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Long term testing and evaluation of PV modules with and without Sunarc antireflective coating of the cover glass

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Abstract

Two Photovoltaic (PV) modules have been manufactured by Swemodule. One with Sunarc antireflective coated glass and one without glass surface treatment. The modules have been tested at DTU during 16 months under realistic outdoor conditions. Exactly the same polycrystalline cells were used in the modules. No cleaning of the glass has been made except for removal of bird droppings and leaves on single cells that could give a very wrong comparison. The PV modules were mounted due south at 45 degree tilt angle. They were connected to the electric grid with small 250W module inverters from Involar that also realized the MPP tracking to give the maximum output of each module. The electric power output was measured both on the AC and DC side and with different measurement equipment to be sure about the accuracy in improvement. The results indicate a potential long term improvement in a system from 3% up to 6%. The improvement is best in facade and off south tilted orientations, where the better incidence angle modifier, has a larger influence. In the PV application only one side of the glass treatment is active. This reduces the possible improvement compared to solar thermal and greenhouse applications. In PV applications the slightly higher cell temperature, due to the higher transmittance of the glass for all solar wavelengths, reduces the potential electrical performance improvement.

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Keywords: Photovoltaics, anti reflective coating, long term testing

1. Introduction

To investigate the long term effect on PV performance with Sunarc antireflection (AR) treatment a side by side comparison test rig was set up at DTU. Except for the glass optical performance one can expect differences in soiling and drying up, after rain and morning dew. The special Sunarc surface treatment is manufactured by etching

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that gives a graded refractive index between glass and air and lower surface reflectance and higher transmittance. The treatment is optimized to reduce the glass reflectance in the PV solar spectrum. One could imagine a treatment optimized for the band gap of each PV cell type, but this would be a very specialized products.

Fig.1. The PV modules during installation in May 2013. Above the PV modules, thermal collectors with the same glass types can be seen.

One module with standard glass and one module with antireflection treated glass were manufactured by Swemodule. The cells in the two modules were selected to be of exactly the same quality and performance.

A standardized STC (Standard Test Conditions) flash test of the performance was made of the modules, at the factory too. The modules were carefully mounted in the same 45 degree tilted plane and oriented due south, see figure 1. Also two thermal collectors were installed with the same glass types. For solar thermal collectors the AR treatment on both sides of the glass is utilized and a larger improvement can be expected.

2. Measurement system

The accuracy requirements in this kind of test are extreme, as the difference between the modules is in the range of a few percent and often at low power levels and over long operating periods when errors can add up. Therefore the modules were connected to the two test systems with quick DC connectors, so that the modules could be switched both on the AC and DC side. In this way the comparison accuracy between the modules could be checked. On the AC side the output was measured in 3 ways: 1) With the Involar inverter logging system, 2) With manual readings of two AC meters and 3) By logging of pulses from the same electricity meters. On the DC side current, voltage and power was measured with a data logger from Ems-Brno type V12 [2]. With this logger also total solar radiation in the module plane, outdoor temperature, cell temperature and wind speed was measured. Also diffuse solar radiation was measured separately with the same logger type in another measurement system. The measurement sensors for the two systems, were also compared to each other, connected to the same data logger and including cabling, connectors and connection boxes, before the test to assure the best comparison accuracy for the whole measurement chain.

3. Results

The long term measurements at 45 degree module tilt and due south azimuth, indicate a full year performance improvement on average of 3-4 %. The improvement was even higher during morning and evening hours, when incidence angles are higher and the Sunarc treatment has the largest advantage. For a week long period with 90 degree tilt in August 2013, giving higher incidence angles also during midday, an improvement of 4.4 % was measured. At lower latitudes, a 90 degree tilted surface on a façade would give even higher improvements than in Denmark.

For the full test period June 2013 to August 2014 the Sunarc module delivered 350.4 kWh to the electric grid and the standard module 339.7. This gives a long term average improvement of 3.2 %. This is based on measured data from the Involar inverter system connected to Internet. The traditional AC electricity meters give a very similar long term result of 3.3 % improvement for the same period.

