THE SOLAR ROOF WINDOW

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ABSTRACT: The purpose of the project is to develop a semi-transparent SOLAR ROOF WINDOW which feeds the produced photovoltaic power directly into the grid (~230 V) by means of a DC-AC inverter built into the window frame. Up two now three prototypes are realised with PV power of 35 Wp, 36 Wp and 45 Wp connected with commercially available module inverters to the grid. These first prototypes are assembled with common crystalline Si-cells. Thus the transparency of daylight between 30% and 51% is realised by proper spacing each non-transparent single Si-cell. The next prototype of the PV-generator will be produced by use of semi-transparent crystalline Si-cells itself - the POWER CELL. A homogeneous view through this PV-generator is expected due to the millions of small holes in the Si-wafers and the reduced spacing between each cell. This development project is performed in close collaboration with the VELUX Swiss AG company with the aim to add another accessory unit to the window product line.

Keywords: 3: Inverter - 1: Roofing Systems - 2: Small Grid-connected PV Systems

1. INTRODUCTION - CONCEPT

In order to install a conventional roof-mounted PV system in the kW power range three groups usually have to co-ordinate their work: the electrician, the roofer and the PV system specialist. The SOLAR ROOF WINDOW, however, can be installed by the roofer alone.

During the development of the three SOLAR ROOF WINDOW prototypes crystalline Si-cells are laminated onto 4 mm glass. This composite is used as the front glass of the usually used two glasses. The serial connected cells feeds the electricity into the grid by the use of commercially available module inverters (Fig. 1). To show the actual produced PV-power a LCD display is integrated into the window frame. Further prototypes with semi-transparent cells (thin film cells or transparent cryst. Si-cells) will be realised.

The expected advantages of this compact PV system are based on the following features**:**

- Daylight can pass through the SOLAR ROOF WINDOW and, additionally, electrical power is produced.

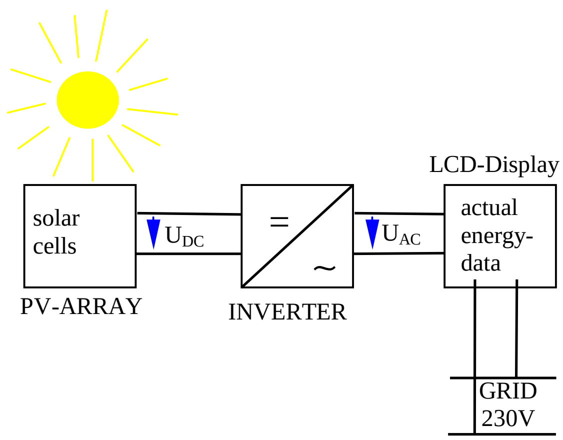

Figure 1: Circuit scheme of the grid-connected SOLAR ROOF WINDOW

- The mechanical frame is that of a mass produced ROOF WINDOW (i.e. Velux 304 standard window size). The mechanical installation of the PV-window causes no extra installation costs, since there is no difference to mounting a conventional roof window. Therefore, it can be assembled by the roofer alone.
- Connecting the SOLAR ROOF WINDOW to the grid is as simple as installing an electric lamp.
- The costs of a 45 W PV system should be less than 700 SFr. It is expected that this price will be attractive to people planning to realise their own PV power plant. The most effective marketing strategy would be to distribute the SOLAR ROOF WINDOW directly to the roofer's trade.
- Different types of solar cells, crystalline, crystalline semi-transparent and thin-film cells, in different arrangements and colouring will be produced. This allows the customer to choose between different transparency and PV power.

