

Executive summary

The European Commission has subsidized project NACIR for concentrated photovoltaic (CPV) from January 2009 to December 2012. The main goal is to bring together the owners of the most advanced European CPV technology in order to research new applications for CPV systems. This research has unveiled possible sources of failure in new environments outside Europe, in order to assure component reliability.

The main objectives are:

- a) Installation of a stand- alone CPV system in Egypt
- b) Installation of a grid connected CPV system in Morocco
- c) Implementation of normative and a worldwide database on CPV systems, and
- d) Improvements of CPV components technology and development of a new CPV system.

Installation of a stand-alone CPV system in Egypt

The design and installation of the off-grid CPV water pumping, desalination and irrigation system has been carried out. The definition of strategies for operation and energy management and its inclusion into the Energy Management System (EMS), under the responsibility of Fraunhofer plus the deployment of CPV Soitec Solar (formerly Concentrix-Solar) arrays in the Egyptian desert are a set of technical and scientific highlights of the whole project. The standardize protocol (CANopen) helps optimizing the electrical generation and allows the inclusion of other generation sources such as wind and diesel. The plant has combined the scientific and technical implementation with the social and economic output of the irrigation leaded by NWRC.

Installation of a grid connected CPV system in Morocco.

The power plant has been deployed at Ifrane, (1600 m. altitude over sea level) in the campus of the prestigious Anglophone University Al Akhawayn, which reached an agreement with Office National d'Electricité (ONE), for participating with professors and researchers in the project.

The deployed HCPV 30MM modules from Isofoton have passed the IEC 62108 qualification standard. The Spanish regulations for PV grid connection are the ones adopted in the connection and the whole installation, which do not collide with the early normative at ONE. Each half-array is associated to a single phase inverter. Fabrication of the entire module, from the MJ cells production to the final CPV module assembly including test, has been carried out at Isofoton. The rating of the installed power has been carried out by ISFOC, who, according with the project and in absence of any international standard, has defined and promoted the method for this test.

The system is operative since January 2011 providing the scheduled power and energy.

Worldwide database and normative

The creation of a database of Worldwide CPV experience has been initiated at ISFOC using their powerful software tools. This database include the results and characteristics of the seven power plants owned by ISFOC, all larger than 200 kW, as well as those of NACIR's in Egypt and Morocco plants and other well reported experiences around the world.

The task devoted to create a network for recording overall and spectral DNI data with components cells has finished. The need for simplest spectrum recording devices has pushed UPM to develop a Tri-band Spectral Helimeter equipped with 3 isotype cells. The Project NACIR has contributes to a draft for a standard for CPV module rating.

The task devoted to link indoor rating with outdoor performance is underway in UPM, ISOFOTON and ISFOC research centres which are developing models for translation of IV curves from one testing condition to nominal test conditions or any else operating condition.

Technological improvement of CPV components

The aim is to improve the efficiency of the CPV systems specially increasing the acceptance angle of the optics. Several activities has been carried out. Fraunhofer and Soitec have initiated the path to use refractive secondary optics to increase the acceptance angle of Soitec modules. Isofoton in cooperation with UPM has analyzed the performance of suitable materials for refractive secondary optics. Isofoton have redesigned the RESET module to solve the weakness of several components uncovered in the IEC62108 testing. UPM has developed the new concentrator Fluidreflex, which uses a fluid as optical index material, as heat exchanger, and as insulator.

Project Context and Objectives:

4.1.2 Summary description of project context and objectives

The European Commission subsidized Project NACIR for Concentrated Photovoltaics (CPV) from January 2009 to December 2012. The main goal of this project was to bring together the owners of the most advanced European CPV technology, with respect to the state of the art, in order to research from their leading position new applications for CPV systems. In addition to opening up new markets, this research should unveil possible sources of failure in new environments outside Europe, in order to assure component reliability. The main objectives of the project were: a) Installation of a Stand Alone CPV system in Egypt, b) Installation of a Grid connected CPV system in Morocco, c) Implementation of normative and a worldwide database on CPV systems, and d) Improvements of CPV components technology, manufacturing and development of a new CPV system. Although it was not emphasized at the beginning of the project the implementations in the Mediterranean countries will really contribute to a socioeconomic development, in education on renewable energies in Morocco and to the progress of irrigation in Egypt and other desert areas.