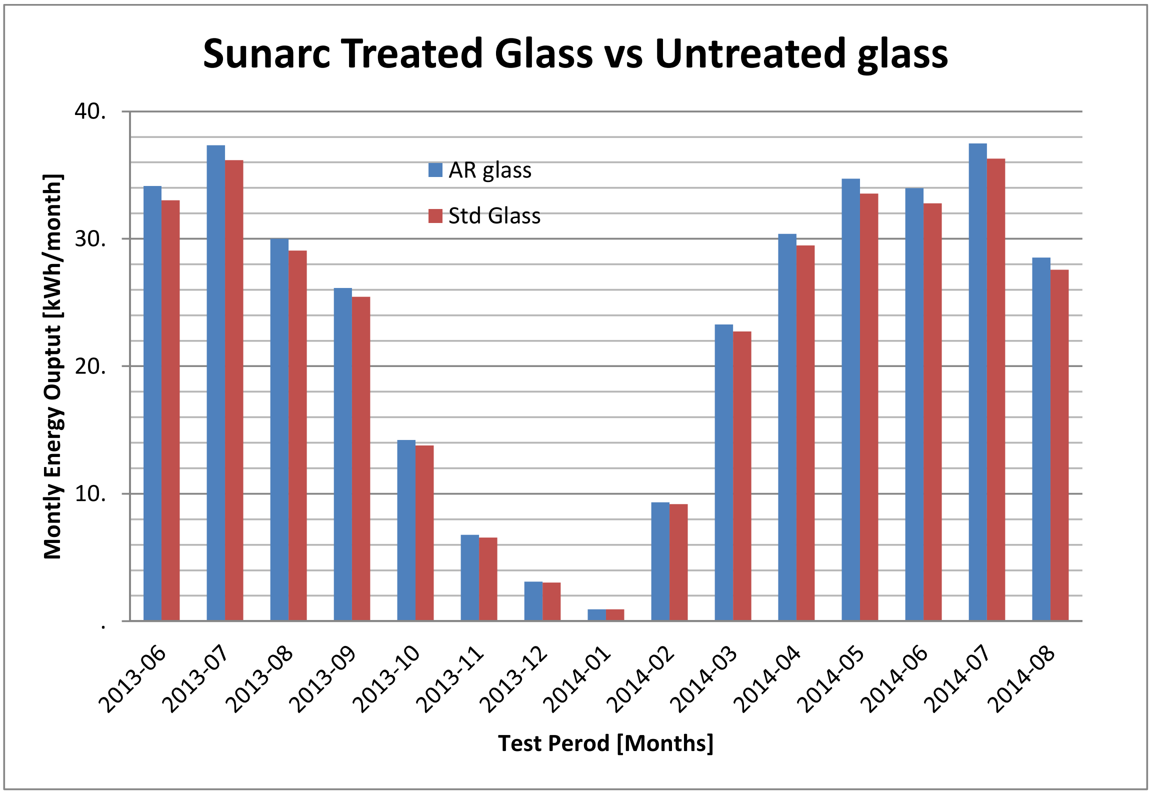

Fig. 2. Long term measurement results for the Sunarc glass treatment for PV modules. The winter improvement is small, but the energy fraction over the whole year is very small from this part of the year.

