Study of shaded PV-Modules without and with the so-called Power Optimizer Solar Magic
-
a Product of National Semiconductor

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1. Preface

In the course of various technical assessments of photovoltaic modules (PV-modules), TEC institute also examined shaded modules during the year of 2009. The incentive for these studies was the newly released Solar Magic, a product of National Semiconductor (see fig. 0). According to the manufacturer, 50% of shading losses can be avoided, when using the SolarMagic. While we were carrying out our testing series, the technical journal *Photon Profi* published the results of their own study, dealing with the same topic, titled “Seltener Zauber” (Rare Magic) (August edition 2009). Neither the colleagues at Photon, nor the employees at TEC knew that the other side was working on the topic. As manner and method of the two studies naturally differed, the results can complement each other.

Fig. 0: Solar Magic by National Semiconductor

2. Set up and implementation

Measuring procedure:

The study at TEC institute was carried out using standard, monocrystalline modules by ANTARIS (ASM 180) in feed-in mode. For the experiment, 6 modules (with respectively 180Wp nominal power) were wired up into a string – i.e. in a row – and connected to the “SMA Sunny Boy SB 1100” inverter. See also fig. 1:

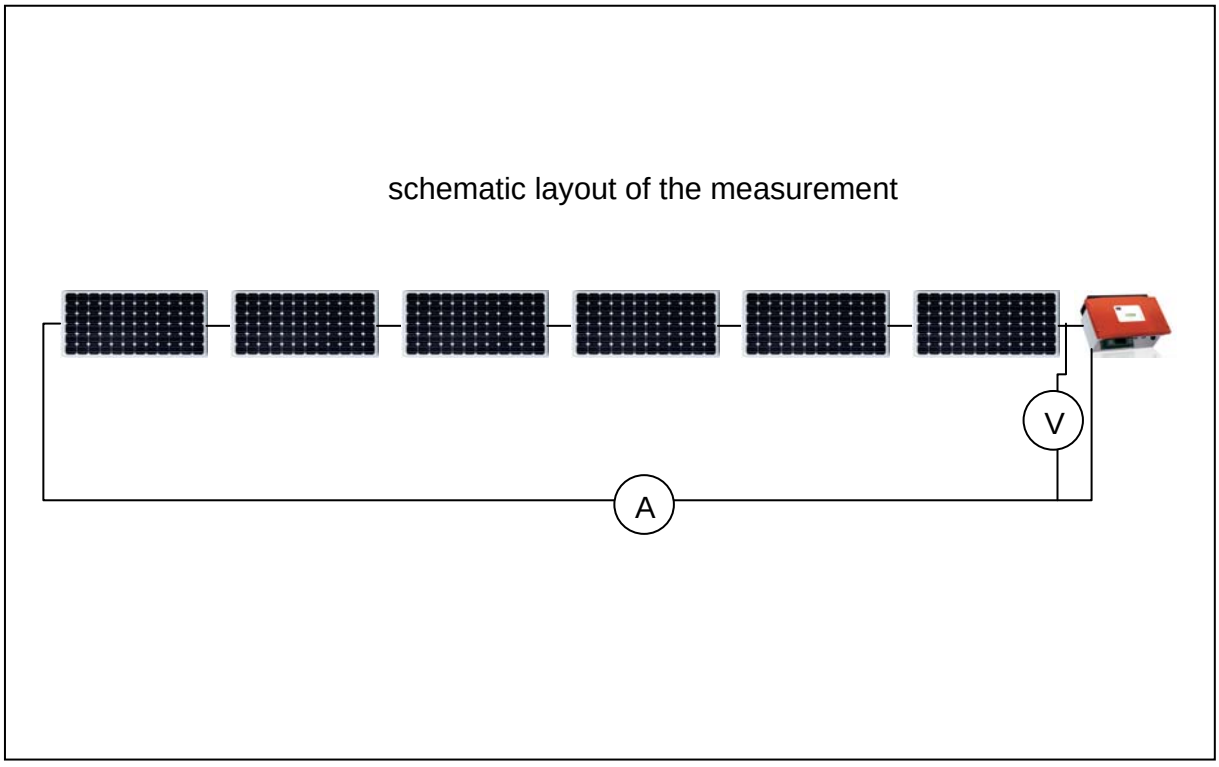

Fig. 1: schematic layout of the measurement wiring

Preliminary considerations:

The measuring modules were set up with an angle of inclination of 30° south. As can be seen in fig. 1, total current and total voltage were recorded with digital multimeters on the DC voltage side. The measured current and voltage values were fed to a measuring computer and recorded. From these data we were then able to calculate the DC power as well as the DC output of the set up. The measuring interval was one minute.

