Conference Proceedings
Solar World Congress 2015
Daegu, Korea, 08 – 12 November 2015

A New Tubular Photovoltaic Solar System with Low Sun Concentration

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1. Summary

The Yuma project is to manufacture and commercialize a new photovoltaic (PV) energy solar system with leading partners. The tubular low sun concentration module, based on a disruptive design, provides a new optimized solution to produce green electricity in sandy or dusty environment. Originally developed and designed by a top-level research team, this system is protected by patents owned by the company.
The product successfully passed the prototype and preliminary performance tests. From early 2015, Yuma entered the industrialization and marketing phases with the ambition to be leader in the Sunbelt regions.
A short summary of photovoltaic market, based on outstanding analysis is given to show orders of magnitude of this market in the near future.
Keywords: *Photovoltaic, low sun concentration, one axis tracking, sun-belt market, grid parity, low LCOE*

2. The PV Market

2.1 Global PV market as of 2013

The global PV market progressed in 2013: after two years of approximately 30 GW of installations annually, the market reached 37 GW in 2013 and 40 GW in 2014. But the most important developments were the rapid development of PV in Asia, combined with a sharp drop of installations in Europe. As indicated in Global Market Outlook for photovoltaics, 2014-18:
“China became the top PV market in the world in 2013 and achieved the world’s largest PV installation figure in one year with 11.8 GW connected to the grid, after Italy installed 9.3 GW in 2011 and Germany installed between 7.4 GW and 7.6 GW from 2010 to 2012. Japan scored 6.9 GW and took the second place in 2013, while the USA installed 4.8 GW.”

2.2 Global PV market forecast by 2018

Previsions for the PV market in the near future are very encouraging: The same reference indicates:
“While European electricity demand is stagnating, this is not the case globally and PV growth will continue to be driven by local and global energy demand. The fastest PV growth is expected to continue in China and South-East Asia in general, with Latin America, the MENA countries and India following. The PV potential of the Sunbelt countries – where PV can already compete with diesel generators for peak power generation without financial support – could range from 60 to 250 GW by 2020, and from 260 to 1,100 GW in 2030. And with the faster than expected price decrease in PV technology that the industry experienced in recent years, even more countries will see PV as a competitive energy source before the end of this decade.”

3. The Yuma Vision

3.1 The Yuma Vision

Yuma intends to provide a disruptive technology to unlock the Sunbelt PV potential

doi:10.18086/swc.2015.05.22 Available at http://proceedings.ises.org

3.2 The untapped Sunbelt potential

According to Global Market Outlook for photovoltaics, 2014-18 and EPIA and "Unlocking the Sunbelt potential of photovoltaics, October 2010, EPIA:

"The 66 Sunbelt countries account for 5 billion inhabitants representing respectively 95% of the Sunbelt and 75% of the world's population. Their 6.800 TWh electricity consumption represents respectively 97% of the Sunbelt and 38% of the world's electricity consumption"".

In the Company vision the huge potential of these sun-rich countries is a key parameter to make possible the introduction of a PV system whose design has been thought for the specific conditions of this market.

3.3 Technology limitation of PV flat panels

Increasing module efficiency is a major strategy for reducing per-watt module price. Consistent improvements in PV cell efficiency have been realized for virtually every PV technology (Fig.7), and module efficiency has followed this trend, albeit with a time and performance lag; this trend is projected to continue.

As single-junction PV technologies approach the theoretical (Shockley-Queisser) efficiency limit for their respective semiconductor materials, the extent to which further cost reduction may be attributable to efficiency gains will be reduced, and more substantial cost reductions will need to be realized via other ways.

CPV technologies offer high efficiency performance. However, at the module scale, HCPV has to deal with major technological challenges as high temperature management in the module, high tracking precision to target small and costly multi-junction cells. At this stage HCPV developers haven't found the solution to solve these issues at a low cost.

