Temperature Reaction and Performance of mono crystalline PV-Modules with Black Surface (Black Tedlar-Foil) compared to mono crystalline Modules with conventional Surface (white Tedlar-Foil)

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Courtesy translation by M. Moore

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1. Introduction

For optical reasons, an increasing number of mono crystalline modules, with an entirely black surface have recently been installed. In this case the matrices (areas between the single cells and close to the frame), which normally are white due to the white Tedlar-foil that is commonly used, are black due to a black Tedlar-foil. Since the frame is painted black as well, a coherent colour impression overall the entire roof is achieved. Many people find this visually more pleasing than black-and-white patterned roofs (see fig. 1).

Fig. 1: left: black-and-white surface; right: black surface

Because a completely black surface heats up more than a black-and-white surface under solar irradiation, it is to be expected, that module performance will decrease. The question is the percentage by which the performance decreases and whether this is will be accompanied by considerable yield losses. For a thorough study on this, we defined the following procedure.

2. Procedure

Two years were planned for the testing period. In the first year, the measurements were taken on a black-and-white mono crystalline ANTARIS ASM180 module pair (module performance 180Wp) see fig. 2.

Fig. 2: Module pair with black-and-white surface

After the first year, the entire measuring sensor technology was connected onto a pair of mono crystalline panels (180 Wp as well) with completely black surface and tested for one year (see Fig 3).

Fig 3: Pair of PV modules with black surface

This type of procedure had one advantage. All test objects were operated with the same measuring sensor technology and thus no variation with different test assemblies had to be regarded. However, evaluation of temperature and performance only made sense if ambit parameters coincided. These included ambient temperature, global irradiation and wind speed, which were logged in addition to panel temperature and performance (see Fig 4 to Fig 6).

Since test series with both module types each lasted a year, it was quite easy to find days or certain parts of days with same or at least similar outside conditions. Reduced output from entirely black panels was thus only expected at high temperatures in summer.

3. Test assembly

Each pair of modules to be tested was connected to an inverter type 'Mastervolt Soladin 600' and thus operated in feed-in mode. Coinciding MPP ranges for the pair of modules and inverter was ensured. The panels were installed at an inclination angle of 25° and oriented exactly south (see Fig 2 and 3). At the DC side, voltage and current were logged to a PC hard drive with a measuring data software program. On each panel of each pair of PV modules, a calibrated PT100 sensor was fastened exactly centred on its rear for recording of module temperatures (see Fig 4).

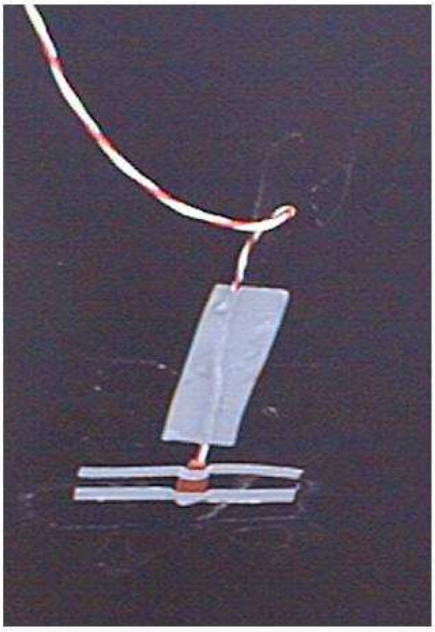

Fig 4: Temperature sensor was affixed, adhesive tape got removed succeeding hardening of heat conducting adhesive.

Operated on the same roof are amongst others a wind speed meter (Anemometer) and a global irradiation meter (Pyranometer) (see Fig 5 and 6). Their data was digitally saved as well as the data from the outside temperature sensor affixed in the shade two meters above the ground. The intervals for all measuring data recordings were each 60 seconds. Readings were performed 'round the clock for two consecutive years. Subsequently all data was evaluated ensuring similar ambit conditions.