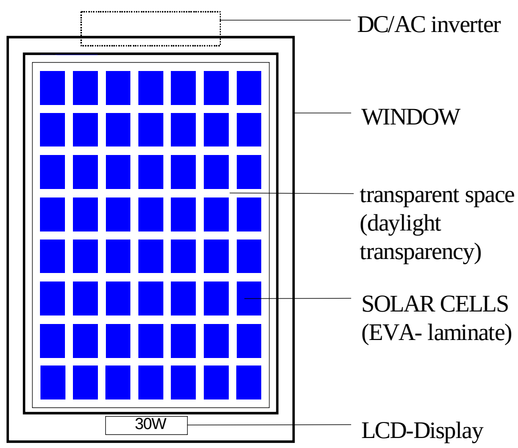

Fig. 2: Arrangement of solar cells and PV-components

2. THE SEMI-TRANSPARENT PV-GENERATOR

The electrical serial connected cells are embedded in soft EVA on the outside glass of the window and covered either by a Tedlar or a PVF or PETP foil. This PV-outside glass was exchanged with the outside glass of a conventional mass-produced roof window. (Fig. 2b) Additionally the PV-array was connected to the module inverter integrated into the window frame. Three prototypes are produced with nominal PV power of 36 Wp (66 cells 36x100 mm^2), 35 Wp (70 half cells 50x100 mm^2) and 45 Wp (70 half cells 50x100 mm^2).

Fig. 2a First SOLAR ROOF WINDOW prototype at the outdoor test on the roof of the NTB - building. The 36Wp PV-generator consists of 66 silicon half cells (each 36x 100mm^2) and connected to the grid by an module - converter. (Daylight transparency of 51 percent)

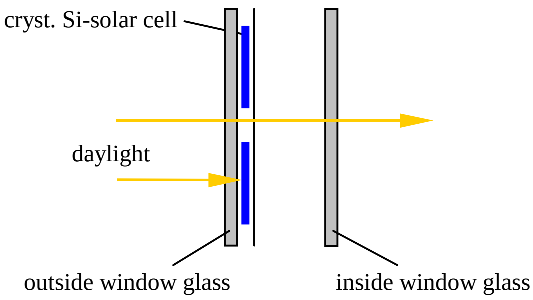

Fig. 2b Cross-sectional view of the photovoltaic-generator with conventional crystalline Si-solar cells

The first prototype covers 49 percent of the 0.5 m^2 window area with non-transparent silicon solar cells leading to half the daylight transparency compared to a usually Velux 304 roof window. (Fig. 2a) The PVF or PETP foil in place of the Tedla foil improves significantly the transparency of the window regions not covered by the Si-cells.

The progress in development of transparent crystalline silicon cells at the University of Constance make it possible to investigate a new design of the SOLAR ROOF WINDOW. [2, 3] Based on the POWER CELL homogenous transparent PV-window glass seems to become possible with double efficiency compared to today's semi-transparent a-Si thin film on glass. The one million tiny holes of a 100 x 100 mm^2 POWER cell wafer lead to about 30% transparency of the cell area.(Fig. 3b) In Fig. 3a the view through such a semi-transparent crystalline silicon cell is shown. Beside the gain in daylight transparency the outside objects clearly can be seen similar to a fine mashed curtain. Tests and measurements of such a SOLAR ROOF WINDOW prototype consisting of semi-transparent POWER CELLS will be performed in the next months.

Fig. 3a Transparency effect in view of the NTB-building through a semi-transparent crystalline silicon POWER CELL wafer and window glass only.

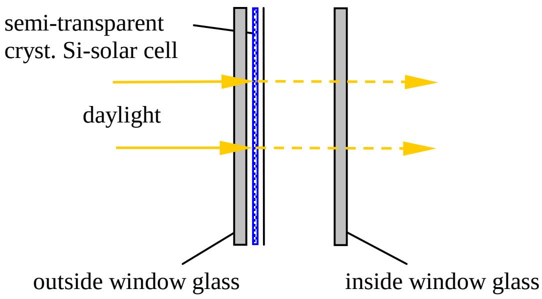

Fig. 3b Cross-sectional view of the photovoltaic-generator with semi-transparent crystalline Si-solar cells