In order to be able to interpret the measuring results later in the document, the interior cell wire up of one of the used PV modules is outlined in fig. 2 as an example.

- Each module consists of 72 monocrystalline cells, connected in series, a so-called string
- Respectively 24 cells are protected by a bypass diode
- Therefore, each module has 3 bypass diodes
- For reasons of space, each group of 24 is arranged in two groups of 12
- Each string is protected by a bypass diode
- These 3 bypass diodes divide the string into three string parts

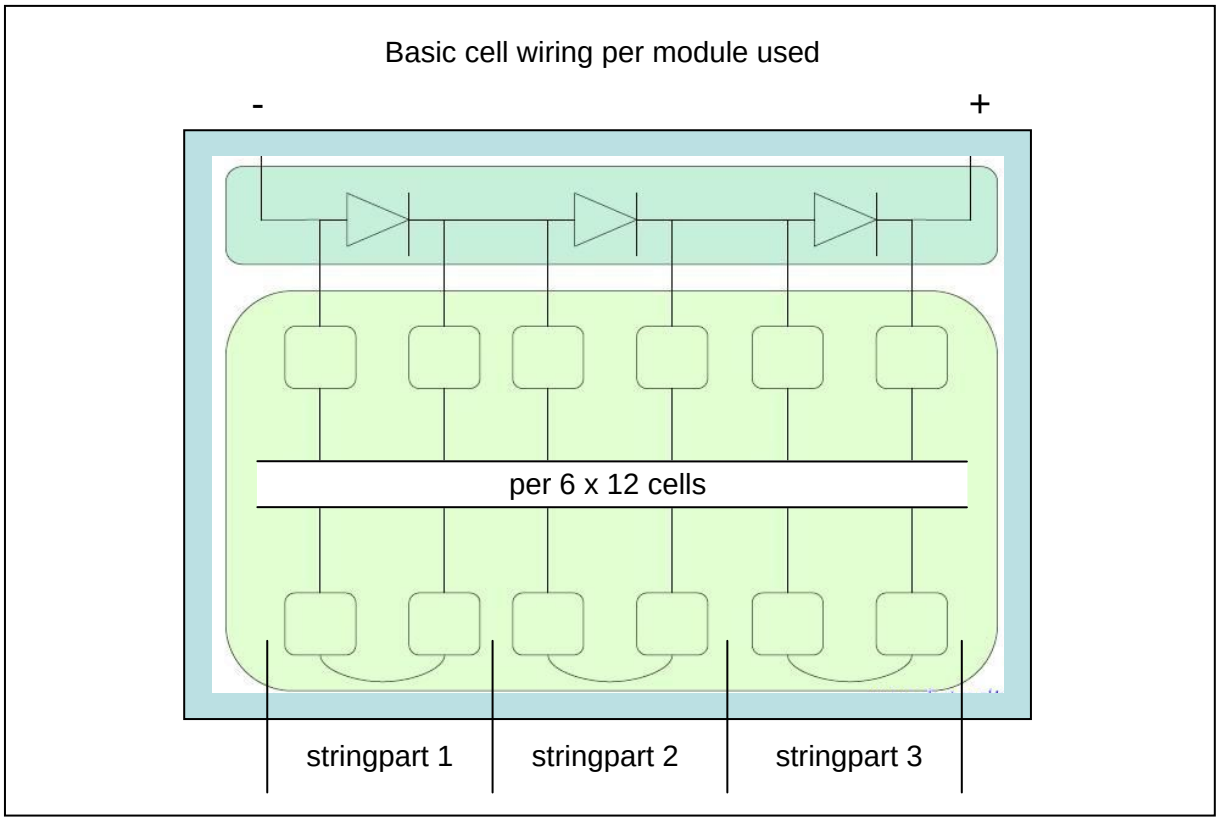

Fig. 2: interior cell wiring of one of the used modules

In case of cell shading within a stringpart, the three bypass diodes' function is to protect the same shaded stringpart from overheating (hot spots). The current from the two non-shaded stringparts is conducted past the shaded stringpart via the respective diode.

Without going too much into technical detail, it should be mentioned that the cells of a partly shaded string heat up without a protective bypass diode. The reason being, that the non-shaded stringparts virtually force their electricity on the partly shaded stringpart. Fig. 3 shows the string arrangement in the modules used.

