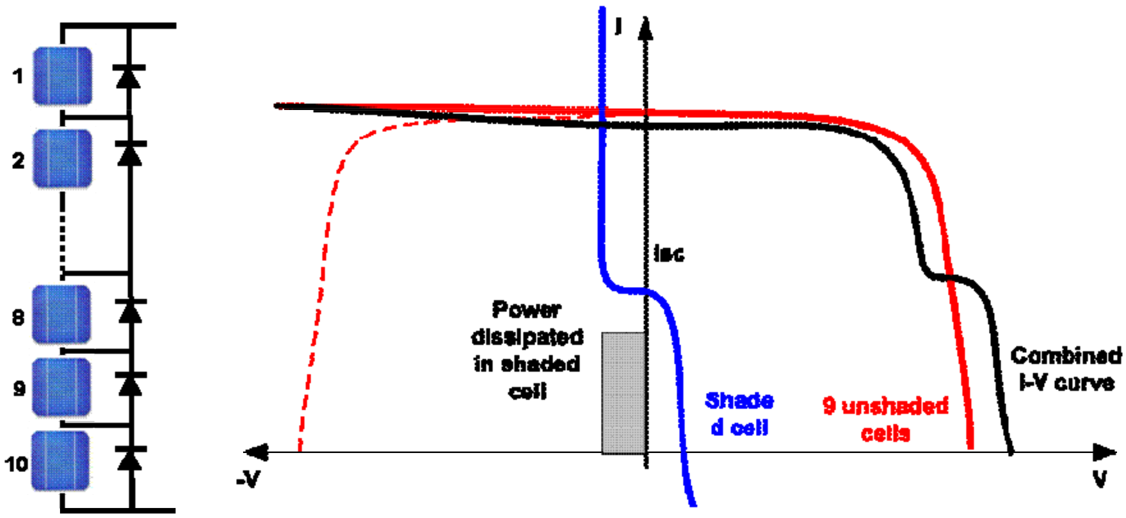


Fig. 5: I-V curve of 10 cells with one cell shaded, with bypass diodes on each cell

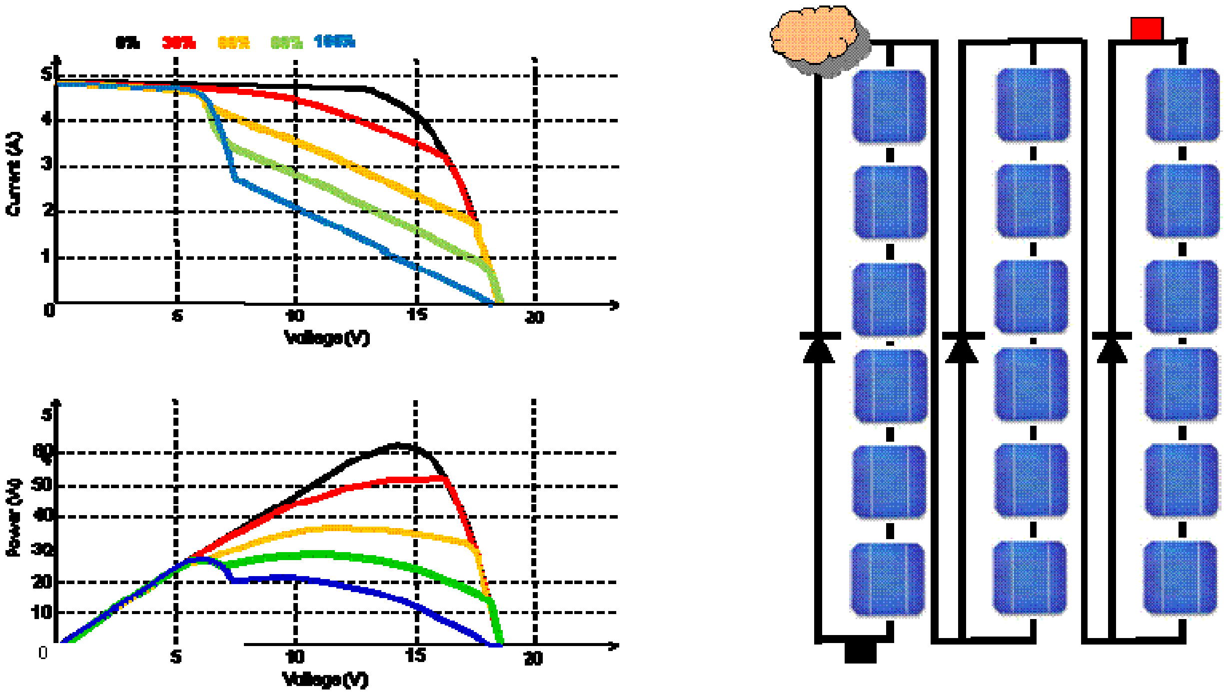
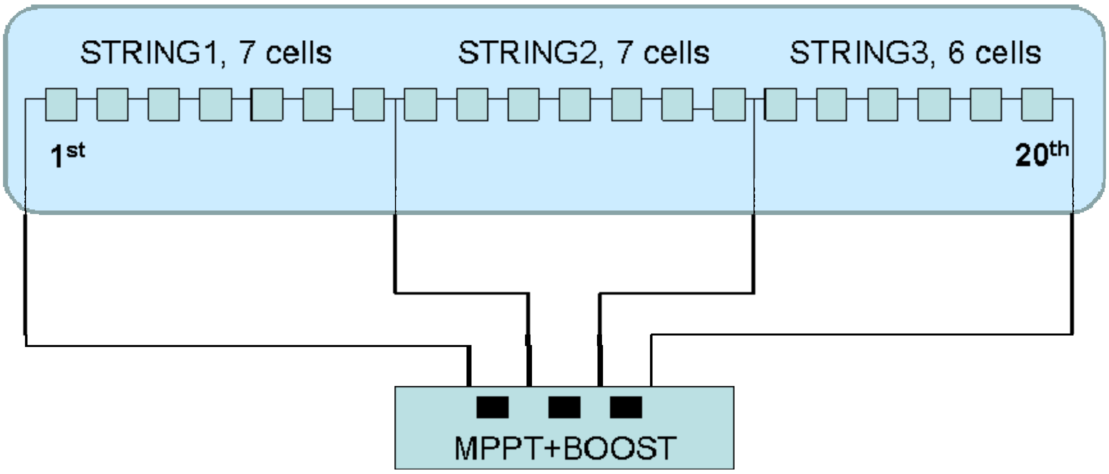