Fig 5: Global irradiation meter (Pyranometer)

Fig 6: Wind speed meter (Anemometer)

4. Test results

The ambit parameters of July 3rd, 2009 and June 28th, 2010 were very much alike, see Fig 7 to Fig 14.

Predefinition:
For each of those two days peak panel temperatures were ascertained and for those time frames the electrical outputs, global irradiations, wind speeds and outside temperatures were established.
The graphs for the modules with black and white surface are to be seen on Fig 7 thru 10. The modules with black surface only are on Fig 11 thru 14.

4.1 Modules with black and white surfaces

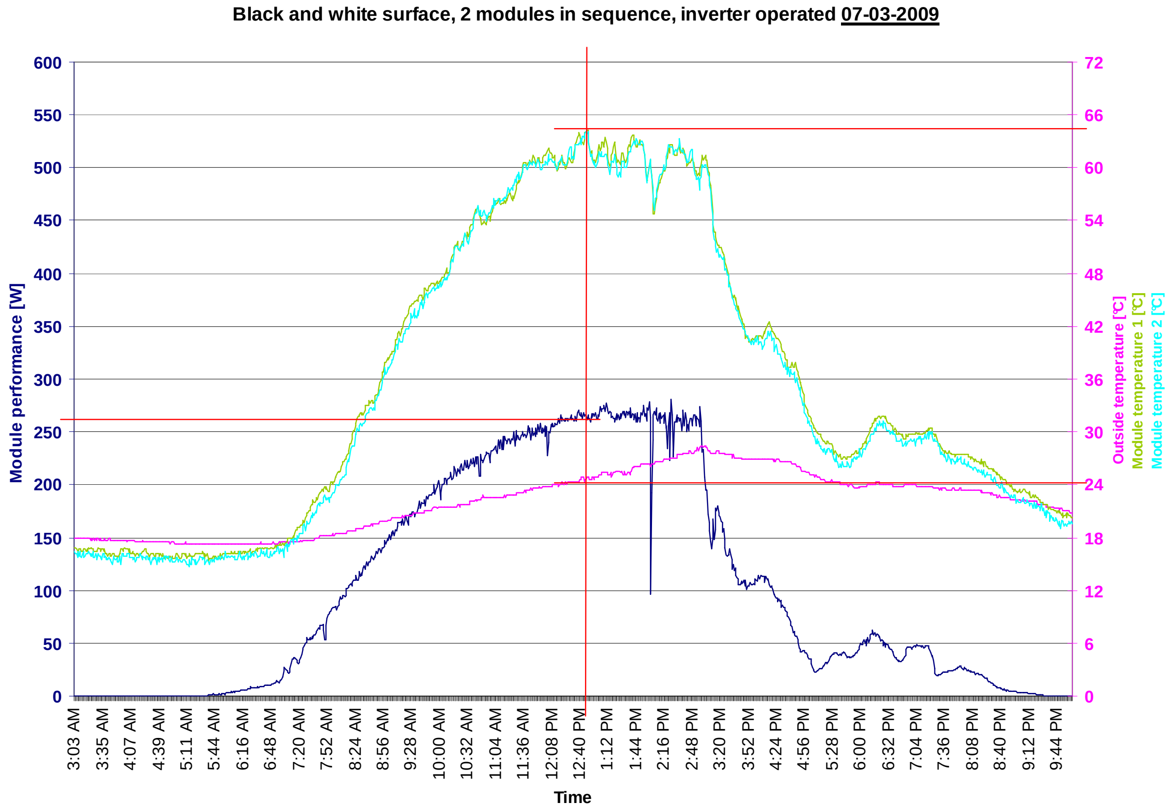

Fig 7: Day curve: module temperatures, power output, outside temperature

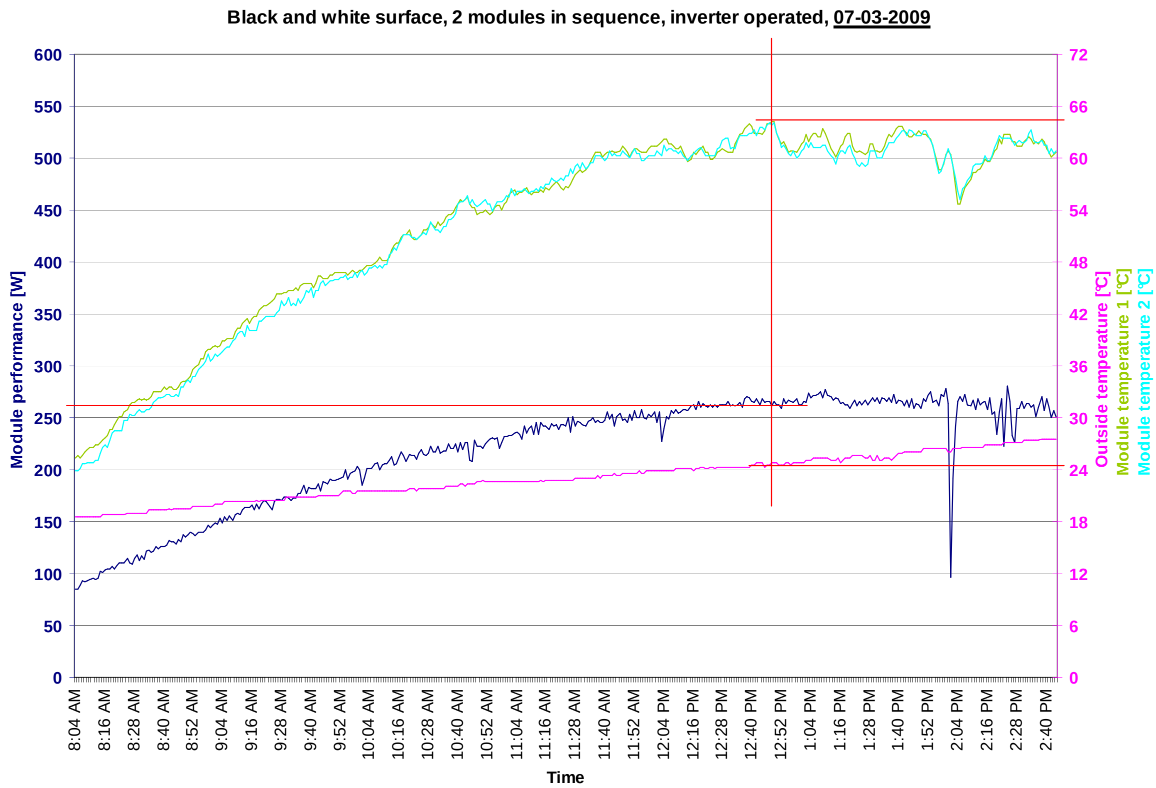

