Concentrating photovoltaics (CPV) for countries with high direct irradiation

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1. Introduction

The ultimate objective of all research work in the area of photovoltaics (PV) is to reduce the costs for PV-generated energy and thus to provide a sustainable energy supply.

The current market is dominated by Si modules. Technologies on a thin-film basis (a-Si, CIGS, CdTe) reached industrial mass production in the last two years.

Concentrator photovoltaics are an alternative approach to reduce the costs per PV-generated kWh. The underlying idea is easy to understand: This technology reduces the need for comparatively expensive solar cell area, by focusing the sunlight via a low-cost optical concentrator. A small cell which converts the high irradiance efficiently is the target for the focused light. In order to concentrate the sunlight sufficiently, the system must track the sun's path. Therefore, the concentrator systems are particularly suitable for countries with a high direct irradiation.

Concentrator systems are preferred as PV power plants in the kW-MW power range. The interest in this technology increased significantly in recent years, as the costs were reduced and system efficiencies of over 25% were reached in the field [1].

2. The technological basis of concentrator photovoltaics

Concentrator photovoltaics are characterised by the fact that the individual components such as cells, cooling, concentrator optics and tracking are highly interdependent and therefore must be optimised as a whole. Concentrator photovoltaics must therefore be viewed as an integrative technological approach. For example, the tracking precision requirements for the mechanics can be reduced if the optical concentrator is designed accordingly by using a second stage. This in turn can result in increased complexity during the assembly process. This example shows the concatenation of technologies and the complexity in the development of a concentrator system. Therefore, there is no one concentrator system – each system must be developed and analysed individually. As a result, there is a variety of possible system implementations.

The true evaluation of a concentrator system is not revealed until in the application, and is specified via the costs per generated kilowatt-hour (€/kWh). Of course, this evaluation value depends on the irradiation conditions, and thus on the location.

The variety of concentrator system approaches is easiest to explain by applying the concentration factor. The concentration factor of current systems ranges from 2 to 1000. *Figure 1* shows two examples of system components: On the left, the low-concentrating ARCHIMEDES system developed at the ZSW in Stuttgart. It uses Si concentrator cells and has a single-axis tracking system. On the right, the high-concentrating FLATCON system developed at the Fraunhofer ISE in Freiburg, and prepared for market introduction by Concentrix Solar, Freiburg. This

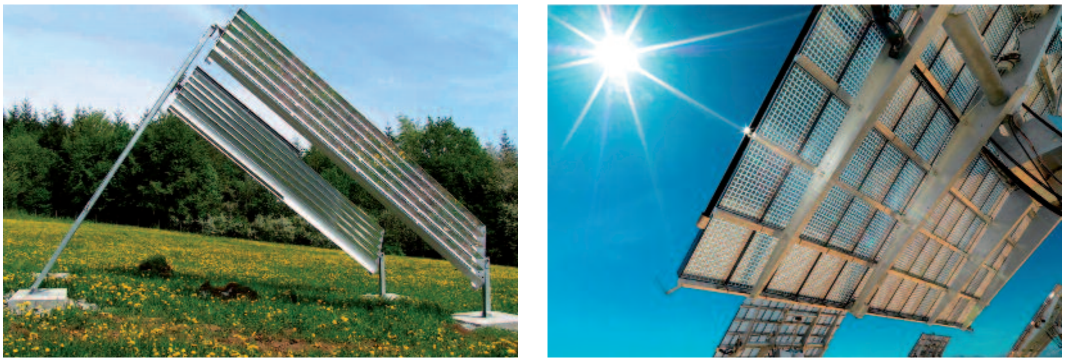

Figure 1
Left: Low-concentrating ARCHIMEDES system (ZSW)

Right: High-concentrating FLATCON system (Fraunhofer ISE/ Concentrix Solar)

