HIGH CONCENTRATION PV SYSTEM

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ABSTRACT

The aim of the European funded project HICON (High Concentration PV Power Systems) has been to develop, set up and test a new high concentration – 1000x or more – PV system. This system uses an actively cooled large-area receiver consisting of III-V solar cells. Two technology fields have been integrated: The high concentration of the sunlight has been obtained by using technologies experienced in solar thermal systems like parabolic dishes or tower systems. The high concentration photovoltaic receiver is based on the III-V solar cell technology. To deal with the high concentration, Monolithic Integrated Modules (MIMs) [1-3] have been further developed and assembled to Compact Concentrator Modules (CCM). The CCM prototypes have been tested in a solar furnace (PSA) and in a parabolic dish (BGU). The results of the project will be presented in this paper.

THE OPTICAL CONCENTRATOR

In this project, two ways were explored targeted to reach a cost-effective solution, the use of existing mature concentrators and the use of a new tailored concentrator. During the development, the focus was on significant cost reduction. Therefore, current cost-efficient concentrators developed in the area of concentrating solar thermal power plants were used in combination with high-concentration PV. The concentrator system had to meet specifications on flux distribution and accuracy, safe operation and reliability. Taking advantage of the achievements in concentrating solar thermal systems, this will reduce system costs significantly due to mass production.

Existing and innovative solar concentrators were evaluated in respect to their properties in high concentration photovoltaics. Plant types were identified that fulfil the technical requirements of homogenous irradiation distribution with solar concentration factors of 500 to 2000 suns and cost-effective implementation perspectives. The conclusions were that a Modified Spherical Dish (Tailored Concentrator) configuration look more suitable to meet current technology requirements than classical Parabolic Dish. As an example Figure 1 shows the flux distribution which was calculated for the proposed Modified Spherical Dish.

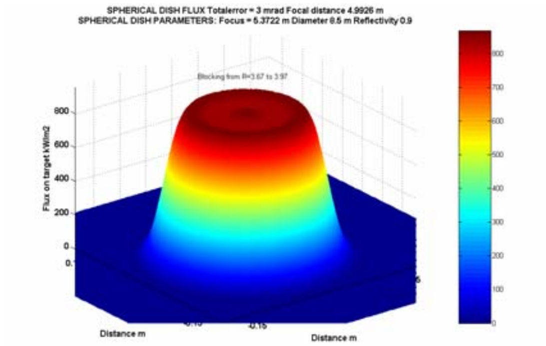

Figure 1. Modified Spherical Dish (Tailored Concentrator) Flux distribution 3D.

Due to the promsing results, this design has been built and tested. An industrial dish concentrator design has been prepared. The concentrator is composed of hexagonal spherical-curved low cost mirror facets. A prototype is already installed (see Figure 2).

The proposed final configuration has been optimised for 1000x, taking into account the optimized structural heliostat concept where the shape of the concentrator is not round any more but rectangular. Rectangular concentrators allow us to keep the gravity centre lower for the same aperture area. This has a strong influence in the structural design and in the final cost.

An innovative heliostat variant was evaluated for its properties in high-concentration photovoltaics. The result was that the so called Torque Tube Heliostat (TTH) design concept promises significant cost advantages over the existing heliostat designs. This could be achieved by a much lower construction height of the TTH, which reduces drastically the wind loads on the structure and the required specific drive power.

Figure 2. Tailored dish at Solúcar's facilities in Seville.

THE PV RECEIVER

Concerning the PV-Receiver, in this project large area single-junction GaAs solar cells were developed suitable for concnetration ratios up to 1000x.

A special technology for the fabrication of III-V solar cells has been developed. To deal with the high concentration, Monolithic Integrated Modules (MIM) [1-3] were introduced and assembled to Compact Concentrator Modules (CCM), see Figure 3. The Compact Concentrator Module (CCM) under operation exhibits a module power of around 1.5 kWp from a module area of about 100 cm² [4].