Fig 8: zoomed display: module temperatures, power output, outside temperature

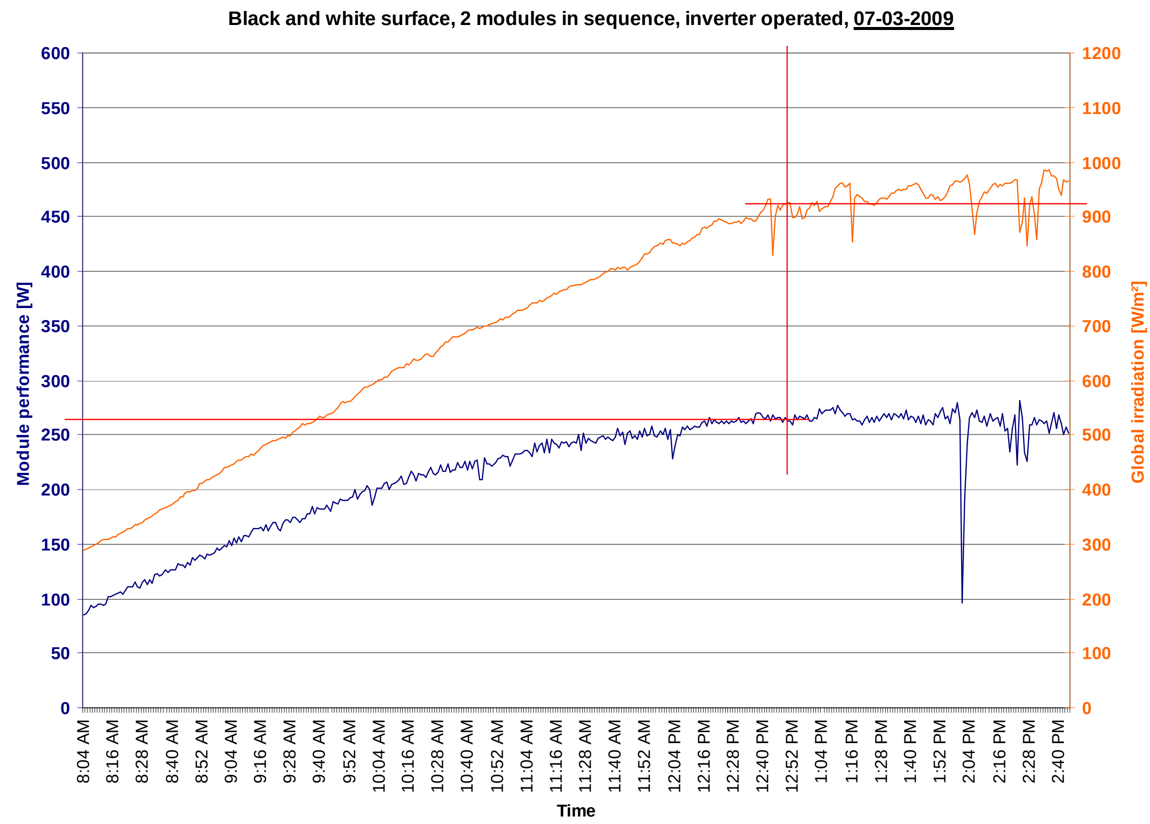

Fig 9: zoomed display: global irradiation, module performance

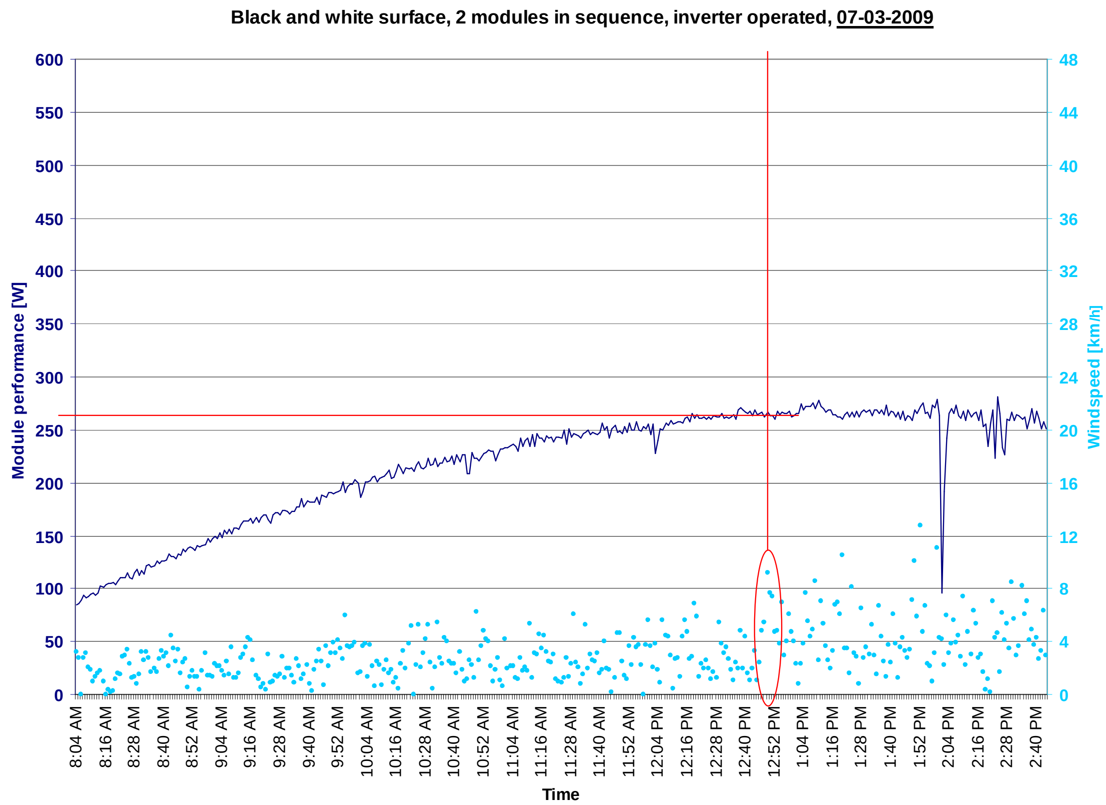

Fig 10: zoomed display: wind speed, module performance

4.2 Modules with black surface