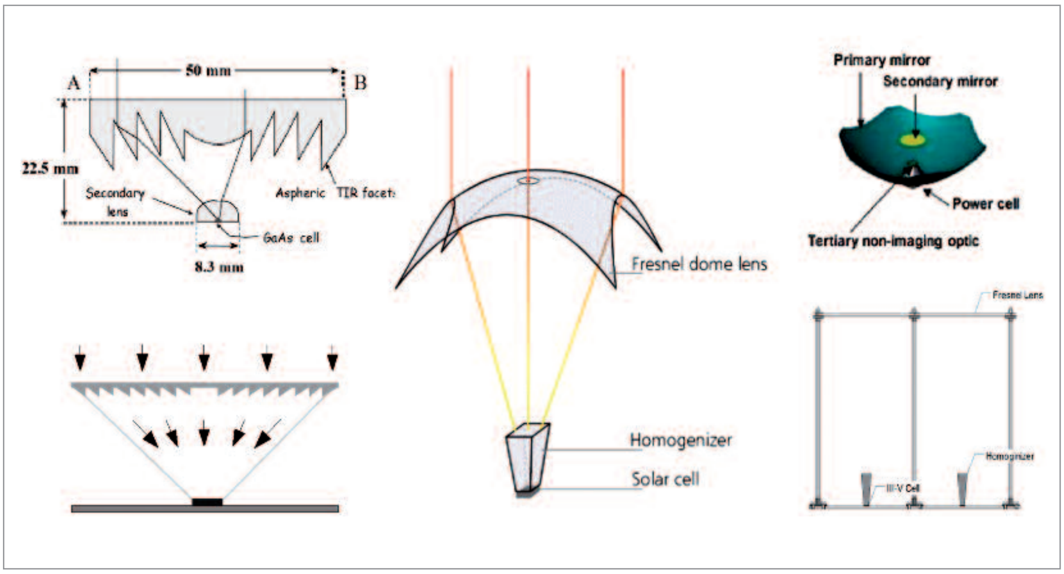

Figure 2
Examples of optical concentrators:

Upper left: Aspherical TIR (total internal reflection) lens in combination with a secondary lens directly on the cell

Lower left: Fresnel lens

Centre: Fresnel dome lens in combination with a ray homogeniser

Upper right: Cassegrain lens, where the light is routed via a parabolic mirror to a small secondary mirror and then to the cell FLATCON system developed at the Fraunhofer ISE in Freiburg, and prepared for market introduction by Concentrix Solar, Freiburg. This system uses III-V semiconductor multiple solar cells and has a two-axis tracking system and a concentration factor of 380.

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The following section discusses the main components of a concentrator system briefly:

The optical concentrator

As optical concentrators, either lenses or mirrors are used. A second optical stage which is generally mounted directly on the solar cell is often used. Fresnel lenses are often used instead of heavy solid lenses. They require less material and can be produced more cost effectively. Where lenses are used, imaging errors, in particular chromatic aberrations, must be taken into account when designing the system. Mirror systems have advantages in such cases. The challenge for the mirrors is to produce highly-reflective coatings with long-term warranties cost-effectively. *Figure 2* is a schematic representation of various optical concentration concepts as currently used in systems.

The concentrator cell

The cells used in concentrator systems must deal with the high irradiance and the resulting high currents. Therefore, there is no one best concentrator solar cell. The solar cell technology must be adapted for the concentration factor.

Resistance losses scale quadratically with the current densities, which requires a higher degree of metallisation of the solar cells, which in turn increases shading losses. Also, the solar cell is not lit homogenously, depending on the optical concentrator, which can be taken into account by designing the front contact grid

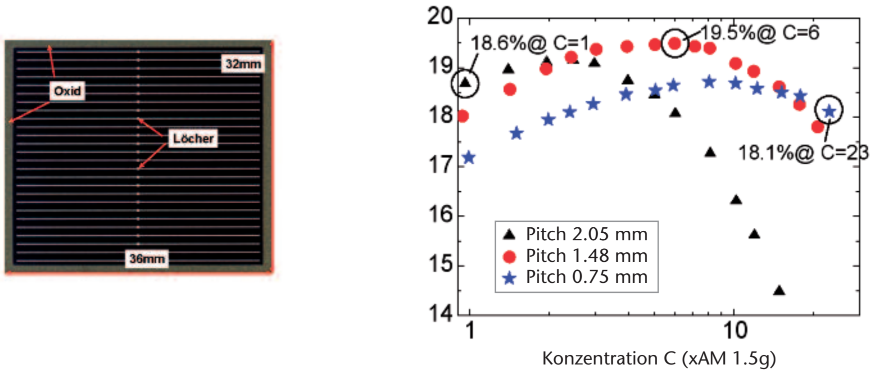

Figure 3
Left: Photo of a MWT-Si concentrator solar cell Right: Depending on the technology used, the cell can be used up to a concentration factor of 20

