5.2 PV AND ARCHITECTURE

15 YEARS OF PRACTICAL EXPERIENCE IN DEVELOPMENT AND IMPROVEMENT OF BIFACIAL PHOTOVOLTAIC NOISE BARRIERS ALONG HIGHWAYS AND RAILWAY LINES IN SWITZERLAND

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SUMMARY/ABSTRACT:
TNC Consulting AG has developed, built and is operating and analyzing three different bifacial noise barrier pilot installations along highways and a railway line in Switzerland. The total capacity of these installations is 20 kWp. The paper focuses on technical progress in cell and overall system technology made during 15 years of experience with bifacial PV noise barriers. The results are based on measurement campaigns carried out during this time by TNC Consulting. The concept of bifacial PV noise barriers offers several benefits for the investor, which shall also be discussed.

1. PURPOSE OF THE WORK

To develop and demonstrate an additional, attractive field of fully integrated PV applications in the existing private and public transportation systems using the potential of the existing infrastructure. The different additional benefits of such integrated PV plants shall be shown as well as the progress on the technical side made in 15 years of bifacial PV noise barrier plants.

2. APPROACH

TNC Consulting planned, built and carries out measurements on three different bifacial PV noise barrier plants in Switzerland. The first plant was built 1997 along a highway in Zürich. This plant was revised and expanded in 2005 and now consists of two PV plants using different cell technologies. Further adjustments have been made concerning the inverter of the system. The newest PV plant is the world's first bifacial PV noise barrier plant along a railway line in Münsingen near Bern, which went online end of 2008. For all of these plants, the different components had to be developed or adapted to the specific requirements of a bifacial PV noise barrier plant.

Fig 1: The original bifacial PV noise barrier built 1997 with a nominal power of 5.96 kWp.

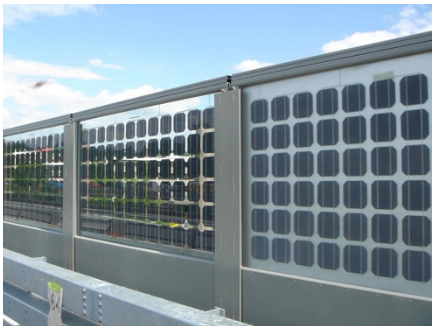

Fig 2: bifacial PV modules in Aubrugg after the refit 2005. Different glas surfaces have been used.

Fig 3: The world's first bifacial PV noise barrier plant on a railway line in Münsingen near Bern with a nominal power of 7.25 kWp.

Bifacial PV technology can help to improve the yield of vertical installations to a similar level as best south orientated PV installations and therefore increase the amount of noise barriers usable for a combination with PV. In Fig. 4, the different possible orientations of PV noise barriers are graphically analyzed. Green areas show highly suitable orientations for conventional and bifacial PV application, whereas orange and red areas mark the orientations with less ideal orientations for PV application. If the concept of bifacial PV is applied to noise barriers, almost all possible orientations of noise barriers can basically be used for the application of PV.

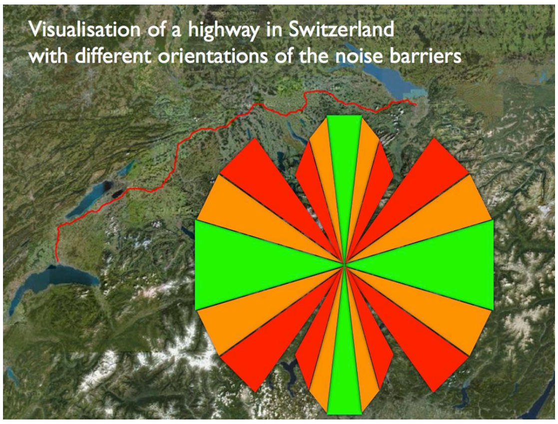

Fig 4: Visualization of a highway in Switzerland with different grades of suitable orientations of noise barriers for application of PV.

DOUBLE USE OF BIFACIAL PV MODULES AS NOISE BARRIER ELEMENTS

The bifacial PV sound barriers fully substitute the conventional vertical sound-reflecting sound barriers as shown in Fig. 1-3. The costs of the conventional transparent noise barriers can therefor be held against the costs of a bifacial PV noise barrier. This applies mainly to the costs for the glass, the framing, the mounting structure and part of the labour. In the last project in Münsingen, it was for the first time possible to get the railway authority of Switzerland to pay such a compensation. This shows the double use of the bifacial PV module as a noise barrier element also in an economical sense and compensates for some of the extra costs of a PV noise barrier for example for the thicker glass needed for the PV module in order to achieve the noise reduction and the mechanical properties required.

Improvements in the process of mounting the bifacial PV modules into the noise barrier structure have been achieved. The bifacial PV noise barrier modules in Münsingen haven been installed in a very short time. This work was carried out by a construction team of the company installing the noise barrier without specific knowledge of PV installations. This also provides an opportunity for companies to find new fields of business.

