CPV Market Evolution and the Potential in Cost Reduction of CPV Modules

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Since the second half of 2008 the prices of standard PV modules have decreased drastically, mainly due to political decisions in China. This fact determined significantly the evolution and strategies of the photovoltaic (PV) sector in general, and the concentrating PV (CPV) sector in particular. For the CPV market this change in market conditions meant that CPV modules that were cost-competitive before the price crash that started in the second half of 2008 were afterwards no longer competitive. In order to be able to compete again with conventional PV technology, CPV module manufacturers have to decrease the prices of its products and installations. One way to achieve this is by improving the design of their modules, for example by increasing its concentration ratio. In this article the different cost drivers for the cost reduction of CPV modules are given. Additionally a comparison of a cost breakdown structure for two similar CPV modules that operate at different concentration ratios is shown, and the effect that the concentration ratio has on its cost is analysed. CPV module manufacturer have the possibility to reduce its product and system costs not only by decreasing the cost of the supply chain, but especially by improving the design of its modules. Since 2009 the situation of the main players in the CPV market has changed significantly, and they had to find their ways to reduce the cost of their products and adapt them to the new market conditions. This led, on one hand, to new developments of CPV systems and the emerging of new players with novel concepts, but also, on the other hand, to downscaling or closures of manufacturing sites.

INTRODUCTION

Concentrating Photovoltaic (CPV) technology has started its commercial deployment in 2007. Since then big efforts have been made in order to make this technology a competitive alternative for electrical power generation in areas with high direct normal irradiation (DNI). Those efforts were mainly focused in reducing the cost of the systems, gaining field experience and improving the reliability of the systems. But despite all efforts, CPV technology has not been yet deployed at big scale and it currently continues having only a marginal share in the overall photovoltaic market. In 2011 the annual installed capacity of CPV technology was of 0,26% **[1]** of the overall installed capacity of photovoltaics (PV). The main reasons for this slow deployment of CPV technology during the last years are the strong competition of PV due to the low prices and the generalised difficulty in obtaining financing for the execution of power plants. This is particularly true for CPV projects, due to the higher risk that a customer has to assume when purchasing a novel technology as compared to an established one like conventional PV, assuming that both technologies have a similar price. One possibility to reduce this risk for the customer is to reduce the price of CPV systems further. This has been even more important since 2009, when the prices of conventional PV modules started to decrease drastically mainly due to political decisions regarding subsidies and other commercial aspects in China. Since 2009, CPV manufacturers could not keep the pace of the decrease in PV module prices, which led to the fact that CPV modules that were cost competitive before 2009 were no longer competitive after that year and CPV module manufacturer had to find ways to reduce the costs of their products further. The rapid decrease in conventional PV module prices was, as mentioned earlier, mainly due to political reasons and to a lower extent to a reduction in the supply chain, but not due to technological improvement in performance of the solar cells or modules. On the contrary, CPV technology has the opportunity to reduce costs of its systems further, not only by reducing the manufacturing costs, but mainly by technological changes, making this technology very promising for large scale deployment in the near future.

PV MARKET EVOLUTION AND ITS CONSEQUENCES FOR CPV TECHNOLOGY

The current situation in CPV industry can be understood when looking back to the recent photovoltaic market evolution. In Figure 1 is given the price evolution of conventional PV flat panel modules and of CPV modules, as well as the installed price of these two technologies. The most striking feature is the significant decrease in price of conventional PV modules since 2009, a fact that changed significantly the market conditions for all players, including other competing technologies like CPV or thin film. Since CPV technology competes with conventional PV technology for electrical power generation plants in areas with high direct normal irradiation (DNI), this change in market conditions have affected also the strategies of CPV players and the deployment of their products.

The first commercial pilot CPV power plants that were mainly in the range of few hundreds of kW, were installed in 2008 and earlier, at a time when the reference price of conventional PV modules was still high. CPV modules that were manufactured at that time were developed so that the levelised cost of energy of a CPV power plant did underbid the one of conventional PV. But due to the drastic decrease in PV prices since 2009, CPV module manufacturers have to find alternative ways to reduce the price of their modules even further, in order to be able to compete again with conventional PV technology.