3. MODULE INVERTER

Today's module inverter on the market are designed with a nominal power of above 100 W. This value is about three times higher than the nominal power of the PV-array in the discussed SOLAR ROOF WINDOW. Therefore measurements of the efficiency are carried out with special respect to the partial load region of the inverter below 50 W DC power. The results are in accordance with given data by the manufacture. Only the OKE 4 inverter reaches the maximum of the efficiency (92% at 30 W) within the power range of the prototype SOLAR ROOF WINDOW. The calculation of the "European inverter efficiency" [5] is dominated by the inverter efficiency at 50% of the nominal DC power of the PV-generator. At a DC-input power of 20 W conversion efficiency between 80% and 91% are obtained for the different inverter products. (Fig. 4)

Detailed simulation of the annual inverter efficiency was done by using the program PVSYST 2.0 [6] based on the measurements in Fig. 4. The results at different PV-generator power is given in Tab. 1. With a PV-array of nominal 45 Wp the average annual efficiency of the inverter is 75% for the DMI 100, 76 % for the "Sunmaster 130" and 89 % for the "OKE 4".

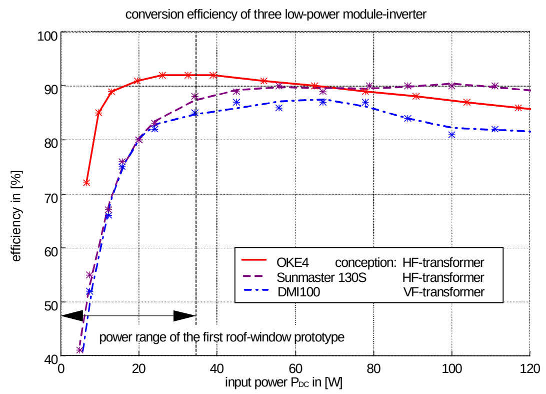

Fig. 4 Inverter efficiency at different DC input power.

Tab.1: Performance of module inverters to be connected to the solar roof window.

Product	Dorfmüller DMI 100	Mastervolt Sunm. 130	OKE4
Nominal DC - power	100 W	130 W	130 W
MPP voltage	28 V...50 V	24 V...40 V	24V..50V
max. inverter efficiency	87 %	90 %	92 %
average annual efficiency* PV**	67 %	69 %	88 %
average annual efficiency* PV***	75 %	76 %	89 %

Location: Trimbach, Switzerland; tilt angle 45°, south 0°
PV** PV- generator: 36 Wp; PV*** PV-generator: 45 Wp

4. PV-SYSTEM OUTDOOR TEST

Real outdoor tests of the grid-connected PV-System as well as laboratory tests of each of the components (PV-module and inverter) are conducted and the performance of the combined system is simulated (used software: PVSYT 2.0 and PVS 1.7). [6, 7]

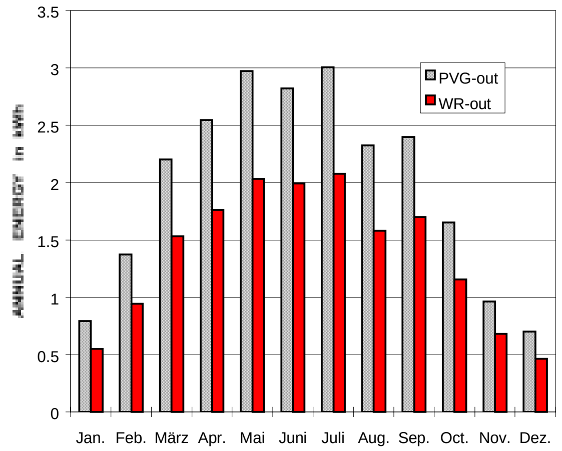

Fig. 5 Simulation of the annual produced DC - electricity out of the PV - generator and the energy powered to the grid by the inverter (differences between PVG-out and WR-out correspond to the inverter losses).