Description of work performed and main results

Installation of a Stand-alone CPV System in Egypt

The provided steps, from design to full installation, of the first off-grid CPV water pumping, desalination and irrigation system in Egypt has carried out with the collaborative work of the 4 partners involved. The definition of strategies for operation and energy management and its inclusion into the Energy Management System (EMS), under the responsibility of Fraunhofer plus the deployment of CPV Soitec Solar (formerly Concentrix-Solar) arrays in the Egyptian desert are a set of technical and scientific highlights of the whole project. The standardize protocol (CANopen) helps optimizing the electrical generation and allows the inclusion of other generation sources such as wind and diesel.

The key parameters of the system are: 28 kWp CPV nominal power provided by 5 CPV Soitec-Solar arrays; a 903 A.h. lead acid battery which allows measurement and control of the power plant overnight and allows the system to remain operational for approximately two days without direct sun. A 1 kWp flat panel PV system is a backup in case of empty energy storage.

Three stand alone inverters create, along with the battery, an island AC mini-grid, providing the voltage and frequency references. Finally, the CPV generators are connected in AC. This contributes to generalization of operating methodology for stand alone and grid connected systems.

The significant operating system parameters as well as the meteorological data are continuously submitted via internet to ISFOC who is disseminating these data to the other partners. This is the first CPV station devoted to a stand alone application.

Installation of a Grid Connected CPV system in Morocco.

The power plant has been deployed at Ifrane, (1.600 m. altitude over sea level) in the campus of the prestigious Anglophone University Al Akhawayn, which reached an agreement with Office National d'Electricité (ONE), for participating with professors and researchers in the project.

The deployed HCPV 30MM modules from Isofoton have passed the IEC 62108 qualification standard.

The Spanish regulations for PV grid connection are the ones adopted in the connection and the whole installation, which do not collide with the early normative at ONE. Each half-array is associated to a single phase inverter.

The system is operative since January 2011 providing the scheduled power and energy.

Fabrication of the entire module, from the MJ cells production to the final CPV module assembly including test, has been carried out at Isofoton. The rating of the installed power has been carried out by ISFOC, who, according with the project and in absence of any international standard, has defined and promoted the method for this test.

Members of the Morocco research team have spent several days at ISFOC to learn, in the Puertollano CPV plants, about the field testing methods. Two members of Isofoton trained the local operators on the characteristics of the systems for maintenance and exploitation. The connection at the end of a grid, the high altitude climate of the site and the frequent lightning has provided valuable experience for the protection and maintenance of CPV systems.

Worldwide Database and Normative

The creation of a database of Worldwide CPV experience has been initiated at ISFOC using their powerful software tools. This database includes the results and characteristics of the seven power plants owned by ISFOC, all larger than 200 kW, as well as those of NACIR's in Egypt and Morocco plants and other well reported experiences around the world.

The task devoted to create a network for recording overall and spectral DNI data with components cells started in 2012. The need for simplest spectrum recording devices has pushed UPM to develop a Tri-band Spectral Heliumeter equipped with 3 isotype cells. Several laboratories in the world have acquired these devices which will favour a wider network. UPM, Fraunhofer and ISFOC are recording such data.

The preparation of a standard for CPV module rating is the most urgent activity in the concentrator field. The Project NACIR has contributed to a draft with the unique expertise of Fraunhofer and UPM in the indoor measurement of large area CPV modules.

The task devoted to link indoor rating with outdoor performance is underway in these two research centres which are developing models for translation of IV curves from one testing condition to nominal test conditions or any else operating condition.

Technological improvement of CPV components

The aim of this activity is to improve the efficiency of the CPV systems specially increasing the acceptance angle of the optics.

Fraunhofer and Soitec-Solar make several module prototypes carried out using refractive secondary optics, which theoretically promised to increase the acceptance angle of CPV modules. Currently the efficiency of pilot production module is preserved and the module acceptance angle has

been increased. The use of a very low cost moulded secondary ensures the economic viability.

Isofoton in cooperation with UPM has analysed the performance of suitable materials for refractive secondary optics. Transparent silicones have been the materials checked. The samples (domes shaped coupled to cells) have been measured indoors and are currently aged in real operation under 500X for 1cm² cells.

The RESET Technology, developed by Isofoton within the FULLSPECTRUM Project has been tested under the IEC62108 Qualification Standard, as scheduled, before going to manufacturing. While prototypes of this technology demonstrated high efficiency, these tests uncovered weaknesses in several components. Therefore Isofoton, according the scheduled plan in NACIR, has re-designed the module in order to preserve efficiency, gain, acceptance angle and performance with a more reliable technology.