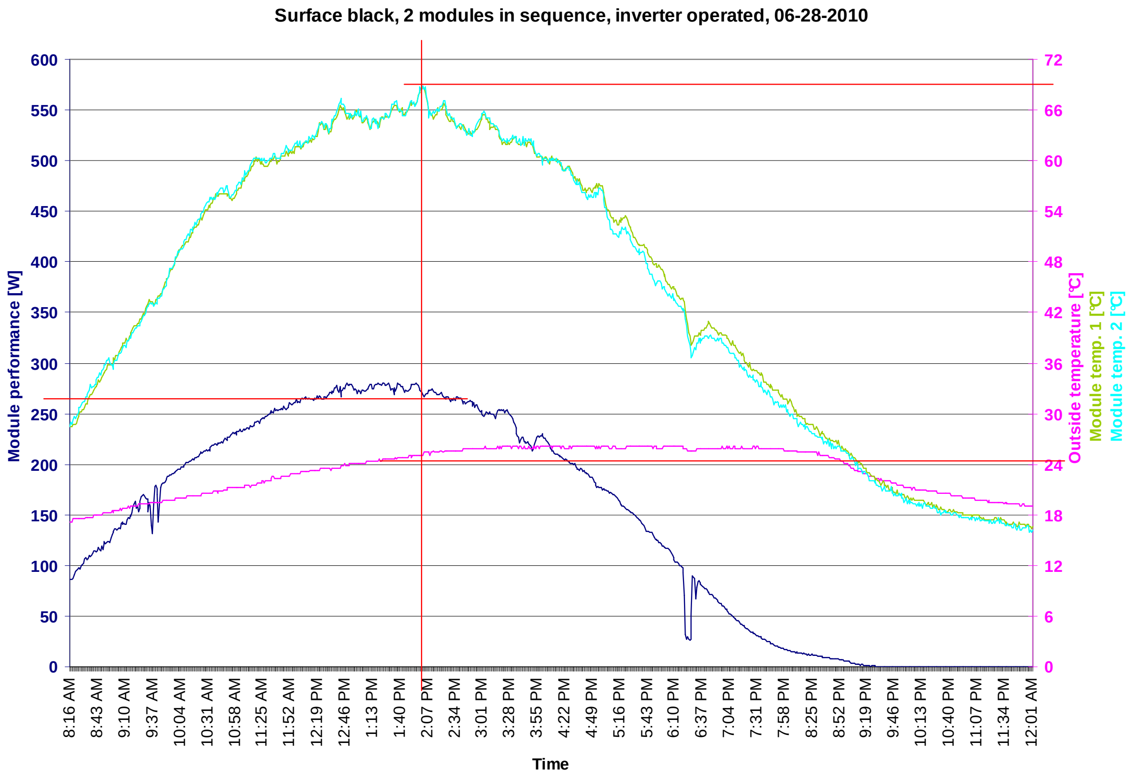

Fig 11: day curve: module temperatures, module performance, outside temperature

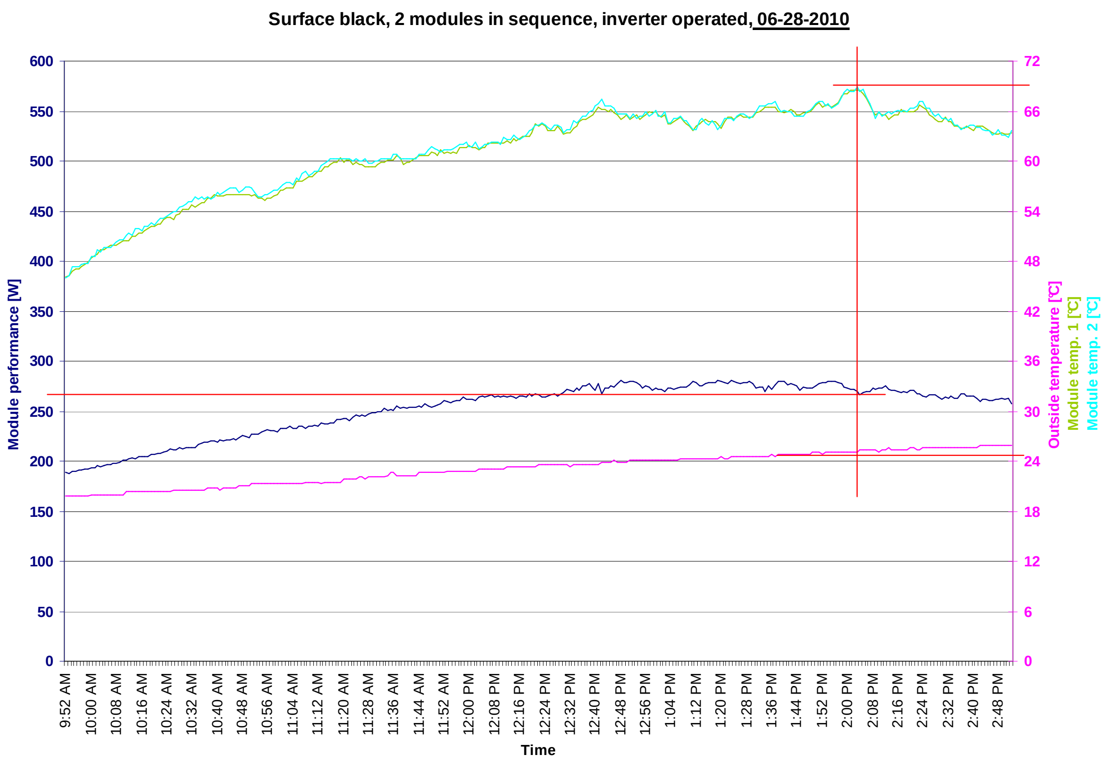

Fig 12: zoomed display: modules temperatures, module performance, outside temperature