3.4 The dust problem

Dust and sand storms are prominent issues for PV installations in many sun-belt countries. (See Fig 1)

First, dust is deposited on solar surfaces every day of the year, and because of the absence of rain, it is not naturally washed from the panel. For example, deposition rate on solar surfaces has been measured at approximately 12.5 g / cm^2/ month in Saudi Arabia. This deposition rate will induce an efficiency drop of 8 to 15 % per month. This dust requires frequent cleaning involving significant manpower and water; it impacts heavily the O&M cost of the PV array. During the life time of a solar field, about 0.5 $/W additional cost to the initial price of the panel has to be paid.

The "dust problem" points out that flat solar panels, originally developed in Western Countries , are not the best fit for these conditions.

Integration of a Levelized Cost of Electricity (LCOE) have to be taken into consideration by developer in a long term vision

PV LCOE in Sunbelt Countries is expected to range from 5 to 12 c€/kWh by 2020 and 4 to 8 c€/KWh by 2030. In North Chile and South Morocco PV solar fields reach already grid parity as indicated by A.T Kearney National Renewable Energy Laboratory, National Technology Laboratory, EPIA Set for 2020, World Bank

Fig.1: sand storm in UAE

3. Yuma Project: An Alternative solution

4.1 The Yuma technology

4.1.1 Yuma's cylindrical LCPV sun receiver

The photovoltaic module consists of glass tubes including in their inner upper part a thin Fresnel lens. The lens concentrates the sun energy ten times along the bottom of the tube where a narrow strip of silicon cells is located (See Fig 2). Each tube, including dry air at atmospheric pressure, is permanently sealed and thanks to a simple rolling system tracks the sun from East to West.

Cells are manufactured out of quite ordinary wafers used for flat panels, however the two electrical contacts are both in the back of the cell allowing automatization of the stringing. Therefore the cost of these cells is close to one sun ordinary cells.

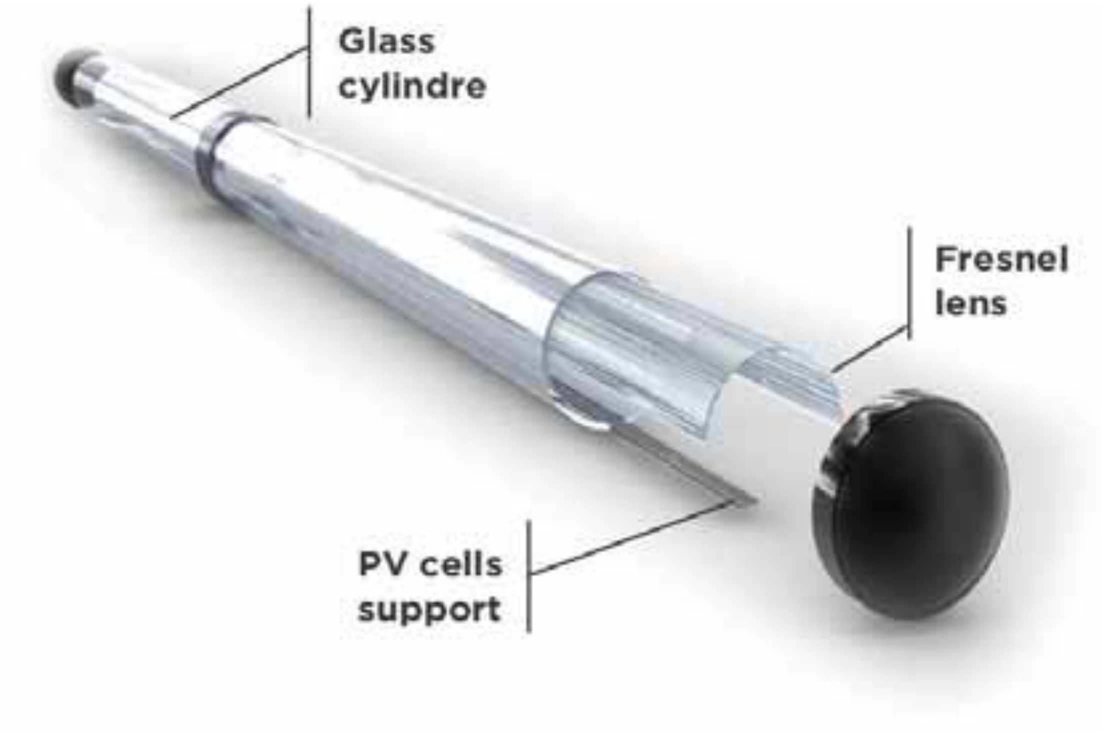

Fig.2: The Tenoga cylindrical LCPV module

Glass cylinder

A borosilicate glass tube with a 110 mm outside diameter and a 2000 mm length, both ends including a mechanical and electrical adaptor which allow a permanent closing of the tubes after assembly operations.
We chose standard tubes used for water heating in China where they are manufactured in huge quantity and at an affordable price. Borosilicate 3.3 was chosen for its good transparency and its proven resistance to UV and field conditions