New CPV Module

UPM is developing the new concentrator FLUIDREFLEX, which uses a fluid as optical index material, as heat exchanger, as insulator, and finally for preventing water condensation inside the module.

The properties of the optical materials have been characterised in order to know how they will perform under the double duty of optical transmission and thermal transport. These data have fed into a 3D finite elements thermal model which may be used to predict operational temperatures.

Direct diamond turning cut prototype mirrors and later injected plastic mirrors have been fabricated.

The initial measurements yielded 78% optical efficiency, and +/- 1.2° acceptance angle at 800X. Currently 83% has been measured, which overpasses the 80% objective. Three journal papers and 7 presentations in Conferences on this topic have been generated, always receiving remarkable interest. Several module prototypes have been fabricated and tested. Laboratory made ones demonstrate that the upper limit for manual assembly procedures yields an overall 27% efficiency. The automation will surely increase that value allowing to reach 31.5% with the commercial cells 40% efficient. Soitec is collaborating to these developments by providing cells for the prototypes.

Final results and potential impacts

Along the project, Soitec has improved its module and system technologies. From Generation 2 available at the beginning of the project they are currently industrialising Gen5. The Soitec arrays have demonstrated more than 25% energy efficiency due to the efficient modules and to highly reliable tracking system mainly in the Egyptian hard environment. The stand alone application of CPV's has been demonstrated and a potential market has been opened in the Middle East. From other side, Soitec has developed and checked a two optical stages module at pilot line level, which could be put in manufacturing if it becomes economically suitable. These facts will assure a leading position to Soitec in this field. In a different ambit, the impact of the Egyptian CPV installation is outstanding, both due to the high performance of the systems and the social-economic impact of the application. In addition the great diffusion of that work by TV broadcasting (Euronews) is also

creating interest in Africa's developing countries for similar applications.

The other Company in the project, Isofoton, has renewed its module technology and adapted its automated manufacturing capability to the new one which has passed the IEC62108 qualification. The vertical integration of many components in the new module will relocate the company in its pioneering position in CPV.

The impact of the Morocco installation will come from the operation of CPV systems at very high altitude and the interferences from the grid. Still political and economic impacts are foreseen thanks to the project and the relationship with the national utility ONE. for this project along next year.

ISFOC is contributing to improve the difficult task for recording and exploiting real data in CPV power plants located in the associated countries. They are becoming the most powerful institution exploiting CPV data and their results will impact the understanding of the CPV power plant production, operation and rating. The software for performance analysis of CPV generators and developed applications at ISFOC, called GOCPV, will allow understanding of CPV operation and provide effective maintenance control.

Finally the development of the very innovative Fluidreflex CPV module is achieving the expected results. In principal, 83% optical efficiency has been achieved and several prototype modules have been completed and tested. The promise of very low cost, lower than the best CPV's is still credible because no problems have arisen yet.

Project Results:

4.1.3 Description of the main Scientific and Technical Results/foregrounds.

4.1.3.1 Scope of the Project

Project NACIR intended answering one of the objectives of the European Commission expressed in the Seventh Framework Programme (FP7) Call for Proposals on Energy by 2008. It was oriented to reinforce a.s.a.p. the reliability of Concentrator Photovoltaic Systems (CPV) by means on experiences and developments for new applications. The second aim, linked to the previous one, was to spread and disseminate the European CPV technology en the Mediterranean associated countries. The combination of these two objectives suggested identifying valuable applications for these countries which were suitable for stressing the operation of CPV systems in the hard natural conditions of that region. The experiment should, probably, accelerate the analysis and improvement of CPV systems reliability.

In addition, the call did not forget to stimulate the technological progress of current CPV thorough inventions and novelties as well as promoting the improvement of manufacturing efficiency of state of the art concentrator modules.

This assembly of objectives determined the composition of the consortium. The two principal European Companies in CPV (Soitec Solar and Isofotón) both with commercial products and manufacturing capacity assured the execution of real applications. Their staffs were prepared for learning and improving their products and competitiveness through the project experiments.

In parallel to the companies two research centres Fraunhofer and Universidad Politecnica de Madrid, with long experience in CPV will participate supporting the invention and evaluation of new products and the fundamentals of the new applications.