Figure 3. CCM concept, consisting of MIMs for efficient conversion of 1000x solar radiation into electricity.

Monolithic Integrated Modules (MIM) with an area of 3.89 cm² were developed and extensively characterised [3]. It has been possible to reach 19,9% efficiency (962x) for a full-sized MIM, see Figure 4. .. An integrated bypass diode concept has been developed by ISE and AZUR Space (patent pending) [4].

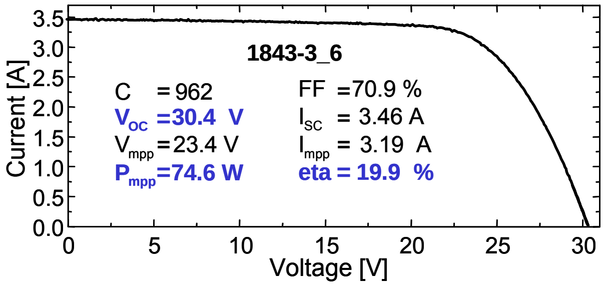

Figure 4. I-V curve for a MIM. 19.9 % efficiency was measured at the targeted light intensity of 962 suns.

CCMs were fabricated at Fraunhofer ISE in Freiburg for outdoor application. After their qualification in the high-flux solar furnace the modules were successfully tested in existing concentrator systems at the Plataforma Solar de Almería, the European test center for concentrated solar energy in southern Spain, as well as in the Sede Boquer Campus in the Negev Desert in Israel, and at the DLR solar furnace. The Hicon16 CCM Prototype has reached a mean efficiency of 14,5% at 1000x.

The heat generated in the receiver at high flux density levels requires an effective water cooling. A microchannel watercooler with a carefully designed flow pattern proved to be an effecticient solution, see Figure 5. Equally important is the very good thermal coupling between the chips and the watercooler that has been achieved with a high performance thermal adhesive.

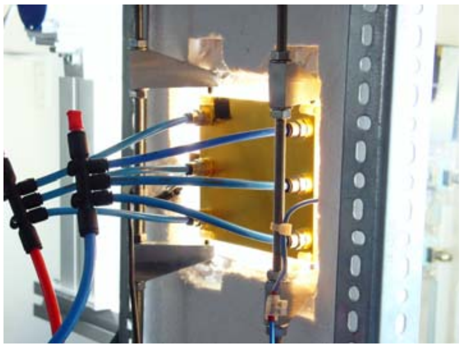

Figure 5. Water-cooling system of the CCM.

OTHER RESULTS

Inverters suitable for this kind of solar system were developed for the use in grid connection, with the option for remote operation mode. For concentrating solar power plants, mainly two new challenges for the inverter design arise. Due to the high fill factor of the solar cells, the overall yield is strongly affected by little variations of the operation voltage. Thus, power stages need to be designed that have very little input voltage ripple only, stemming both from the MPP-tracker and the usual 100 Hz power fluctuations from not perfectly symmetrically feeding into the grid. Furthermore, MPP control and tracker control were incorporated into the inverter in order to allow control schemes that actively optimise the system output. CCM interconnection schemes have been studied. A series interconnection of all solar cell segments would lead to higher voltages and a higher inverter efficiency whereas a combined series and parallel interconnection reduces the current mismatch losses. A parallel interconnection of 6 rows of 100 segments each proved to be the most advantageous solution.

Parallel to the technical development, different simulations were carried out. The annual performance and levelised electricity costs for available design options for high-concentration PV were compared during the conceptual definition phase. Layout parameters and test results were parameterised and implemented in the performance simulation tool.

Comparison to non- and low-concentration PV as well as to solar thermal power plants depending on system size and site conditions identified the technology implementation and market potentials of high-concentration photovoltaic systems. Due to their variability in size they can bridge the gap between small unattended PV systems and the large scale solar thermal power. The models included site-specific data like solar or water resources and grid connection cost. A study estimated the installation potential in European and non-European countries. The costs for different production numbers and system sizes as well as cost reduction potentials were evaluated.

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