Fresnel lens

A thin TPU film (around 100 µm thick) includes in one of its face a linear Fresnel Lens structure made of UV curing lacker; the TPU is slightly sticky on glass and the bond becomes very strong when heated. Moreover it has a good behavior when submitted to UV without yellowing.The Fresnel lens is located inside the glass tube on a 120° sector; its special design focused the solar irradiation linearly on a seven mm width-band, located on the low part of the tube.
The Fresnel Lens film was developed and manufactured by Film Optics specially for our application. The use of TPU allows a relative low cost and an easy integration in the glass tube. We chose Fresnel lens technology to avoid the use of big mirrors or sun concentrators.

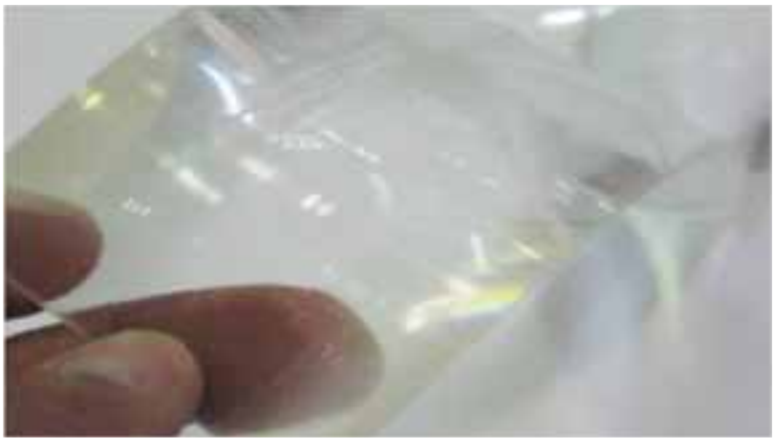

Fig. 3: Fresnel lens film

PV cells support

On a thin aluminum bar, located at the focal point of the Fresnel lens are connected in series forty MWT cSi photovoltaic cells with back contacts. This design allows to manufacture on the bar copper electrical contacts and to use an automatic process of pick and place to bond the cells on the bar. Bonding the cells must not introduce significant local electrical resistance; a special process using point soldering by laser was used.

Each tube will deliver around 25W.

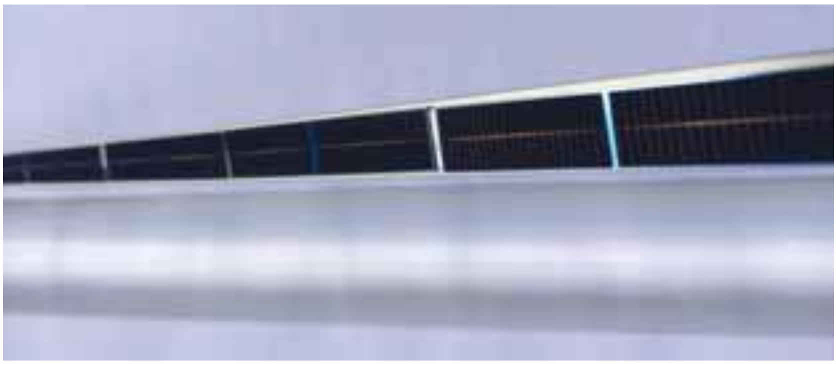

Fig. 4: PV cells support with back contact

Heat Sink

A Heat sink is made of a thin sheet of aluminum flattened by pre-stress against the inner wall of the tube; the bar with the solar cells is thermally bonded to the heat sink. The heat sink design is very important due to the large decrease of cells efficiency with temperature increase.

