Developing instrumentation for analysis of CPV TwinFocus® system

M Nardello1,2,a and S Centro1,2,3,b

1Museo Storico della Fisica e Centro Studi e Ricerche “E. Fermi”, piazza del Viminale 1, Roma, Italy.
2Università degli studi di Padova, via 8 febbraio 1848, Padova, Italy.
3AtemEnergia srl, via Padania 19, San Vendemiano, Italy.

a)nardello@atemenergia.it
b)centro@atemenergia.it

Abstract. Concentrator photovoltaics (CPV) is a technology that offers an alternative to standard silicon modules, being more efficient and eco-friendlier. AtemEnergia is developing a CPV product with good characteristics of efficiency and reliability. To monitor the progresses of our prototypes, test their quality and discover potential defects in the devices and in the production lane, custom experimental setups were necessary, to investigate the peculiar characteristics of this technology, avoiding the huge costs of commercial instrumentation in this field. Here is an overview of the tests necessary to guarantee the correct production quality, along with the custom solutions we adopted for their implementation.

1. Introduction

Photovoltaics is the most interesting among renewable energy production technology, because of the abundance of the energy source and other strong points like long lifetime, low maintenance, ease of installation, no fuel requirement [1]. It has, however, some drawbacks, like the not optimal efficiency of the cells, which increase the area of installations and the costs of the product, the lack of energy production at night and in cloudy weather, the costs associated with used silicon treatment that render impossible the recycling of spent panels.

CPV overcome some of these problems, because it avoids the use of silicon, preferring the more efficient multijunction solar cells. Standard silicon solar cells have a theoretical efficiency limit of 33.16% [2] that is due to the fact that light absorption is impossible for energies lower than the band gap of the material and conversion to electricity is rendered inefficient due to competitive relaxation mechanisms at energy higher than that of the band gap. But using different junctions made of different materials stacked together we can modulate the band gap so that each junction absorbs with minimal losses a different part of the spectrum, thus reaching a theoretical efficiency limit of 86.8% [3].

For practical application CPV cells have reached 46% record efficiency, rapidly increasing towards the 50% goal, against 27% of Si. Commercially available cells report 44% efficiency against standard silicon cells around 20% [4].

The superiority of these types of cell is given by another important characteristic: their efficiency is less affected by operation at high temperature. While for standard Si cells we note a decrease of 0.4%/°C efficiency for every degree of deviation from standard conditions (25°C), for multijunction solar cells the efficiency drop is only 0.04%/°C [5]. This allows for concentration of light in smaller areas,
decreasing drastically the amount of semiconductor used. Typical concentration factors for CPV go in fact from a few suns (LCPV) to more than 1000x (HCPV). The main structures of CPV modules are not composed by the “active” material, but by optical elements, lenses or mirrors, capable of reflecting light and concentrate it on the small cells. Optical materials used are glass, aluminum, plastics, very cheap and recyclable.

The correct alignment of the optics is guaranteed by moving structures, which follow the sun throughout the day. This characteristic maximizes the amount of produced energy, since solar rays strike the surface of the panels perpendicularly also in the morning and late afternoon, when efficiency of standard fixed panels decrease instead. The gain in produced energy provided by tracking can reach +20%, as shown by measurement made by us, independently by the type of cells used (figure 1).

Figure 1. Graph showing measurement of produced power throughout the day for a fixed silicon panel, a silicon panel mounted on a tracking system, a prototype of our CPV system TwinFocus (first version). Measurement are normalized to the peak power production of TwinFocus system.

The properties just described make CPV a favorable technology for energy production, especially in dry and sunny areas, where scattered light is not predominant and there is high DNI (direct normal radiation). But the intrinsic complexity of these type of structure makes it less competitive on the cost issue; for this reason, CPV systems developers have to pose a great deal of attention in research both to develop a design that limit the costs and to maintain the high-quality standard that is the counterpart of the greater initial investment.

2. TwinFocus®

It is in this context that in 2010 began the collaboration between University of Padova, Centro Fermi, and a group of private companies, operative in the design and production of molds and plastic products, for the realization of a CPV product, with a custom optical design and the ambition to become a reliable and competitive solution for energy production.

The resulting product is named TwinFocus®. It saw a series of modifications and improvement from its original design to arrive nowadays at a 31% efficiency at concentrator standard test conditions (CSTC). Its design has already been described elsewhere [6], so here we will show just a brief illustration.

2.1. Opto-electrical unit

The core of the system is based on a curved mirror, divided in two halves that deviate and focus the solar light on two receiver assembly, located on the sides of the optical elements (see figure 2 and 3).
Figure 2. The mirror is shown, it is connected on the right with the aluminium bar that act as a support. On the same bar is glued the receiver

Figure 3. Schematic representation of the optical element, the light path is shown for the right half of the mirror.

2.1.1. Primary optics. The mirror was designed and realised internally. The design is off-axis, with each half of the mirror composed by 6 quadrants of parabolic shape, focusing on different points of the receiver. It is realised in polycarbonate coated with a reflective layer of aluminium.

2.1.2. Receiver assembly. The light deflected by the mirror strikes first on a secondary optic, a silica prism that funnels it, thanks to total internal reflections, towards the solar cell located at its base. The solar cell is an Azur Space 3C44C [7], a triple junction solar cell with nominal efficiency of 44% and dimensions 5.5x5.5 mm2 to attach the cell to the wall of our modules is necessary a substrate that eliminates thermal stresses and provides the electrical connection. This is a DBC (direct bonded copper) made of a layer of alumina sandwiched between two copper foils.