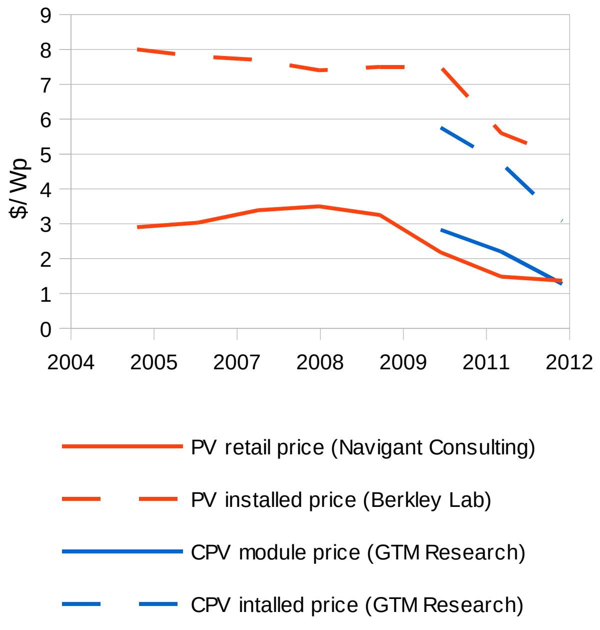

Figure 1. Flat panel PV and CPV price evolution from 2004 – 2011.

Figure 1 shows the price evolution since 2005 for conventional PV technology and since 2009 for CPV technology. There are given the retail prices for PV modules [1], the installed prices for commercial PV installation with an installed capacity between 100kW and 2MW [2], and the prices of CPV modules and installed CPV systems [3]. For the price of installed PV power plants, it has been taken a price for the power plants with a capacity smaller than 2MW, since this corresponds to the typically installed capacity of CPV installations during that time period. In these curves it can be seen that between 2009 and 2010 the price advantage that CPV had against PV at both, module and installation level, has decreased. This fact made CPV technology less attractive for investment and hence slowed down the deployment of this technology.

Unlike the situation of conventional PV, the big opportunities of cost reduction in CPV systems rely in a major extent in the improvement of performance due to technological modifications in design of CPV modules and systems, and in a lesser extent in the reduction of price of the supply chain, at least in the initial ramp-up phase where no big production volumes can be expected.

In order to reduce the cost figure of CPV technology, the systems composed of modules and trackers should be considered as a whole. In the early days of CPV technology deployment, the development of CPV modules was generally made separate from the development of the trackers. The consequence was that in general, the size of CPV modules were small and added additional labour cost to its installation. The reason for the additional cost is that CPV modules need to be aligned on the tracker in the field, which is an expensive cost as compared to the manufacturing cost in a factory, when this alignment is automatized. This insight led recently to a shift from small CPV modules to bigger CPV modules or CPV module arrays by several companies, in order to reduce as much as possible the time and cost of the installations of their modules.

Apart of the size of the CPV modules, the other three main factors that affect the cost figure of CPV modules are the concentration ratio, the size and efficiency of the solar cells and the cost of the supply chain. All four factors are key issues regarding cost reduction of CPV technology, and should be considered in the design of CPV modules in order to make CPV technology again competitive for electrical power generation.

HIGHER CONCENTRATION RATIOS FOR COST REDUCTION OF CPV MODULES

The concentration ratio affects directly the output power of the modules. The higher the concentration, the higher the module output power. But an increase in concentration has two drawbacks. The first one is that an increase in concentration leads to an increase of heat generation in the solar cell and its consequential increasing demand in cooling. This means that higher technical efforts have to be made to dissipate additionally generated heat of the solar cell, what it turn will also increase its cost. One way to solve this drawback is by reducing the solar cell size, which will facilitate the cooling of the device.

The second drawback is that when increasing the concentration, the lens system has to focus more precisely on the solar cell, which means that higher precision requirements are set to the tracking system. This is a drawback that might add additional cost to the overall system, depending on how much higher the needed accuracy is, which in turn depends on the design of the used optical system and its acceptance angle. This means that depending on the level of concentration ratio, some of the mentioned effects might be predominant, which might lead or fail to lead to the desired cost reduction of the overall system.