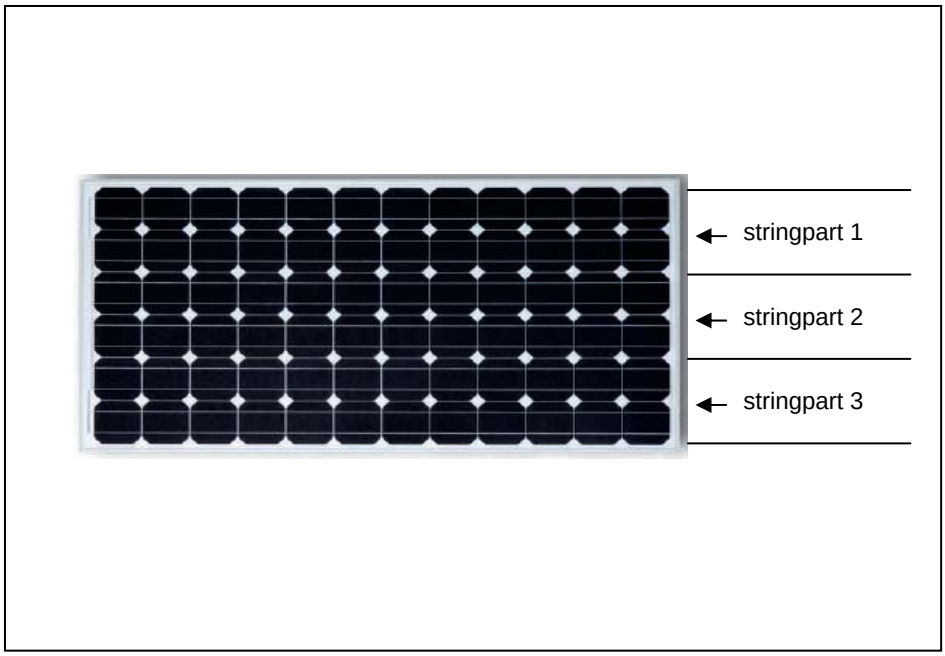

Fig. 3: actual string arrangement per used module

In the course of this paper, we will speak of row-by-row shading and column-by-column shading. See Fig. 4.