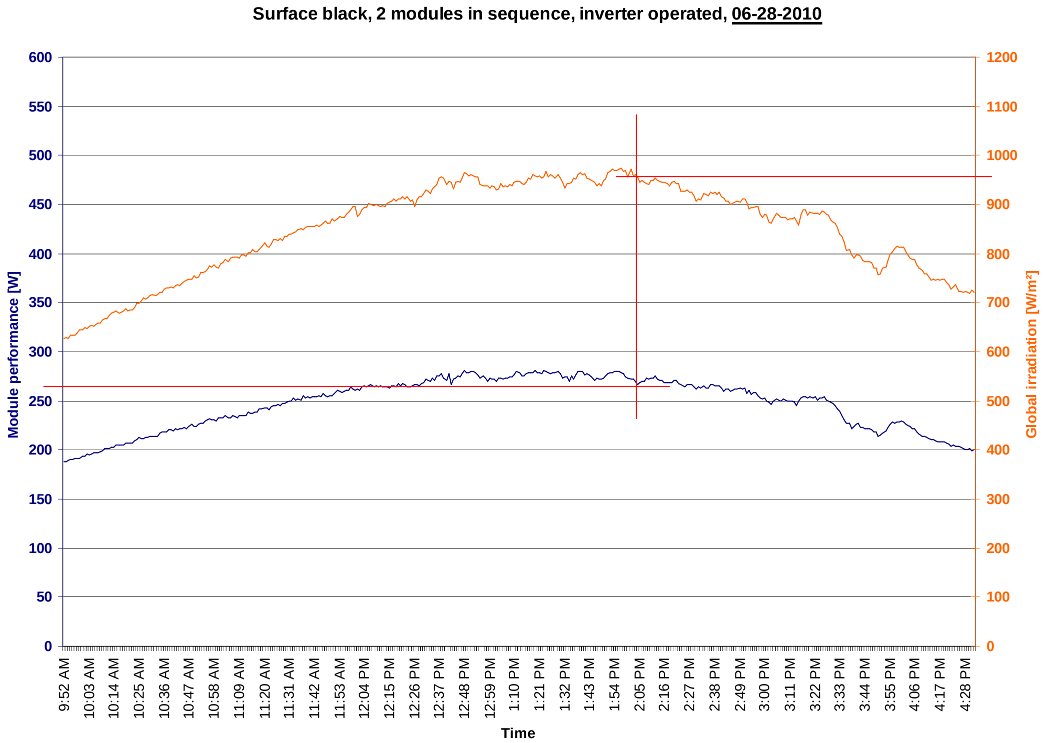

Fig 13: zoomed display: global irradiation, module performance

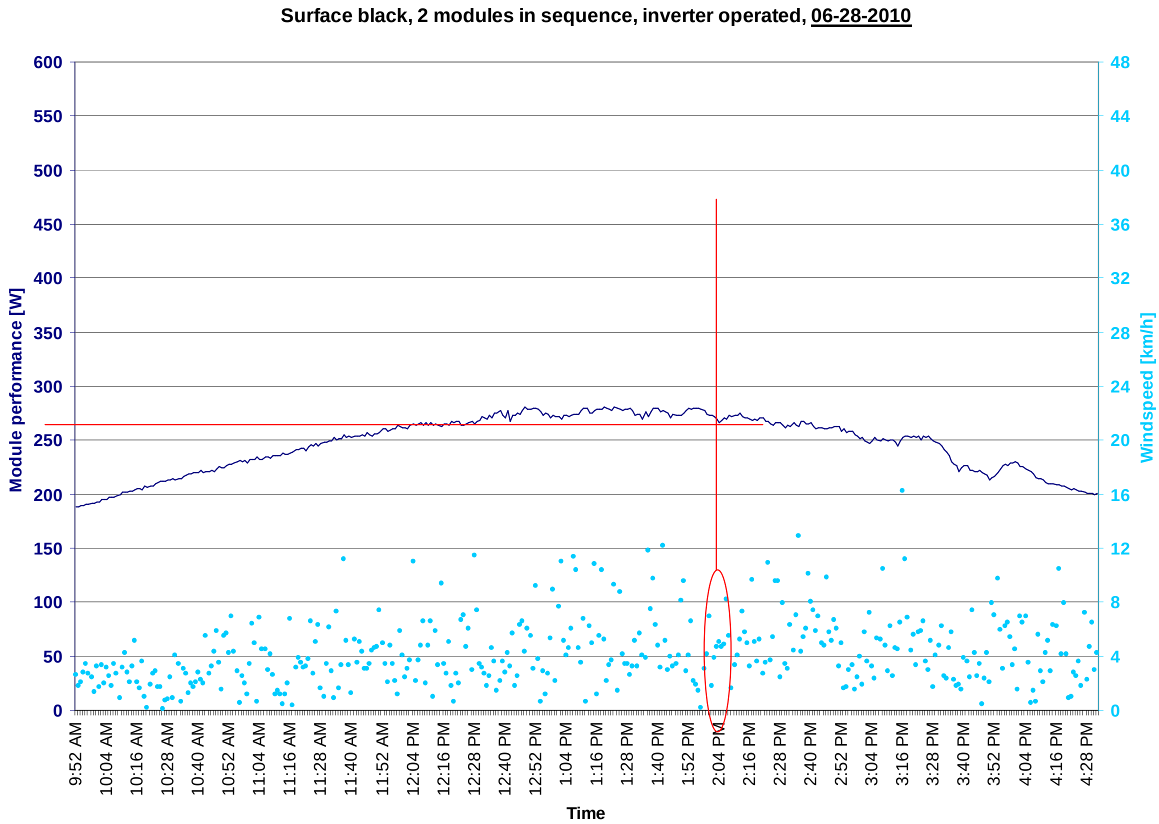

Fig 14: zoomed display: wind speed, module performance

4.3 Results in tabular illustration

Date	Module surface	Module temp. [°C]	Performance pair of modules [W]	Global irradiation [W/sqm]	Wind speed [km/h]	Outside temp. [°C]
07-03-2009	black & white	64	~270	~920	~8	~25
06-28-2010	black	69	~270	~960	~8-9	~25

Auditing conformance of measuring data and spec sheet values:

Performance-Temperature-Factor acc. spec sheet:

- for modules with black and white surfaces: -0.45%/°C
- for modules with black surfaces: -0.45%/°C

Spec sheet values (nominal values) are established in laboratories under STC (standard test conditions). Thereby, a module temperature of 25°C must be maintained. For an increase of every °C the module's performance decreases by 0.45%.
The factor of -0.45% in this particular case pertains to the nominal power of 180 Wp (for two modules in sequence: 360 Wp). Furthermore, a global irradiation of 1000 W/m² must also be maintained during STC laboratory tests.

This signifies:

- For the modules with black and white surfaces heating up to 64°C causes a performance drop of (64°C – 25°) x 0.45% = 17.6% respectively 63.4 Wp. The pair of modules would (solely arithmetically) yield only 360 Wp – 63 Wp = 296.7 Wp, due to a 39 °C higher temperature. Considering the global irradiation, which remains at about 920 W/m² (8% beneath STC value of 1000 W/m²) as well as a minor power loss in supply cables and commonly minor pollution on the surfaces, our readings of the realistic performance of the pair of modules ranges at about 270 Wp (at a module temperature of 64 °C).