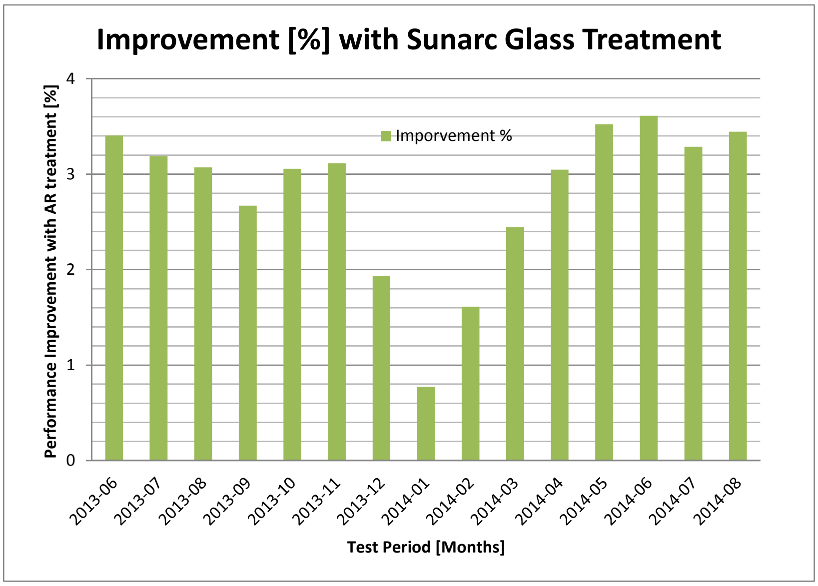

Fig. 3. Long term performance improvement in % for the Sunarc treated PV module. The low improvement in the winter, has several reasons. The main reason is low irradiation effects and a large fraction of operating time with wet glass or frost cover. More heavy soiling during winter can also influence. The measurement accuracy can also influence slightly, as long periods with very low power output is added up.

The low improvement in winter in figure 2 and 3 may have several reasons. The main reason is low irradiation effects and a large fraction of operating time with wet glass or frost/snow cover when the AR treatment is masked almost totally by the extra surface layer. An increased soiling during winter can also influence. The measurement accuracy is also at stress during winter, as long periods with very low power output are added up. Also the inverter performance at low power can have a small influence. But for the full year performance improvement, the winter period can almost be neglected.

A PVSYST model has been validated and used to extrapolate the results to different locations and orientations [1,2], like vertical facades, where one can expect a higher advantage from the Sunarc glass. An overview result for tilt dependence for three locations is given in table 1 from [1]

Table 1. Overview of results from PVSYST simulations for different locations and tilt angles from [1].

PV module with Anti-reflective treatment $(bo = 0.02)$							
kWh/year Tilt angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**
Copenhagen AR	205	228	241	241	229	205	173
Athens AR	316	343	351	342	313	269	212
Beijing AR	277	305	316	312	292	258	213
PV module with STD glass type and $(bo = 0.05)$							
kWh/year Tilt angle	**0**	**15**	**30**	**45**	**60**	**75**	**90**
Copenhagen Std type	194	218	230	231	219	196	164
Athens Std type	300	328	336	327	299	256	200
Beijing Std type	264	291	303	299	279	246	201
Difference (%) Between AR with bo=0.02 and STD type with bo=0.05							
Copenhagen	5.67	4.59	4.78	4.33	4.57	4.59	5.49
Athens	5.33	4.57	4.46	4.59	4.68	5.08	6.00
Beijing	4.92	4.81	4.29	4.35	4.66	4.88	5.97

It can be seen in table 1, in the lower third, that the lowest improvement is for the test lilt of 45 degrees for Copenhagen and it increases for higher and lower tilt angles from horizontal. The difference in improvement between the different climates/cities is comparatively small. Vertical position can give up to 6% improvement according to these simulations.

It is also important to see the chain of small losses determining the annual AC kWh result for the test systems. From PVSYST one can derive these two Sankey diagram shown in figure 4 and 5 below. Here one can see that the IAM improvement, is around 1 % on annual basis (4.3% IAM losses for standard glass module and 3.5% for AR glass)

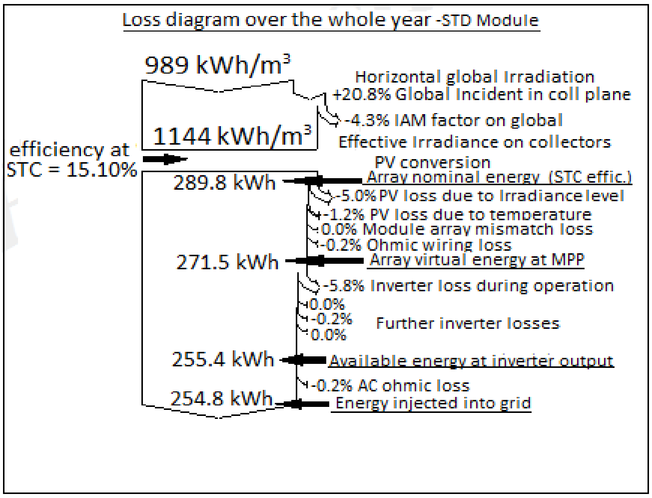

Fig. 4. Detailed PV module and system losses. **Standard module** compared to an ideal PV module calculation.