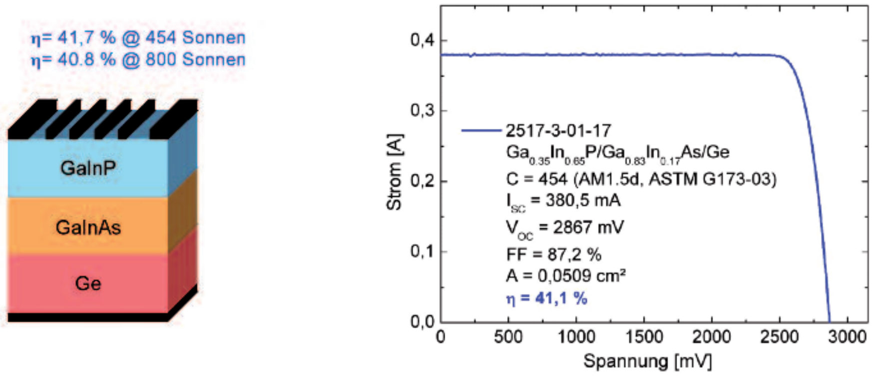

Figure 4
Current voltage characteristic curve of a monolithic triple solar cell from GaInP/GaInAs/Ge when illuminated under 454 times solar concentration. An efficiency of 41.1% was measured. Even at a solar concentration of 800, an efficiency of 40.8% is reached.

accordingly. Therefore, the "optimal" solar cell design is highly dependent on the system design. In general, it can be said that only slightly modified industrial silicon solar cells are used, in particular for low concentration ranges (*Figure 1*, left). *Figure 3* shows an example of cell development at Fraunhofer ISE [2]. Here, the metal wrap trough (MWT) solar cell was modified such that it can be used for concentration factors of up to 20 depending on the design.

Multiple solar cells, in which different III-V semiconductor materials are deposited above one another, allow extremely high efficiencies to be reached. This cell type is used in high-concentrating systems. *Figure 4* shows the coating structure and characteristic curve of the Fraunhofer ISE record solar cell which reaches an efficiency of 41.1% at a concentration factor of 454 suns [3].

Trackers

Tracking systems have been utilised to an increasing extent for flat modules, as tracking can be expected to increase the yield by between 20-35% [4]. As a result of this development, there are now multiple providers of tracking systems on the market, which benefits concentrator photovoltaics. However, the precision and stability requirements for concentrator systems are significantly higher. The required precision depends on the concentration factor and on the optics used in the system. As a guideline value, a concentrating system with a factor of 500 aims for and reaches mechanical precision of 0.1 °.

A good control system is important to reach this goal. At Fraunhofer ISE in recent years, a development has been pursued, which integrates the tracker control into the inverter electronics:

The resulting tracker inverter reduces the costs of the concentrator system. For low-concentrating photovoltaics, a single-axis tracking system with a mechanical precision in the degree range is often sufficient. In general it can be stated that the reliability of the tracking system is not a problem and that the power consumption for the drive on average is significantly lower than 100 W [5], which is negligible with system sizes in the kW range.

3. Concentrator systems in operation

Concentrix Solar manufactures high-concentrating FLATCON concentrator modules. Since autumn 2008, a production line with a capacity of 25 MW has been available. This fully-automated production line is used to produce modules with efficiencies of 27%. The modules are mounted on two-axis tracking units. The nominal system capacity is 6 kW. *Figure 5* shows a photo of a Concentrix concentrator system and a measured DC characteristic curve of the system. With favourable irradiation conditions, DC system efficiencies of over 26% have been reached.