Fig.6: 70W panel of 36 cells with three bypass diodes. 35 cells are irradiated with 1000W/m2, one cell is partially shaded from 0% to 100% with 10W/m2 remaining irradiation (diffused).

The search for the compromise in between the number of cells to be connected in series, the selection of the number of by pass diodes and the minimisation of the overall wiring complexity has been the activity of PMOB in the first 12 months. Wiring and by pass diodes influence the lamination process and in that direction several manufacturing procedures have been experimented. To reduce the complexity of the lamination the overall panels have been contained in size. For instance the PV panel for the roof of the PMOB vehicle has been partitioned in three parts. The following figure show the approach adopted.



PV cell:
Fig. 7: Manufacturer: SUN POWER, Model: C60, Performance @1kW/mq: Voc = 0.680 V; Vmp = 0.575V, Isc = 6.28 A; Imp = 5.92 A, Rated Power: 3.40 W, Efficiency: Up to 22.6%

Other configuration including 20 cells per every diode have been implemented as well.

4 Selection of the appropriated electronic including MPPT and management of by pass diode

The usual approach to maximise the output of a PV panel is the use of the so called MPPT maximum power point tracking electronic.Because of the shadowing impact, electromobility does require a combination of high efficiency by-pass diodes and fast MPPT electronic. To maximise the energy stored into the Li-ion battery the power output has to be continually adapted in relation to the state-of-charge of the battery. The electronic board that does the work can integrate the by-pass diodes simplifying the lamination but increasing the wiring length and complexity.

To simplify the development of the electronic board the cells can be connected in a number that assures a voltage slightly below the battery pack and in any case above the threshold necessary to assure the operation of the board without the need of an external supply. For instance if the battery is at 12V the number of cells to be connected in series can be 20. In that case the board operates in the boost mode with minimum losses.

Low consume by-pass diodes have been purchased from ST microelectronics. Similarly specific autoadapting boards have been developed by ST microelectronics.

The work performed in PMOB has considered both diodes directly laminated into the panel and by-pass diodes integrated into the electronic board.

The following figure shows the overall scheme adopted for the experimentation. A specific 12V Li-ion battery including a battery managing system has been assembled for the purpose.