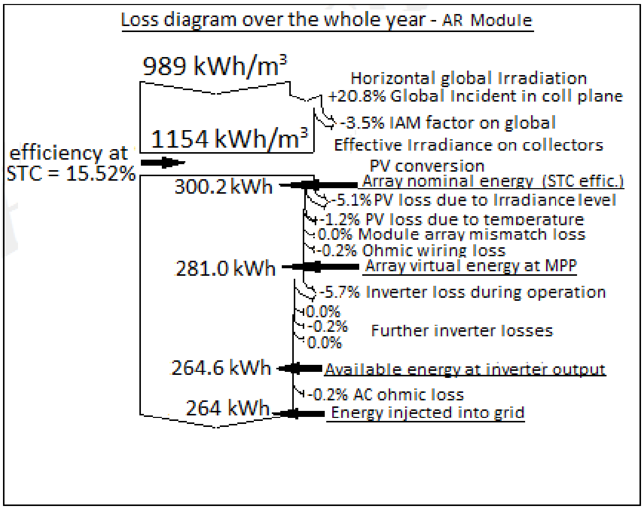

Fig. 5. Detailed module and system losses. AR module compared to an ideal PV module calculation.

To give a detailed measured picture and verification that the Sunarc glass really is better at higher incidence angle and also that the measurement accuracy is very accurate, special DC short circuit measurements have been done before and after the long term test period with grid connected operation. Figure 4 shows a clear day and figure 5 a partly rainy day. Here it can be seen that the improvement increases up to almost 8 % and that the improvement disappears during rain. This indicates a very good measurement accuracy and resolution for the comparison.

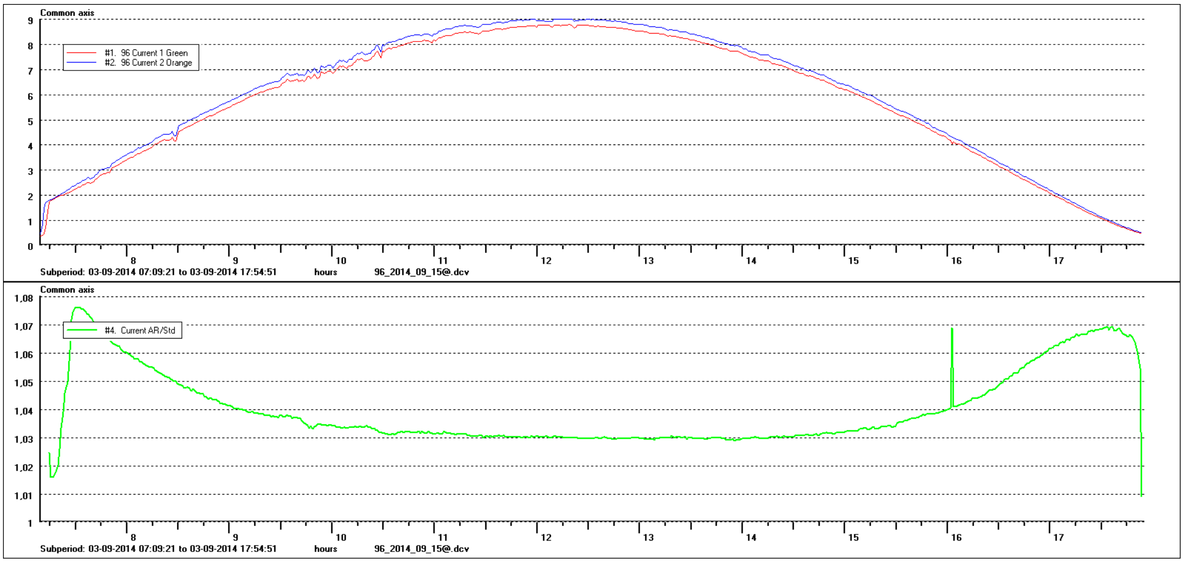

Fig. 6. DC short circuit current measurement (upper diagram) during a clear day and improvement (green line in lower diagram).