TECHNICAL IMPROVEMENTS ON THE BIFACIAL TECHNOLOGY

In the time-period of 15 years the technology of industrially produced bifacial solar cells has improved substantially. Starting from the physical dimensions of the solar cells, to the cell efficiency, the improvement of the ratio of the front side to the back side of the solar cells there have been major improvements.

	Aubrugg	
	ASE Cells (1997)	Hitachi Cells (2005)
Cell side length	100 mm	125.5 mm
Cell efficiency Front Side	14.3%	12.3%
Cell efficiency Back Side	11.6%	10.7%
Ratio Back to Front Side	81%	87%
	Münsingen Hitachi Cells (2008)	Now, EarthOn Cells Hitachi (2012)
Cell side length	125.5 mm	156 mm
Cell efficiency Front Side	15.0%	19%
Cell efficiency Back Side	11.0%	18.5%
Ratio Back to Front Side	73%	96%

Table 1: Improvement of bifacial solar cells in cell efficiency and ratio back side to front side.

Besides the improvement of the cell efficiency, the ratio of the stronger front side of a bifacial solar cell to the weaker back side has also improved. This is important in order to achieve a higher overall yield of the PV plant and to optimize on the layout of the system components, especially the inverter. Figure 5 shows the yield of a bifacial PV plant with a lower output during morning hours due to lower cell efficiency although solar irradiation is almost identical during morning and afternoon. Since the modules are connected to one inverter only, the front and back side have identical electrical conditions. The difference in the yield in Fig. 5 is due to the difference in the efficiency of the solar cell on the front and on the back side.

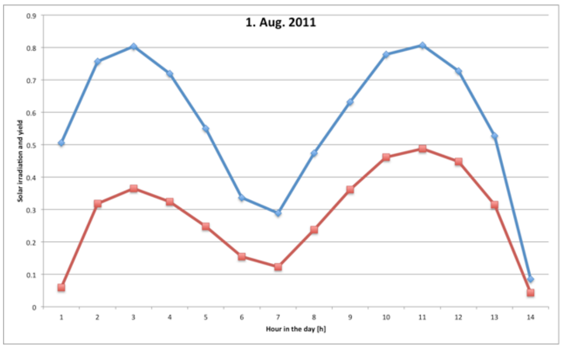

Fig 5: The blue line shown the solar irradiation with similar values during morning and afternoon. The red line is the normalized yield of the plant in Münsingen is shown, with the weaker back side of the bifacial solar cells in the morning and the stronger front side in the afternoon.

With the newly available bifacial EarthOn/Hitachi solar cells from PVGS, sample noise barrier PV modules have been produced. Samples of those modules have been measured by TüV Rheinland. Each side of the bifacial PV noise barrier module has been measured separately while the other side was in the dark. The measured nominal power values of each side are used to calculate the bifaciality factor. This factor is the ratio between nominal power on the front and the back side of the bifacial module and in an ideal case the factor would be 1. This would mean that the front and the back side are equivalent. With the new EarthOn cells, this value is almost reached as shown in Fig. 6, where a bifaciality factor of >95% is reached.

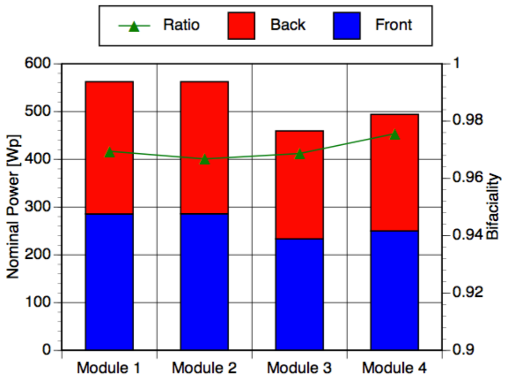

Fig 6: Calculation of the bifaciality factor of >95% between front and back side of four bifacial PV modules

Figures 7 and 8 show the normalized yield based on the measured data for different bifacial PV noise barrier plants. It shows the improvement in the overall yield of the bifacial PV plants during the last 15 years.

Improvements have been made on both the cell level as well as the system components. Especially in the Aubrugg plant the influence of a new inverter led to a rise in the PR. In the newest bifacial plant in Münsingen, a PR of 84% was reached during June 2011 for one of the three sections of the plant which has least issues with shading because it is located on a bridge.

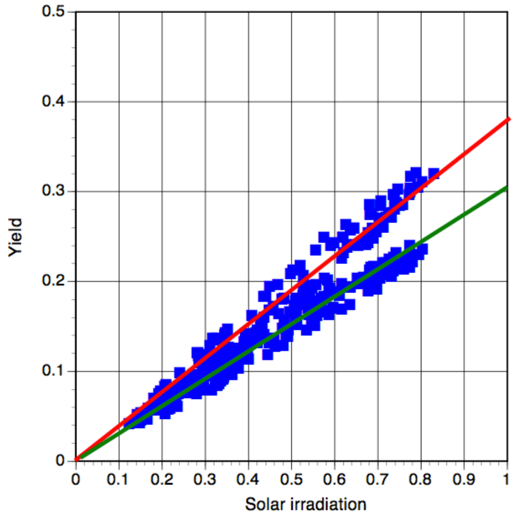

Fig 7: Normalized yield of the first bifacial PV plant in Zürich.