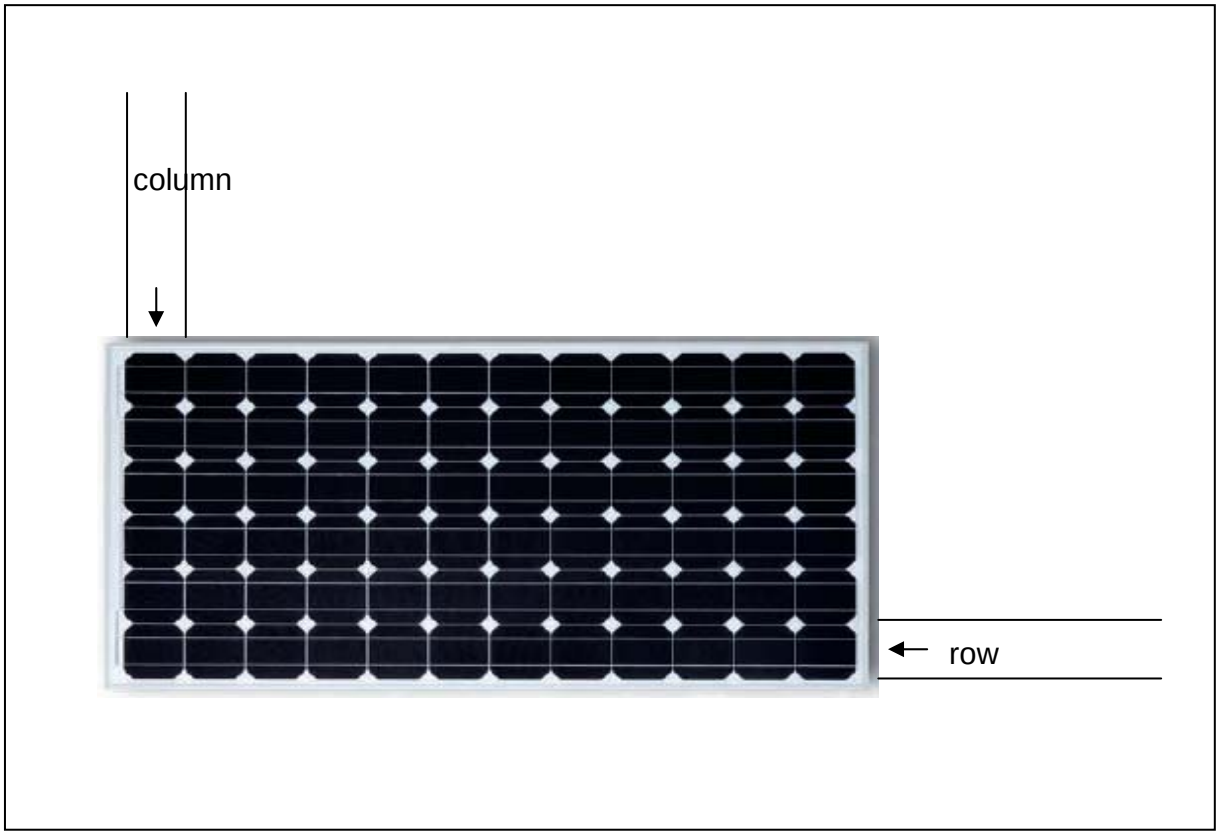

Fig. 4: definition of the terms row and column

An example of column-by-column shading can be seen in picture 5. Six columns on the right side of the module are shaded. The remaining five non-shaded modules (serial connection of modules), are located left of the partly shaded module (not visible in the picture).

Fig. 5: Example of column-by-column shading

Picture 6 shows an example of row-by-row shading. The four lower rows of the module are shaded. The shading is not as clearly visible as in fig. 5, due to clouds moving in front of the sun just before the picture was taken.

Fig. 6: example of row-by-row shading

Connecting the SolarMagic:

National Semiconductor proposes to add a SolarMagic to any module within a line, see fig. 7.

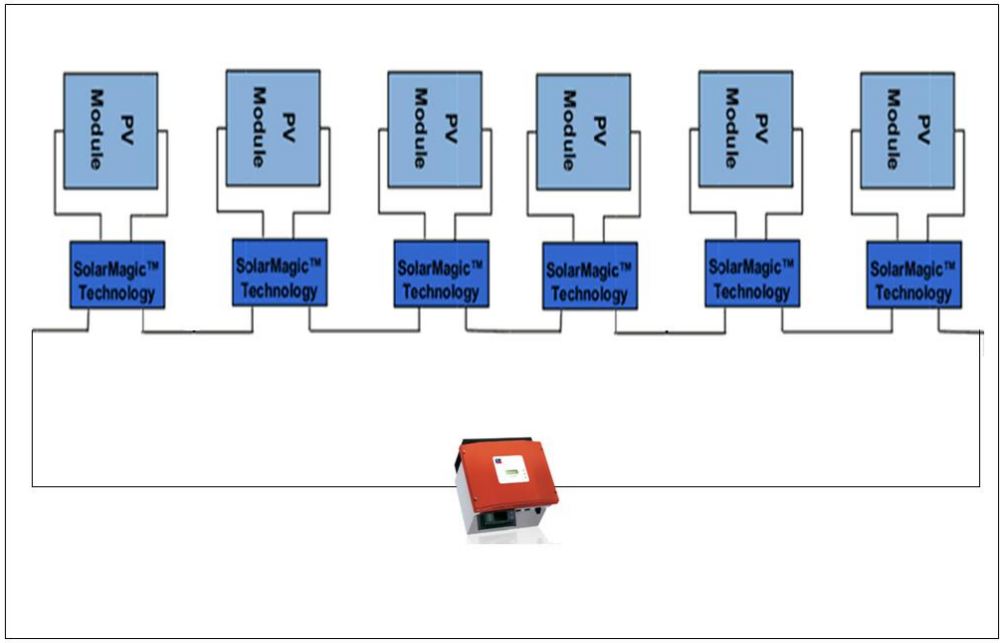

Fig. 7: connection diagram

For our test, only the shaded module was connected to a SolarMagic. See fig. 8.