- For the modules with black surfaces the same computation can be made. These modules reach a temperature of 69°C at days peak, thus became 5°C hotter than the modules with black and white surfaces. Due to the 5°C higher temperature than in comparative modules, we solely arithmetically obtain a loss of 19.8% equalling 71.28 Wp. Therefore (again solely arithmetically) the black pair of modules would yield a 288.7 Wp performance. The global irradiation in this case remained at 960 W/m² (thus 4% beneath STC value). Again, in this case our readings show the realistic recorded performance value of likewise app. 270 Wp – considering minor power loss due to lead cables and minor common pollution of the surfaces – approaching the computed values quite closely.

5. Conclusion

The most important perception of the study is PV modules with black surfaces, at nearly identical environmental/ ambient conditions on typical summer days at peak heat up merely more than comparative modules with black and white surfaces. In our case it was 5°C. Solely arithmetically these 5°C yield in a power loss of 2.3%. From 'good' manufacturers, that carefully sort their modules (i.e. to Plus tolerance), these 2.3% losses (caused by a higher module temperature of 5°C) would actually range within the common spreadsheet tolerances of +/-3%.

6. Equipment

Device	Type	Manufacturer/Vendor
Multimeter	Fluke 45	Fluke
Multimeter	Fluke 89 IV	Fluke
Inverter	Soladin 600	Mastervolt
Independent disconnection	ENS 26	UfE
Data reading computer	GX260	Dell
Software	MS Visual Basic 6.0	Microsoft
Software	MS Excel 2003	Microsoft
PV Module	ASM 180	ANTARIS Solar
Pyranometer	CMP3	Kipp u. Zonen
Anemometer	WW-B1 Typ3	Warema

Waldaschaff, 09-10-2010
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