The purpose of this article is to show how the choice of the concentration ratio impacts on the cost of the overall CPV system. For this purpose, two similar designs of imaginary CPV module are analysed, in which the external geometrical size is the same but the concentration ratio and solar cell size vary. The starting point is a CPV module with a concentration of 500x and a solar cell with an aperture area of 100mm^2. This module design has a primary lens area of 500cm^2. For the aim of this study, it is assumed that the overall efficiency loss is of approximately 80%, and that each solar cell (after reducing the efficiency loss) gives a power of 15W at 500 suns.

In the second module the solar cell has been exchanged by a smaller one, one of a aperture area of 30.25mm^2, which corresponds to the typical aperture area of a square 5,5mm x 5,5mm solar cell and when keeping the primary lens area the same, will have a concentration ratio of 1650x. It is assumed that the focal distance of the overall optical system is almost the same in both types of CPV modules, so that the same housing can be used for both cases. In fact, and depending on the focal distance of the lens, this design might have a focal length that is slightly larger that of the first design, but it will be compensated due to the shorter length of the secondary lens of this second type of module. The output power of one of these solar cells is assumed to be of 5W at 500x and of 16.5W at 1650x.

For the purpose of this study it has been assumed that the efficiency of the solar cells and the power does not decrease with increasing light concentration, what means that it is linear with concentration. In reality this might not be the case, since there are basically two effects that affect the performance of the solar cells when comparing its performance in these two designs.

The first effect is that, when increasing the concentration ratio at a constant solar cell size, the efficiency and therefore also the output power of a solar cell decreases. The amount of the decrease in efficiency depends on the solar cell manufacturer and on the manufacturing process of the solar cells, and can range between 2% and 8% for an increase in concentration from 500 suns to 1650 suns. On the other hand, when decreasing the size of the solar cell from 100mm^2 to 30.25mm^2, the efficiency of the solar cell can increase up to 3%, also depending on the solar cell manufacturer. This means that the reduction in size of the solar cell compensates at least partly the decrease in efficiency when increasing the concentration ratio. In any case, since these two effects are very much dependent on the solar cell provider, and the resulting impact on cost per watt can be very small, it has been assumed linearity of efficiency when increasing the concentration ratio.

Regarding the level of concentration ratio, it has to be mentioned that in practice lower concentrations in the range of 800x to 1300x are recommended. This is because higher concentration ratios demand higher performance components like secondary optics, heat dissipation or tracking systems. For the purpose of this study no additional cost is assumed regarding any of the mentioned aspects, since the intention is only to show the impact of the concentration ratio on the cost in a similar CPV module.

COST BREAKDOWN OF CPV MODULES FOR TWO DIFFERENT CONCENTRATION RATIOS

In this section the cost breakdown structure of the two types of modules is given. The initial cost breakdown structure of the first module, which will be the base for the following calculations is assumed and should therefore not be seen as an accurate or even representative value for any type of CPV system. The different CPV systems that are currently on the market differ too much between each other and it is therefore difficult to make any price estimate about the system cost.

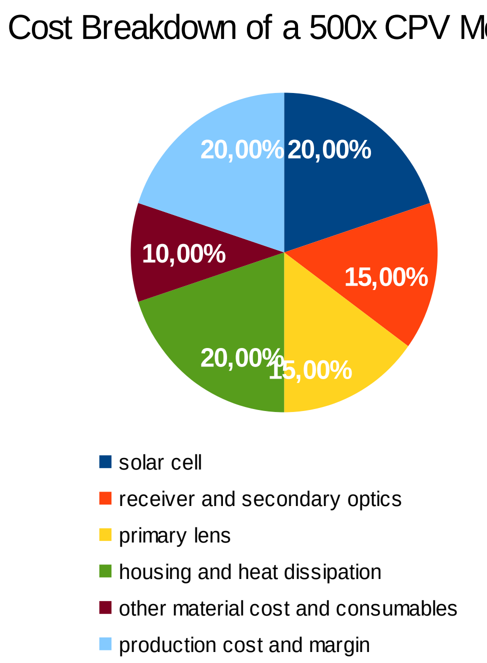

Figure 2. Costs breakdown of a CPV module that operates at 500 suns with solar cells of an active area of 100mm^2.