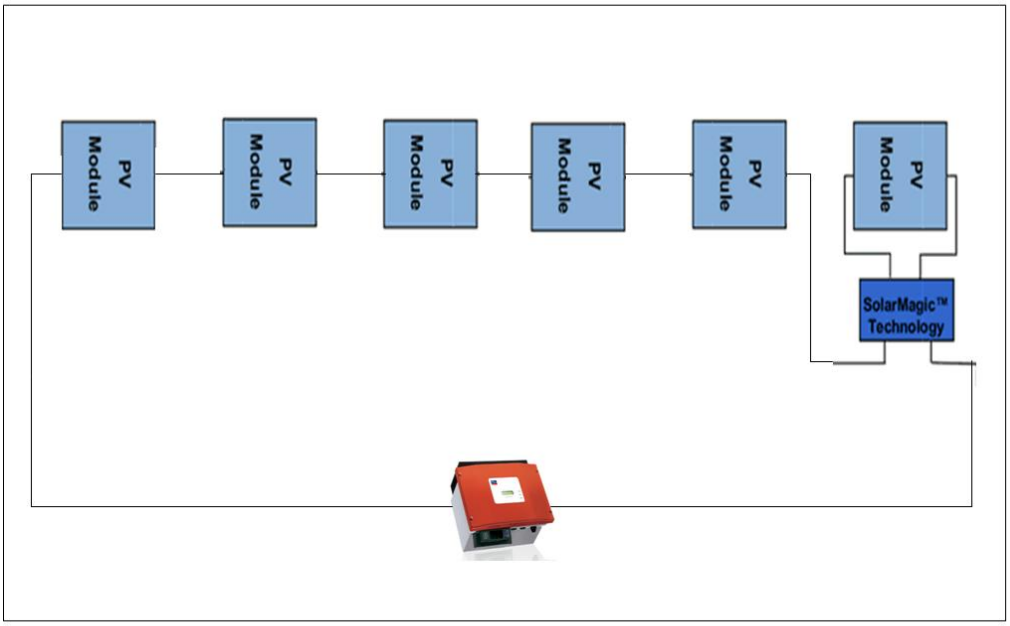

Fig. 8: connection diagram during our tests

Fig. 9: installation of the SolarMagic

Implementation:

As it can be seen in figure 8, we only shaded one module in our testing series.

We approached the shading process as follows:

- Column-by-column shading of one module **without** SolarMagic
- Column-by-column shading of one module **with** SolarMagic
- Row-by-row shading of one module **without** SolarMagic
- Row-by-row shading of one module **with** SolarMagic

Figure 10 shows the effect of column-by-column shading with SolarMagic in the form of a day performance curve. The blue curve shows the output trend of the whole line (6 modules). The area hatched in red, shows the output loss which developed after

one, two, three, four, five and finally six columns were shaded on the module connected to the SolarMagic.