The most advanced Mediterranean countries, Morocco and Egypt were the Associated Countries selected because their previous activities and interest on CPV were known by the Coordinator and partners. They are the Organisation National d'Electricité and National Water Research Centre respectively.

A project like this should generate a large amount of information which is necessary to record and exploit for reaching conclusions about reliability in short time: the ISFOC was viewed as the best partner thanks to its experience on field rating of many CPV technologies and because the possibility for adding the value of the Spanish administration investment in this centre to favour the knowledge at European level. A summary of the objectives, activities and results follows.

4.1.3.2. The new applications of CPV in Mediterranean countries.

4.1.3.2 A Stand alone CPV plant for water pumping and irrigation at Wadi el Natroon (Egypt)

The life in Egypt has been linked to the water availability from millennia. Their engineers have the highest know how and experience for managing that scarce resource: In their interest for widening the cultivable area, transforming the desert into productive land, they tried every possible method for extracting the water from the deep aquifers

under the sands. They are acquainted how expensive, tiring, noising and requiring are the diesel generators which usually power the electrical well pumps. The National Water Research Centre installed photovoltaics under their initiative twenty years ago looking for a noiseless and reliable source of electricity.

With the NACIR project the opportunity for updating their old PV field with the most effective PV technology, and joining a set centres and companies experts on PV systems, become an exciting option for every partner. It would allow modernising the experimental irrigation station at Wadi-el-Natroon, renewing the PV generators and reinforcing the socially interesting project for cropping in the desert.

In consequence, the worldwide first concentrating photovoltaic (CPV) stand-alone system with 30 kWp was installed by Soitec Solar at the test site of the National Water Research Center (NWRC) in the desert at Wadi-el-Natroon in Egypt within the NACIR project. The CPV system provides electric power for water pumping, desalination and irrigation applications.

At Fraunhofer an energy management system (EMS) was developed for monitoring all energy flows and calculating an optimized load management to support the direct use of solar energy by the loads. Thus the system requires only small sized battery storage to secure power supply only for measurement and control equipment.

Another highlight of the NACIR project is the development of the standardized CANopen communication protocol (application profile CiA 454) to realize the control algorithm and to enable an easy expansion of the system. This all helped to successfully install the first CPV island system worldwide.

All components of an energy supply system like PV chargers, battery management systems, loads etc. are able to communicate in a standardized way if they comply with this profile specification. Thus a communication infrastructure is available allowing a seamless integration of new components and communicability of different manufacturers' components. Furthermore, the goal is to achieve plug and play options so that new system components are automatically configured and integrated into the energy management system. This new invented application profile is now working reliably in the field.

The EMS allows the operation of controllable loads like water pumps, desalination units or air conditioners with direct use of solar energy. The EMS consists of three modules one prognosis module, one optimization module and a system control module.

We were searching for a general optimization algorithm which can manage many loads to support the future plug and play ability of the CANopen infrastructure. The Field operation of the NACIR system shows: direct use of PV power for saving expensive battery storage capacity is possible. Storing water instead of energy is a good way to reduce off-grid system costs. If there is enough power the well pump brings water up to the reservoir, depending on the irrigation timetable the irrigation pump starts and stops, taking the water out of the reservoir. To solve this optimization problem a genetic algorithm was developed. The solution of the known "packing-problem" was transferred to off-grid systems. The

system in Wadi El Natroon proves that there are no technical barriers for using CPV in Island grids.

Paying now more attention to the CPV generator components of the Egypt site it is important to point out several highlights achieved in the project execution. The CPV power plant consisted of 5 two axis tracking arrays each 5kW nominal power equipped with FLATCON 2nd generation CPV Modules.

One key achievement was the successful integration of the CPV systems into a harsh desert environment. With a distinguish preparation of the system components of the CPV System, e.g. tracking structure, inverters, cabinets, the complete system was shown to be desert proof. No single environment related hardware issue during the complete project period can be seen as good measure to distinguish these result. Another result, also showing the good preparation for harsh environments, was the uptime record on the complete installation. This showed similar results compared to the uptime results of all our other installations e.g. in Spain or USA.

The power plant has really served the objective of feeding, in stand alone mode, the needs of the irrigation plant, cropping and fresh water supply, and generate data for the improvement of the reliability and better knowledge of CPV power plant operating characteristics. ISFOC contributed recording data and presenting them in a comprehensive way.