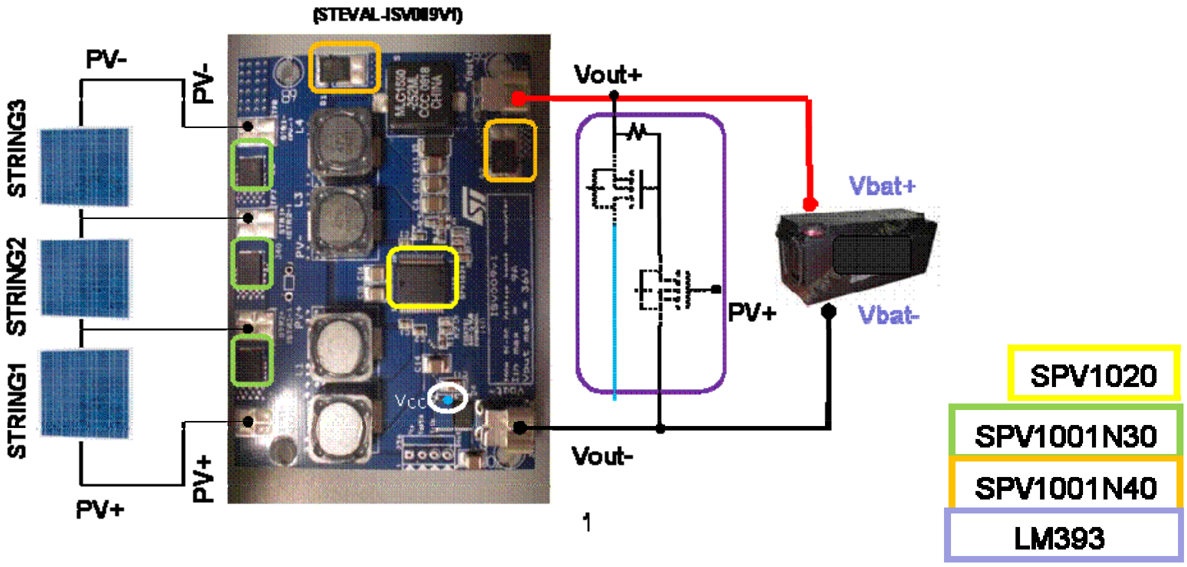


Fig. 8: SPV1020 is supplied by the 12V battery. A dedicated simple circuit (P-ch + N-ch) avoid any undesired current consumption in case of shading or during the night. Battery 12V Li-ion.

An example of a panel of Sunpower corporation laminated cells in polymer sheets is shown in the following figure including the experimental set up used to characterise the performance.

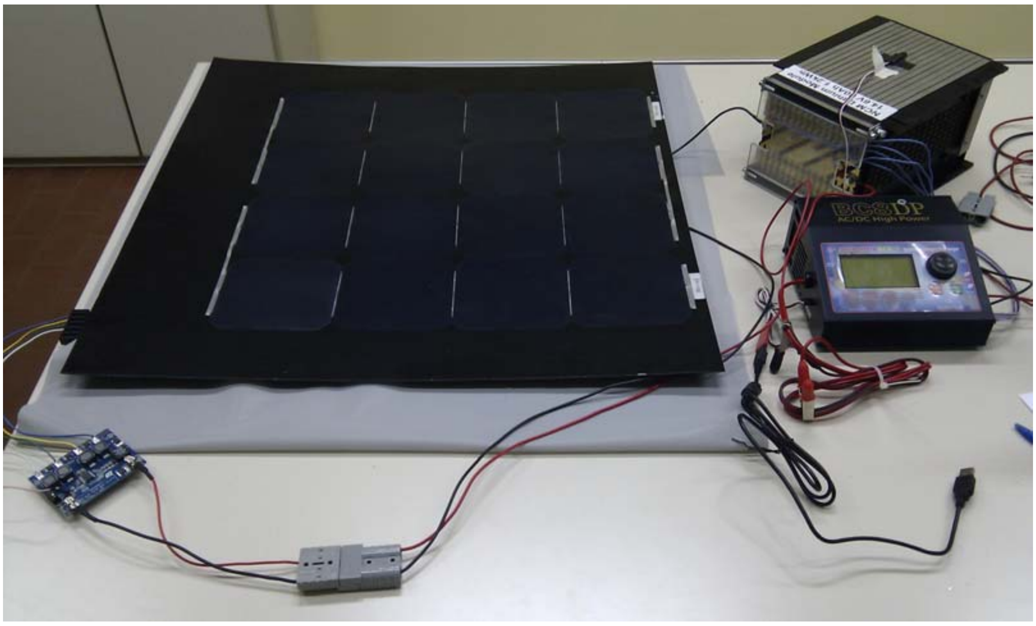


Fig. 9 Overall experimental system including a laminated panel, electronic module, Li-ion battery and dedicated BMS.

The currently developed roof modules produce a peak power of 190W. Further introduction of cells are possible so that the roof could produce 220W. Other 40W are expected from cells integrated into the glazing (the two small rear windows). The introduction of solar modules in other panel surfaces are delayed and at the moment considered secondary.

A campaign of extended measurements has still to be accomplished, specifically in all condition of usual exposition to shadows and heterogeneous irradiation (trees and buildings).

The expected total energy produced by the roof and the two rear side windows, in the average day of the year, is in between 1.6-1.8 kWh. With a consume of 65-70 Wh/km, the P-MOB vehicle is confirmed with a range of 20-25 km/day in the average annual solar day of the Torino area. In pure urban mobility the consumed energy per km is reduced but lower is the output because of the higher shadowing impact, consequently the range should remain the same.

5 Integration of PV modules into vehicle panels

The activity is under development aiming at the definition of an industrial integration of the laminated modules into the vehicle panels.