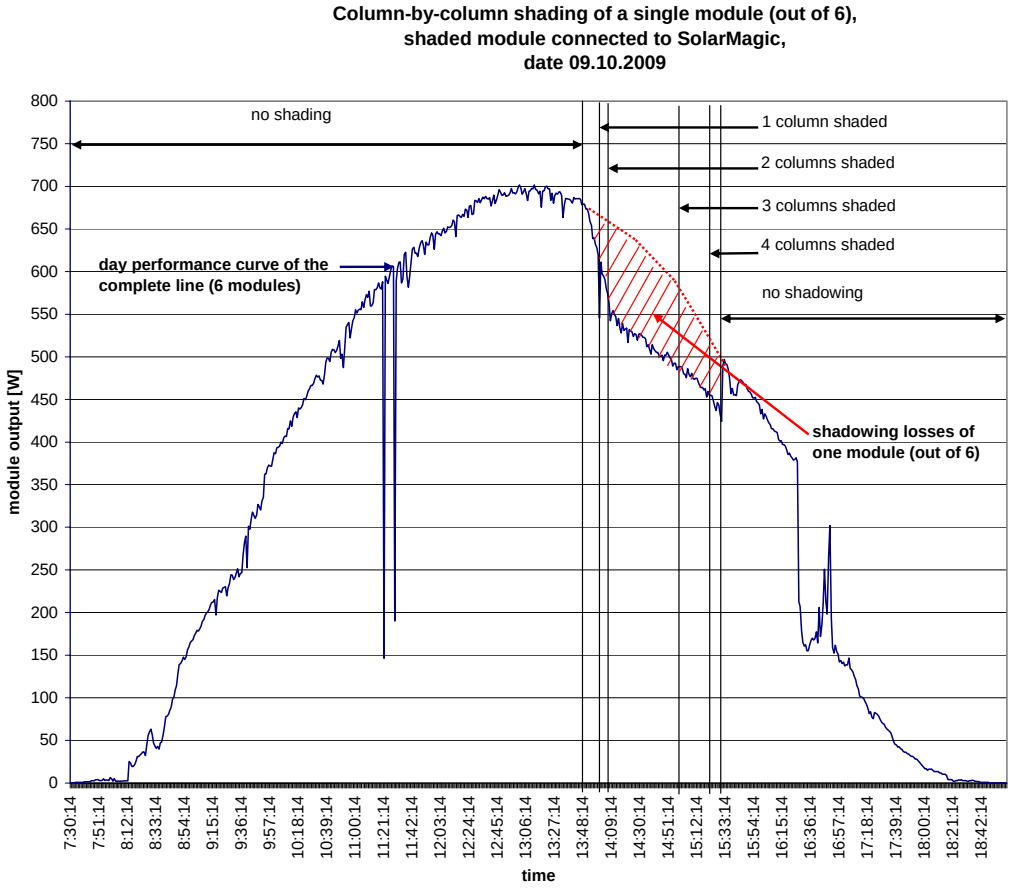

Fig. 10: column-by-column shading of a module connected to SolarMagic

The measuring series in figure 10 displays the 9th of October 2009, with relatively sunny autumn weather. As the sun is already low in the sky in October, an output like the one in midsummer cannot be expected (see values in fig. 11). The distance which the sun rays have to cover through the atmosphere is considerably longer than in summer, thus, the incoming global radiation is lower. Figure 11 shows the development of global radiation on the 9th of October 2009, measured with the institute's own pyranometer, right beside the test set-up.
In order to gain meaningful and authoritative results, we took care to carry out the measurement series (with as well as without SolarMagic) in realtime and under comparable conditions.

Furthermore, the measurement series were repeated several times, in order to calculate a mean for each shading situation (i.e. with SolarMagic and without SolarMagic).

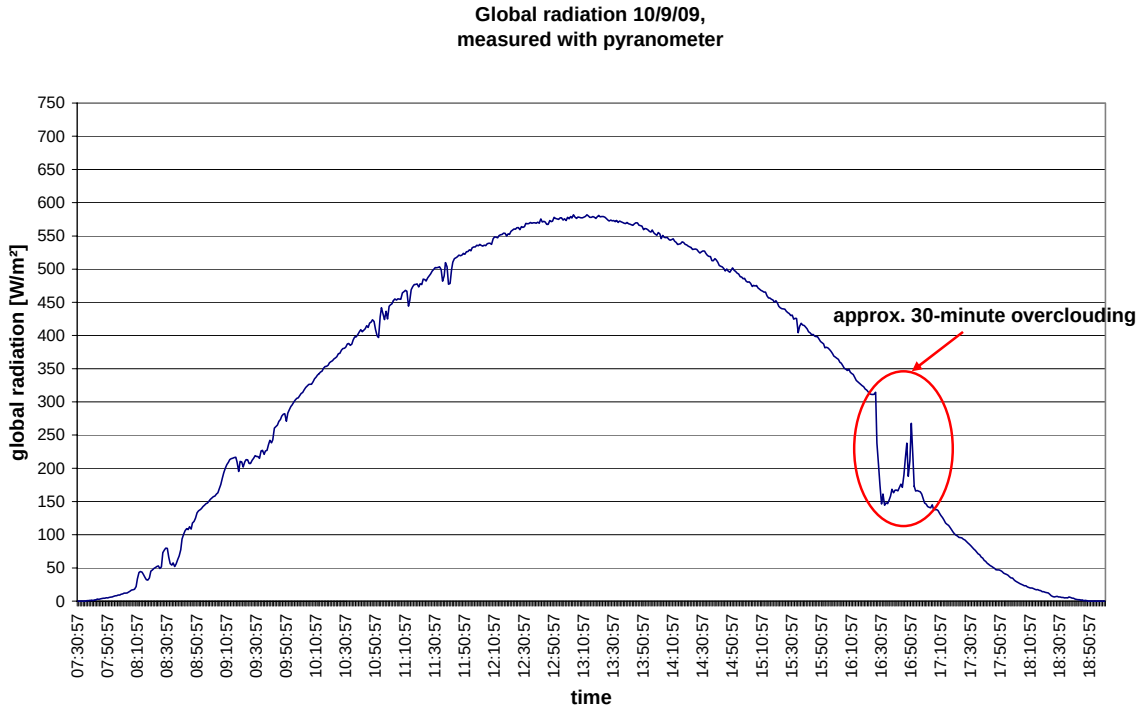

Fig.: 11 global radiation curve, 9th of October 2009

3. Measuring Results

Results from our measurement series:

The following two diagrams, figure 12 and figure 13 show the results of our measurement series. Both diagrams show the losses of the module, which was shaded with (respectively without) SolarMagic.