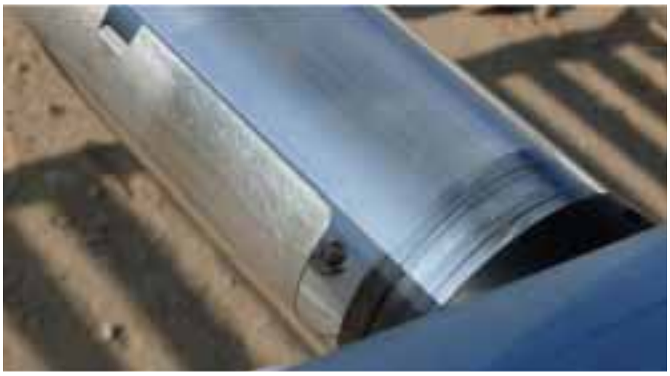

Fig 5: Heat sink

The thermal flux produced by the cells is quite small; therefore conduction through the heat sink and the glass tube occurs with a quite small loss of temperature. Radiation helps partly the cells to remain at a reasonable temperature. The area of the heat sink contributing to the cooling is about twice that existing on flat panel. Finally thermal flux is absorbed outside by natural or forced convection.

Laboratory simulations and site tests have confirmed that with a DNI of 1000 W/m^2 and with a wind speed of 0 km/hour, temperature elevation at the surface of the cells is no more than 30 °C above ambient temperature. With a 1 m/s wind this elevation will be 20 °C only.

So even with a sun concentration of ten, the design of the sun receiver and the efficiency of the heat sink avoid high temperature elevation of the cells.

Fig 23 shows a simulation of temperatures on the heat sink for a DNI of 1000 W/m^2 and without wind.

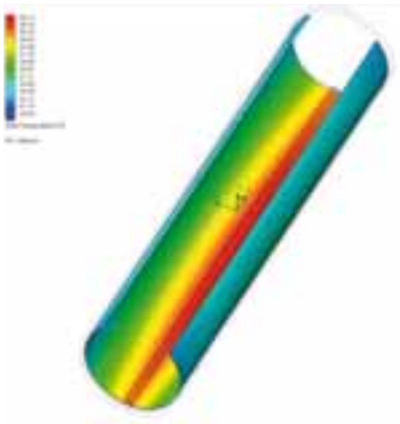

Fig. 6: Heat sink thermal simulation

4.1.2 Yuma's one axis tracking system

A one-axis tracking system enables each tube to rotate and to follow the sun in the East-West direction: hundreds of tubes can be rotated together driven by one small electrical motor.

The tracking system includes:

- A sun tracker with its control box
- A small electrical motor driving together a line of hundreds tubes
- A simple mechanism allowing the tube rotation without translation.

The whole mechanism with all electrical contacts is pre- installed in factory; it is protected against UV and dust inside Aluminum beams which are both support of the system and protection of components.

Fig. 7: Rolling mechanism stress tests

4.1.3 Ground installation

All cylindrical modules are mechanically and electrically «plug and play» connected to dedicated Aluminum beams. These beams include the electrical connections as well as the tube rotating mechanism and are ready to be installed on site.

The whole design enables a very easy and quick ground installation which *does not require any civil work.*

Moreover replacement of tube or of electrical motor does not require time nor special qualification.

Fig. 8: Pilot ground mounted installation

4.2 R&D

4.2.1 First Phase: Research

A first phase of R&D conducted in 2011-2013 focused on:

- Technical and economical feasibility studies
- Design of each component of the system including photovoltaic and mechanical items.
- Build pilot equipment and conduct laboratory tests and also tests in a desert environment in order to valid the system performances.

This first R&D phase has led Yuma to the installation of one prototype system tested in desert situation. This 500 W generator has strengthened the expected performance forecast of the future commercial product.

This first phase was supported by national institutions and private companies in particular Navallon Groupe.

Components developments:

Yuma uses basic components like standard borosilicate glass tubes and existing under-control technologies with a dedicated design for Yuma System, such as focusing optics developed by Film Optics in Great Britain and MWT cSi cells developed at Fraunhofer Institut in Germany.

Availability of components has always been a driver in the development of the Yuma technology.