The cost breakdown of a first type of module is given in Figure 2. It is assumed that its cost distribution is as follows: 20% solar cell, 15% receiver with secondary optics, 15% primary lens, 20% housing and heat dissipation, 10% consumables and 20% production cost and margin. These values are based on price information given by suppliers of CPV module manufacturer for a production quantity of 1MW. It is further assumed that the CPV module has 20 solar cells of which each of them gives 15W at 500x, leading to a total power output of 300W. According to a study conducted by GTM Research in which the roadmap for CPV technology was analysed [3], the cost of a CPV module including margins was approx. $2.8/W in 2009, what means that the cost of this module would be $840.

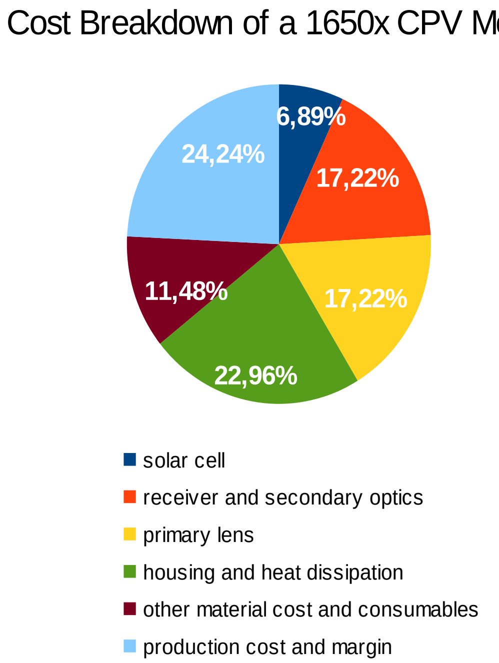

Figure 3. Costs breakdown of a CPV module that operates at 1650 suns with solar cells of an active area of 30.25mm^2.

With these data it is possible to estimate the total cost in $/W of a second module that operates at 1650 suns. It is assumed that all costs except the one of the solar cell are the same as the ones of the first module. The cost reduction of the solar cell is calculated to be of 70%, which corresponds to the reduction in area size from the solar cell of the first module with respect to the solar cell of the second module. The resulting cost breakdown of the second CPV module design is given in Figure 3 and is as follows: 7% solar cell, 17% receiver with secondary optics, 17% primary lens, 23% housing and heat dissipation, 12% consumables and 24% production cost and margin.

This module would have a total output power of 330W, if assuming the same module configuration of 20 solar cells, and that each solar cell has an output power of 16.5W at 1650 suns. Its price would be $720 taking into consideration the cost reduction only due to the decrease in cost of the solar cell. With these data it has been calculated a cost per watt of $2.18/W, which is 22% less than the same module working at 500 suns. This means that the sole fact of reducing the solar cell size reduces the cost of the CPV module by 22%.

Another important fact that can be observed in Figure 3 is that the impact on cost of the solar cell has been reduced to 7%, whereas the relative impact in price of the other parts of the module has increased. This means that additional cost reduction of the of the CPV System can be achieved by reducing other costs of the supply chain, like housing or consumables, which are costs that are very much dependent on the production scale. This means that when going to higher concentrations, the effort of price reduction of the supply chain will have a bigger impact on the overall CPV system cost.

CONCLUSIONS

It has been analysed the evolution of the PV market in the last five years and how changing market conditions due to the decrease in price of conventional flat panel PV have affected the development and deployment of CPV technology and therefore also the strategies of CPV manufacturer. The high potential of CPV technology is to be able to reduce the cost of its modules and systems primarily by technological modifications in their design, and afterwards by additional reductions in production costs. It is given an example to show the effect of that the increase in concentration has on the overall cost of the CPV module.

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