Column-by-column shading without and with SolarMagic:

The results from the column-by-column shading can be seen in figure 12.

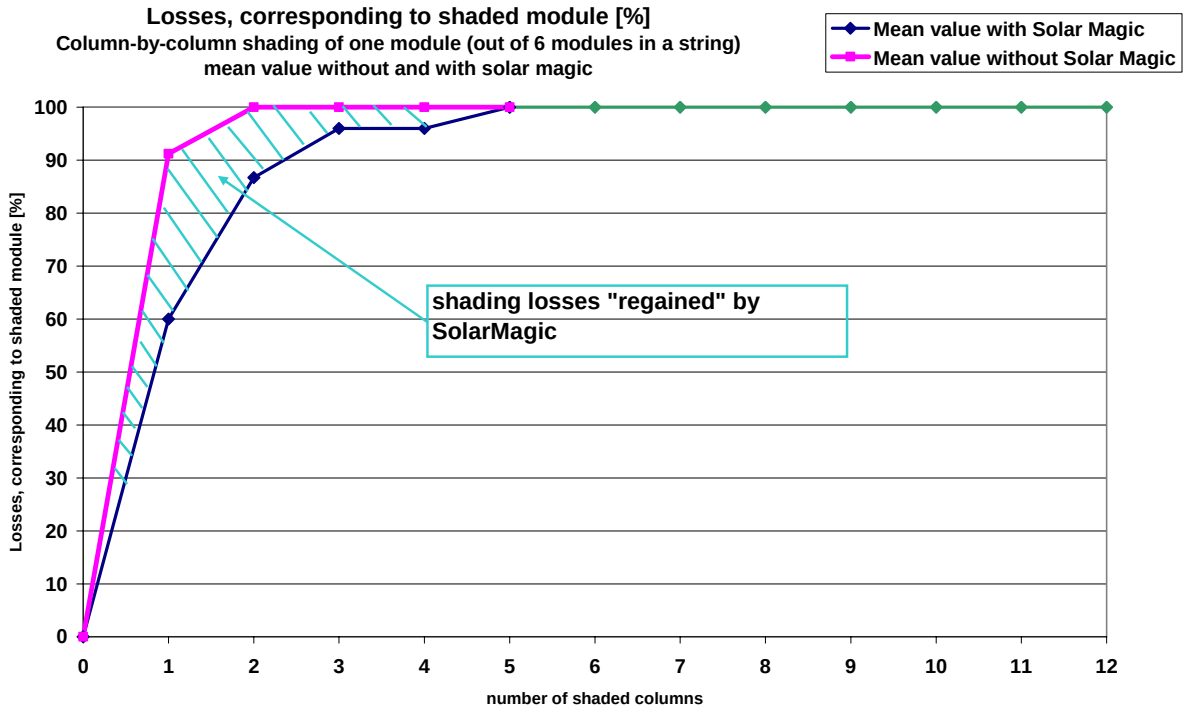

Fig. 12: losses with column-by-column shading

Row-by-row shading with and without SolarMagic:

Figure 13 shows the losses with row-by-row shading.