4.2.2 Second Phase: Development

Supported by Institutional and financial partners as BPI (Banque Publique d'Investissement) , Midi Pyrenees Region in France and technological leaders as CEA, Fraunhofer Institut, Yuma has entered in a 2 years development phase leading to the construction of a 50 KW industrial pilot and the certification of the commercial product. (2016)

This phase includes additional components modification to fit industrial cost and time manufacture:

- *Lens:* Fresnel lens will use a 100 µm TPU substrate cheaper than PMMA and allowing a simple bonding process inside glass tube.
- *Cells:* Fraunhofer Institut tested successfully blue wafers produced by IrySolar in France. It will allow in the future production of MWT back contacts cells at competitive price
- *Electrical Connection:* Using technology Aluminum bars with copper electrical connections will enable to manufacture bars ready to include solar cells by a pick and place automatic bonding process.

5. Yuma system advantages:

Yuma PV solar system presents numerous advantages:

5.1 Price

The cost of a solar systems includes mainly the initial investment for the project, all hardware, ground preparation, financial cost, field installation, insurance, but also all the expenses during the life time of the array to allow a good installation efficiency (cleaning, new inverters).The energy produced during the life time of the PV generator depends on the sun irradiation and on the system efficiency. The LCOE which is the ratio of all costs divided by the total energy harvested in c$/kWh is a good integral indicator of the value of a solar field; today the lowest proposed LCOE is the key to win public tenders. Yuma, with a hardware cost around 0.5 $/W, a very low cost of installation and maintenance and a high level of irradiation, can reach LCOE less than 7c$/kWh.

5.2 Self cleaning

We showed that maintaining sun receivers clean is a main issue in order to maximalize the energy harvested. In our case the tubes are horizontal and separated by a small gap; therefore they collect much less dust and sand that flat surfaces. Moreover automatic dry cleaning, if necessary, is very easy and cheap.

5.3 Installation time

Is very small due to the facts that:

- There is no need of ground preparation and of concrete basis
- The forces due to wind are small and the system stays by its own weight
- Aluminum beams and supports come pre-integrated from factory
- Cylindrical sun receivers are put in place like Neon tubes

5.4 No danger of robbery

In several countries robbery of flat panels is quite usual because they can be used for TV; so the solar field has to be closed by fences and monitored by cameras. In our case it is very easy to rob a glass tube but there is no utility.

5.5 Flexibility

Future, more efficient, new cells can be incorporated in Yuma system very easily

5.6 Easy maintenance

Failure of a sun receiver or of an inverter will be automatically identified and replacement of the failed item is very quick and simple

6- Competition

Today more than 95% of solar fields are equipped with flat PV panels. Other technologies like thermal solar or PV with high sun concentration have not succeeded for the moment to gain a relevant part of the market:

the main reason is cost.
The idea to use PV with low concentration was tested some years ago [1], [2], [3] but without success; the main reason was the system design using big troughs leading to high cost.

7 Conclusions:

Yuma is building an industrial Pilot of 50 kW, based on a new tubular PV technology including low sun concentration and one axis tracking. This Pilot will be ready for real-life tests in desert conditions before the end of 2015. The maturity of this technology will allow us to market and manufacture Yuma systems before end 2016. . No other market solution provides comparable level of efficiency and competitiveness in sun-rich regions.

8- References

[1] Performance Results of a Low-Concentration Photovoltaic System Based on High Efficiency Back Contact Cells by Zachary S. Judkins, Keith W. Johnston, Charles Almy, Ryan J. Linderman, Brian Wares, Nicholas A. Barton, Matt Dawson, and Jack Peurach 2010 SunPower

[2] Low-Cost 20X Silicon-Cell-Based Linear Fresnel Lens
Concentrator Panel Mark O'Neill, A.J. McDanal, Don Spears, Clay Stevenson and David Gelbaum
Entech Solar, Inc., 13301 Park Vista Blvd., Suite 100, Fort Worth, Texas 76177 USA

[3] Technology:A Disruptive Low-Concentration PV Proposition From Cogenra by Herman K. Trabish
November 21, 2013 by Herman K. Trabish
November 21, 2013