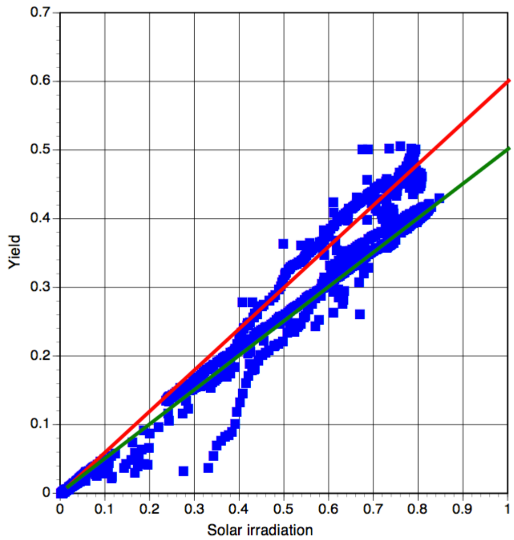

Fig 8: Normalized yield of the newest bifacial PV plant in Münsingen.

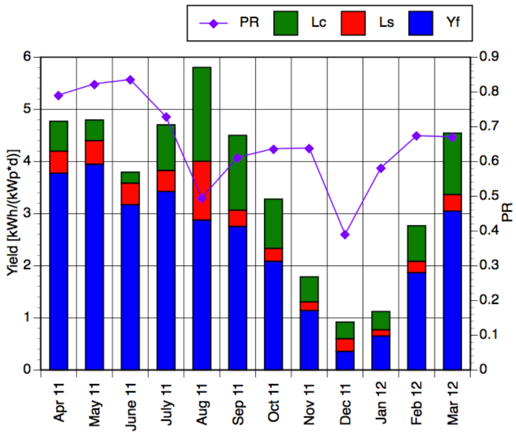

Fig 9: Yield and losses of one of the sections of the bifacial PV noise barrier plants in Münsingen.

The yield for one of the three sections of the bifacial PV noise barrier plant in Münsingen is shown in Fig. 9. The capture losses can be rather high, leading to a lower performance ratio PR. The reason for this has to be further investigated. The overall annual yield reaches 832 kWh/kWp calculated on an average for a year. Considering the east and west oriented, vertical installation, this is a rather good result. The inverters do not yet fully cope with the special situation of a bifacial PV power plant with two daily maxima occurring. The inverter efficiency is measured on a monthly average of slightly below 80% to slightly above 90%, but always below nominal efficiency.

ADDITIONAL BENEFITS OF BIFACIAL PV PLANTS

In areas of high PV penetration the utilities are aware of surplus energy in the electrical grid system at midday and have to take measures like, initiate short term storage of electrical energy. With east/west oriented bifacial PV systems there would be no power-peak at midday. While a normal south oriented 45° tilted pane has an irradiation as shown in Fig 10 with a peak at noon, the peaks of the bifacial PV application appear during morning and afternoon hours. Also shown is the sum of the irradiation of both planes, east and west. This time shift is for the plant in Münsingen 3.5 to 4.0 hrs during summer and around 2.5 hrs in the wintertime. The combination of bifacial PV applications with conventional south oriented and tilted PV application would lead therefor in the right balance to a nearly rectangular energy production with PV during most of the hours of a day. This would make short time storage unnecessary during sunshine.

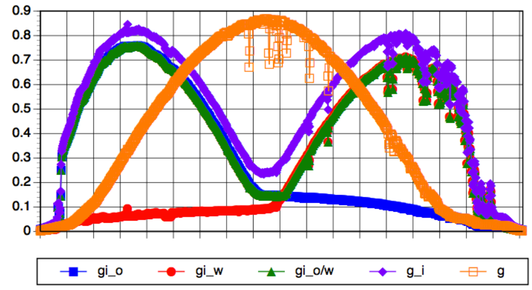

Fig 10: Measured irradiation in high time-resolution for Münsingen. The time shift of the morning and the afternoon peak are about 3.5 hrs off the south oriented peak.

5. CONCLUSIONS

- The application of bifacial PV allows the use of north-south oriented structures for PV with a yield tha is similar to that of a south oriented inclined PV plant, increasing the number of possible PV applications on existing infrastructure.
- In the last 15 years there have been significant improvements in the industrial production of bifacial solar cells. The front side efficiency has increased to 19% and more and the bifaciality has improved to up to 97.5% making the layout of electrical components easier and more efficient.
- The bifacial PV modules can fully substitute conventional vertical transparent and sound-reflecting noise barriers. This leads to a reduction of mounting and BoS cost for the bifacial PV noise barrier plant.
- One of the added values of bifacial PV applications is the time shift of the two production maxima in the morning and the afternoon of up to 4 hours in regard to the noon peak from conventional PV plants. The combination of bifacial PV application and conventional south oriented PV plants leads to a higher possible penetration rates and a better grid integration.

7. REFERENCES

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