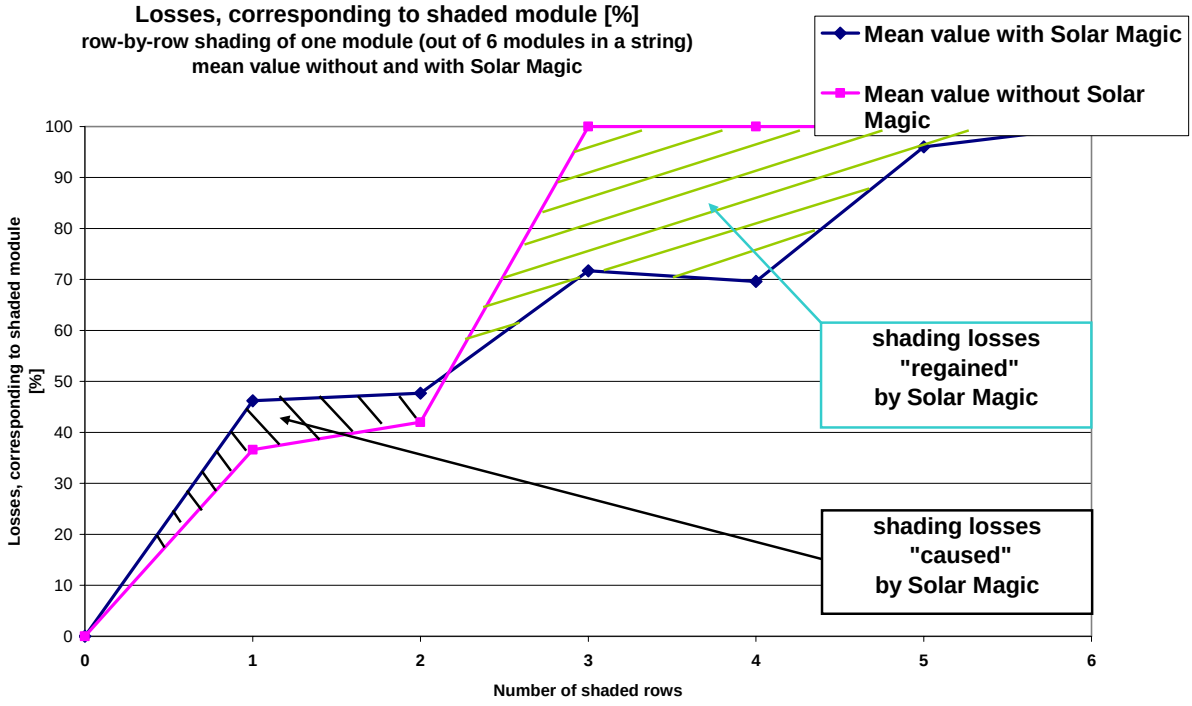

Fig. 13: Losses with row-by-row shading

4. Analysis:

Analysis: column-by-column shading without and with SolarMagic:

The following can be deduced from figure 12:

- Every single shaded column results in 2 shaded cells on each of the 3 stringparts. This is due to the construction of the module. (see also fig. 2 and fig. 4).
- This is also the reason why, with only one shaded column, 90% of a module's output are lost without the SolarMagic. With a minimum of 2 shaded columns, shadowing losses are 100%.
- When using the SolarMagic, output shadowing losses are reduced to 60%, thus a lot less than without the SolarMagic (around 30%).
- Only when two rows are shaded (with SolarMagic) the output losses move within the same range of 90%. Even when 3 or 4 columns are shaded, 5% of output still remains. A loss of 100% (with SolarMagic) occurs when a minimum of 5 columns are shaded

Analysis: row-by-row shading without and with SolarMagic:

The following can be deduced from figure 13:

- When the first as well as the second row are shaded – both rows constitute the first stringpart – the module shows losses of around 40 to 50%. It should be noted that in this particular shading situation, losses are higher with SolarMagic than without SolarMagic. The differences are not great, however they are clearly measurable and move around 15%.
- When more than 2 rows (meaning more than 1 stringpart) are shaded, the advantages of the SolarMagic become evident. While, without SolarMagic the output shadowing loss is 100% with 3 shaded rows already, output loss with SolarMagic is only 70% with 3 or 4 shaded rows (meaning 2 shaded stringparts)
- Even with 5 shaded rows (meaning, only half a stringpart works actively) an output of around 5% is still measurable.

Conclusion:

- Our measurements have shown, that the SolarMagic (a product of National Semiconductor) can definitely reduce losses in certain shading situations. During our tests, up to 30% could be regained from the shaded module.
- However, we only tested two variants of shading: "column-by-column" and "row-by-row" shading. In fact, there is an unlimited number of different shading situations. A shade could fall across the module, there could be single shadow streaks moving across the module, and so forth.
- Our general aim was to test, whether the SolarMagic can
    - "Regain" shading losses
    - How much can be regained
- A benefit-cost analysis is recommended, if the acquisition of SolarMagic units is considered for a partly shaded PV-system

5. Future Perspectives

The full potential in shading loss reduction has not yet been tapped. Developmental efforts are known to be taken by enterprises and other institutions. It remains to be seen what results the future will bring.

6. Equipment

Equipment:	**Type:**	**Manufacturer/Supplier:**
Multimeter	VC 820	Voltcraft
Inverter	Sunny Boy SB 1100	SMA
PV-modules	ASM 180	ANTARIS-Solar
Measuring computer	GX 260	Dell
Software	MS Visual Basic 6.0	Microsoft
Software	MS Excel 2003	Microsoft

7. Sources:

“Seltener Zauber” in: Photon Profi. 8/2009, p. 66-71

Waldaschaff, 11th of February 2010

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