2.2. Structure and installation

The units described in §2.1 are linked together in a series of 12 and enclosed in an aluminum structure, that provides stability, water tightness and thermal dissipation. The overall design is lightweight, simple, and allows for easy electrical connections among cells and to the outside. An UV transparent glass covers the module on top. Figure 5 shows the design.

The modules are mounted on a tracking system. Our choice is that of a pole installation, that allows for passing underneath and keeping the land available for other uses, such farming, parking etc minimizing the impact of the structure on the surrounding environment and its activities. Figure 4 show our first prototype installation, on which we are now collecting the first efficiency and power production data.

Figure 4. TwinFocus tracker 3.6kW installation
3. Testing activities
A fundamental part in the development of a new product is the analysis of its performances and the overall quality of the process. CPV has characteristics that differentiate it from classic photovoltaic and thus need different instrumentation especially designed for its testing. This instrumentation can be not easily available for custom devices such as ours, and often very expensive. We realised optical and electrical setups specifically tailored for our needs and used them to monitor every step of the creation of our modules.

3.1. Electrical and optical performances tests

![Figure 5](image)

**Figure 5.** Experimental setup, Xe lamp in the centre with power supply (up to 300W), mechanical rotating support for the cell on the optical bench, active load on the right, NI hardware on the optical bench. The substrate is rotated at the angle that maximise the absorption of light from the cell.

Solar cells are current generators, whose power production is dependent on the electrical load applied to them. They present a characteristic curve of produced current as a function of the applied voltage which is comparable with the characteristic of a diode [8]. If no load is applied to the cell, the produced current is called short circuit current ($I_{SC}$), increasing the voltage to the cell the current decreases until become zero at the open circuit voltage ($V_{OC}$). The maximum power that can be obtained from the cell is $P_M$; defects in the cell can lower $P_M$ modifying the shape of the curve.

Looking at the IV curve is a good method to test the quality of a solar cell. To do so we realised a setup composed by a Xe lamp (with a spectrum similar to that of the Sun), a plano-convex lens to focus the emitted light on the cell, and a support for the cell providing electrical connections and a variable load able to generate a voltage ramp applied to the cell and to collect the produced current as a function of the voltage (figure 5). The obtained signal is analysed by National Instrument hardware and the characteristic values are calculated thanks to a program created in Labview (figure 6).

The Xe lamp is useful not only for electrical tests of the cell but also to check the performances of the optical elements. With a system of optical fibres, filters, diffusers, beam splitters, a photodiode and a spectrophotometer, we can check the punctual reflectivity of mirrors and the transmittance of glass and secondary optics.

3.2. Thermal performances tests
An aspect that is peculiar to CPV is the great importance of thermal management, since concentrating light brings a lot of power in small areas; power that has to be dissipated efficiently if we want the cell to work at optimal conditions. For this reason, the choice of the glue was made after careful examination of the available options. Sadly, values of thermal conductivity of various products are obtained with different techniques and are not trustworthy.
Figure 6. View of Labview program. The window shows the acquired I-V curve (blue line on the right), highlighting (bottom left) key parameters as $V_{OC}$, $I_{SC}$ and FF. Units of measurement are volts for voltage and ampere for currents. FF is the fill factor, a quality check parameter obtained as the ratio between the maximum obtained power and the maximum theoretical power given by $V_{OC} \cdot I_{SC}$.

To overcome this problem, we devised a temperature testing setup to directly measure the temperature of the cell. The increase of temperature is provided applying a current through the cell (the cell acts as a LED) of 4A. The cell is glued with the product under test on its substrate and to an aluminium heat sink. The heat sink is kept at a fixed temperature by an active cooling system (a metal block with channels of flowing water cooled at 10°C). The difference of temperature between cell and substrate reach at equilibrium a constant value dependent on the conductivity of the glue. Applying a resistance thermometer to the cell we can easily calculate the best thermal glue (figure 7).

Figure 7. Comparison between two commercial glues. The cell shows a smaller increase in temperature when AG glue is applied and reach a lower equilibrium temperature when current (4A) is applied for a long period of time.
3.3. Visual quality checks

Applying current to the cell is a good way to spot other defects in the device. Since the cell under these conditions emits light (photoluminescence), the observation of the emitted light shows details not evident observing the cell with the naked eye.

Of particular importance is the intensity of the emitted radiation because points in the cell may present slightly different electrical conduction properties, favouring the passage of current and increasing locally the temperature (hot spots). This in turn increase the conductivity and establish a cascade effect that can bring to the rupture of the cell (figure 8).

Electroluminescence emission shows these defects as brighter spot, allowing to recognise and isolate the faulty cells.

![Figure 8. Electroluminescence test for two cells. In the top row a brighter spot is visible on the bottom right corner. Increasing the current (from left to right) the difference become more visible, until the cell breaks (picture on the right). The bottom row shows a cell without defects.](image)

4. Conclusions

The project TwinFocus is a great example of collaboration between industry and university. It allowed for developing a fully mature and competitive technology that can produce energy with great efficiency. It involved a good amount of research, of which I have shown here some example relative to the development of custom instrumentation.

Of particular importance were the realization of electronic devices for performance testing and the setup for the thermal management of the cell.

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