PV-generator: **36Wp**, U_{mpp}=33V, 45° tilt to south
Transparency: 51%
Inverter: OKE4
Annual inverter efficiency: 88%
Annual production PVG-out: 23 kWh
Annual energy to the grid WR-out: 21 kWh
Annual PV-system performance: **580 Wh/Wp**

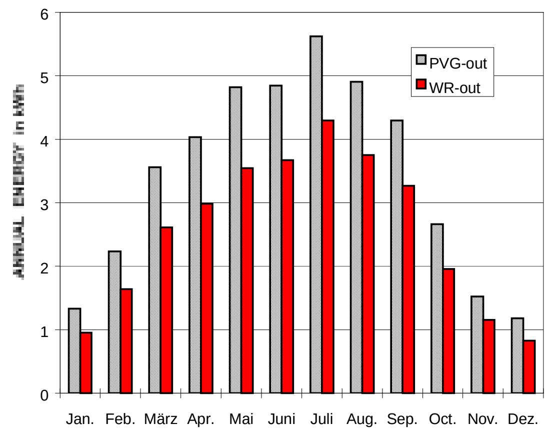

Fig. 6 Simulation of the annual produced DC - electricity out of the PV - generator and the energy powered to the grid by the inverter (differences between PVG-out and WR-out correspond to the inverter losses).

PV-generator: **45Wp**, U_{mpp}=35V, 45° tilt to south
Transparency: 30%
Inverter: DMI 100
Annual inverter efficiency: 75%
Annual production PVG-out: 41 kWh
Annual energy to the grid WR-out: 31 kWh
Annual PV-system performance: **690 Wh/Wp**

The first prototype is equipped with a planar PT100 temperature sensor between the Tedlar foil and the Si-Wafer. During outdoor test of the SOLAR ROOF WINDOW the cell temperature measured by the PT 100 was 64°C while the temperature from the ESTI-reference cell (positioned at the same tilt angle) revealed 57°C (solar power in plane 970 W/m^2).

According to a series of above measurements and the measured inverter efficiency (Fig. 4) the annual performance of the small-grid connected PV-system was calculated. The 45 Wp-prototype PV-array will produce 37kWh/a by use of the OKE 4 inverter. The same PV-array feed 32 kWh/a electricity into the grid using the Sunmaster 130 inverter and only 31 kWh by use of the DMI100 (Fig. 6). This result of the simulation give an annual system performance between 690 and 815 Wh/Wp according to different inverter performance.

Due to the bad power match of today's DC/AC module inverters a redesign with nominal power of lower than 50W has to be done to meet the requirements of the 0.5 m^2 SOLAR ROOF WINDOW system with suitable transparency.

5. SUMMARY AND COSTS

Obwohl schlechte the best inverter 815 Wh/Wp with a 45 Wp PV-generator which is the same than the average system performance of all grid connected PV-systems in Switzerland. [8]

Colouring of the semi-transparent PV-glass give rise to new design features. High efficiency with polycrystalline cells homogeneous

Because of the about three times higher nominal power of the available module inverter compared to the PV-array (45 Wp) the average annual efficiency of the inverter is 76 % (Sunmaster 130), 89 % (OKE 4). Only the OKE 4 inverter reaches the maximum of the efficiency (92% at 30 Wp) within the power range of the prototype SOLAR ROOF WINDOW.

Solar electricity cost of 1.5 SFr /kWh are estimated for the SOLAR ROOF WINDOW (based on real discount rate of 4% and a lifetime of the whole PV-System of 20 years, performance of 815Wh/Wp/a). Approximately one percent of the annual electricity requirements of a typical household in Switzerland could immediately be covered by this grid-connected PV-System. Considering that for the year 2010 it is optimistically estimated that only 1 % of the electricity produced in Europe will be produced by PV - systems, the owner of a grid-connected solar roof window is well ahead of his time.

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