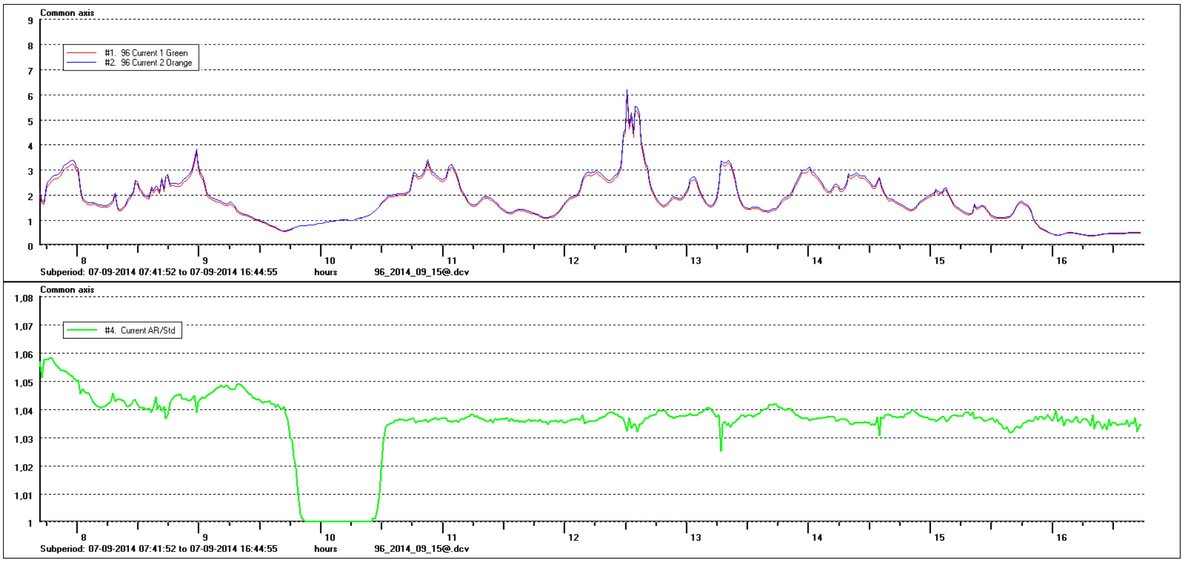

Fig. 7. DC short circuit current measurements (upper diagram), during a cloudy day and current improvement (lower diagram).

4. Conclusions and Recommendations

The Sunarc Glass treatment clearly improve the long term PV performance in all weather conditions except for very short periods with very low solar radiation and rain, when the glass is completely wet and the surface properties of water determines the optical properties of the surface. The largest advantage of the Sunarc glass is gained at high incidence angles. Therefore application on facades and off south roofs will give the highest improvement.

The tendency to slightly higher cell temperature of a PV module with Sunarc glass, giving lower cell voltage and therefore reduced power output, means that a well-ventilated installation of the PV modules can be recommended to gain the highest advantage from the glass treatment. Also the use of PV cells of good quality, that have high efficiency and a low shunt resistance, are recommended to gain the best economy, when using Sunarc glass.

No significant long term performance effects have been found due to for example differences in soiling or drying up after rain for the two glass variants. Visibly only small differences in soling or drying up, have been observed for short periods. The apparent reduced performance improvement during the winter 2013-2014 was completely recovered during the spring 2014 and maintained during all summer 2014. This dip in performance was probably caused by low radiation, shading and frost/snow performance effects in winter.

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