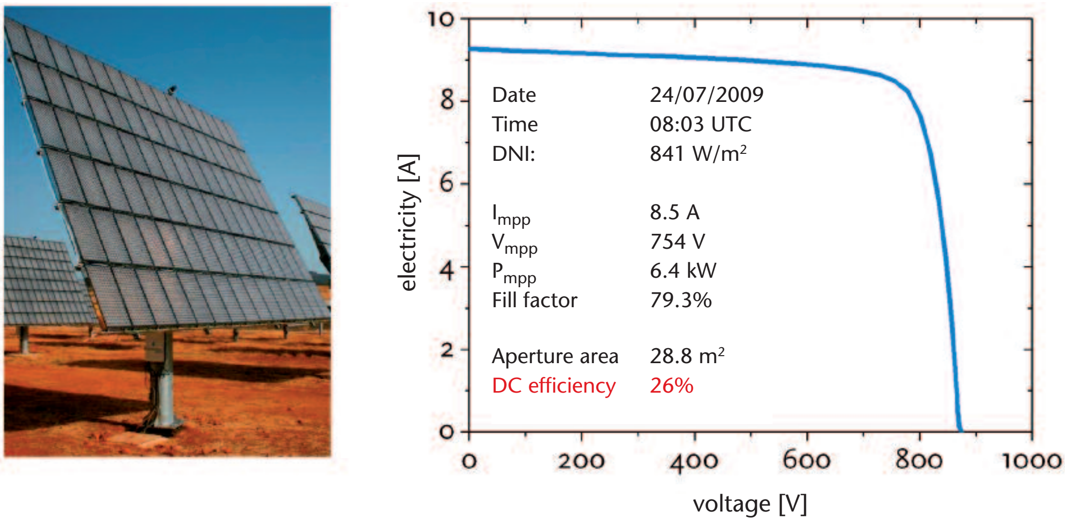

Figure 5
Left: FLATCON concentrator system by Concentrix Solar. The aperture area is 28.8 m². On the right, the measured DC characteristic curve of the system is shown. An efficiency of 26% was measured.

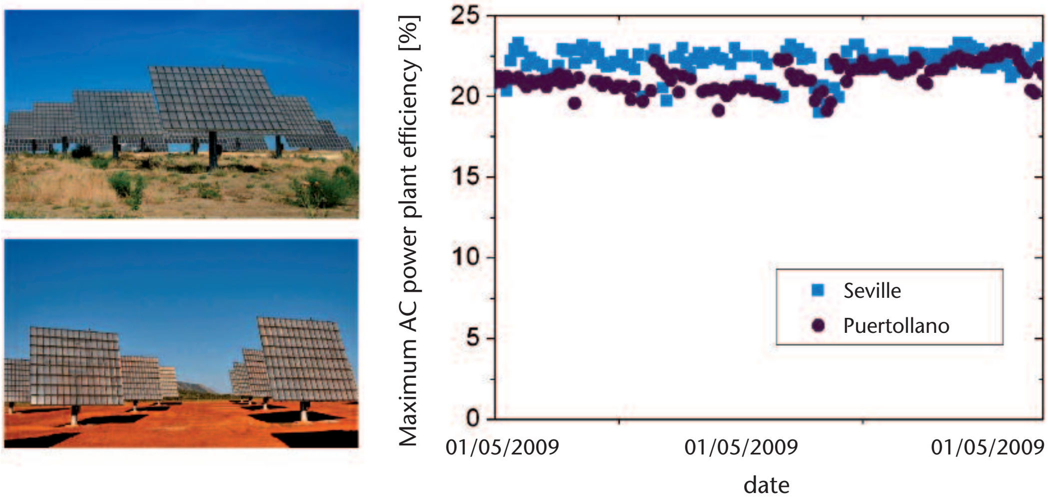

Figure 6
Left: Photos of the 100 kW systems in Seville (top) and Puertollano (bottom) in Spain.

On the right, the maximum AC power plant efficiency of the two systems from May to September 2009 is shown.

Figure 6 shows the maximum AC efficiency from May to September 2009 for two 100 kW power plants at the sites in Seville and Puertollano in Spain. The efficiencies remained constantly significantly above 20%, and peak values of up to 24% were reached.

4. Summary and conclusion

Concentrating photovoltaics have now reached a development level at which the transition from laboratory to industrial manufacturing has been made. This technology can now penetrate the market. The cost and yield analyses lead us to expect that CPV systems on sites with high direct irradiation can reach electricity generation costs which are significantly lower than those for classic PV technology. If these forecasts are proven true in the coming two years, this technology will grow rapidly.

Literature

[1] A. Hakenjos, J. Wüllner, H. Lerchenmüller, Proc. 22nd European Photovoltaic Solar Energy Conference, 2007, pp. 156-159.

[2] T. Fellmeth et al., 24th European Photovoltaic Solar Energy Conference, Hamburg 2009

[3] W. Guter, J. Schöne, S. P. Philipps, M. Steiner, G. Siefer, A. Wekkeli, E. Welser, E. Oliva, A. W. Bett, F. Dimroth, Appl. Phys. Letter, 2009, 94, 223504

[4] H. D. Mohring, H. Gabler, Proc. 29th IEEE Photovoltaics Specialists Conference, 2002, pp. 1608-1611.

[5] V. D. Rumyantsev, V. M. Andreev, N. A. Sadchikov, A. W. Bett, F. Dimroth et al., PV in Europe – From PV Technology to Energy Solutions Conference and Exhibition, 2002, pp. 521-525.