4.1.3.2 B The grid connected CPV power station at Ifrane (Morocco)

The NACIR installation at Al Akhawayn University (AUI) was completed by ISOFOTON by October 26th, 2010 and connected to the grid of ONE by the end of the same year. The power plant consist of 3 two axis tracking arrays,equipped with "TIR ISOFOTON CPV modules".

The electrical configuration of the power plant consist of 6 subarrays, two per tracker. Each sub array is conecteed to one single phase inverters. The power is distributed to the three phases of the grid 220/380V.

The connection to the grid of the partner ONE has been carried out following the current Spanish normative for grid connection. Also the connection follows the local security protocols. This subject has promoted a significant interchange of information in this field with the Morocco partner.

Isofoton has learnt about exportation and transportation of CPV plant components material to the site, as well as identifying local providers which will serve to future busines. The majority of actions of relevance in the station have been covered by Isofoton staff moving from Malaga to Ifrane. This allowed acumulative formation of the local staff.

The monitoring of the plant operation and the testing of local meteo parameters were already active in 2011, provided by ISFOC and allowed for access by the implied project members.

The localisation of the plant at the English speaking International Al Akhawayn University (AUI), contributes to the project thanks to the cooperation of its scientific staff. This College level education centre is the best suited for knowing and understanding the European CPV expertise and also the most adecuate for irradiate and disseminate this

technology to the Morocco society and decision makers. This effect has been widely reached as it will be presented later in Dissemination achievements paragraph.

The environmental conditions at Ifrane, located at 1700 m. above sea level, plus the hard winter and summer conditions, allowed to accelerate the experience on reliability and performance analysis for CPV industry. The site has been used for observing effects of soiling, abrasion, and discoloration of components by placing several samples outdoor which are periodically analysed by local researches at AUI, in cooperation with UPM.

Maintenance incidences

Several incidences occurred along 2011 due to meteorological, grid effects and wrong operator actions during 2011 which forced to replace mechanical elements and several inverters. The protection against over voltage was interfied.

During the second semester 2012 the only problem registered at DC level (this is: modules and grid overvoltage protection) was a failure of electrical insulation of a module: it was substituted. The most frequent problem was due to WIFI communication connection.

The hard conditions of the site and the instability of the grid at ifrane required several visits of Al Akhawayn University researchers from the department of information technology systems and from the ground and maintenance services. They solved the data transfer communication and electrical connection problems, respectively.

One overall cleaning operation was performed by AUI personnel in mid July 2012.

The tracker is the element with more relative (percent) incidences. Most of them are simply solved resetting the system. On the other hand, some mechanical problems were observed in the elevation drive of the tracker. The hard winds recorded, over 100 km/hour, were, probably, the cause of this mechanical failure.

The rule is that the tracker problem remains as the most significant when the assembly of all failures are reduced. The last incidence breakdown plot is similar to the one found in other power plants. The CPV modules, as happened with flat plate modules, were the most reliable elements of the plant.

Lessons learnt and principal actions carried out after the system installation

Much valuable information has been collected with respect to system incidences. The analysis of these incidences has led, on one hand, to some improvements in the tracker, and on the other, to apply the experience in the design of the new Isofoton's tracker. This company will continue carrying out experiments in the NACIR site after the end of the project. This is an excellent perspective for the project partners that will continue taking value from the CPV realization.

i) Improvements in the current system

Some improvements have already been implemented while others are scheduled for implementation in 2013: Elevation drive and mechanical

reference sensor are changed: Position of limiting sensor for elevation modified; better encoder fixture.

ii) Solutions adopted in the new system

In the new tracker, all these aspects have been addressed since the conception phase. It has been designed to focus on reliability and minimum maintenance. The concept is completely different, with hydraulic drives replacing electromechanical ones and a dramatic reduction in the number of sensors:

- To control de motion, there is only one absolute sensor with no moving part. No limit switches, no reference sensors (4 limit switches + 2 reference sensors + 2 incremental encoders are replaced by 1 sensor).
- There is only 1 motor driver and no electromechanical drives (2 AC motors + 2 AC drivers + 2 electromechanical drives replaced by 1 hydraulic motor + 1 AC driver + 2 hydraulic linear actuators).

This way, many of the potential incidences are not possible any longer. The fact that there are many less sensors also decreases the probability of failure. In addition, it has much smaller area and also smaller weight density. This decreases the drives load and hence the possibility of overloads in the drive electronics.

The experience has shown that Ifrane is an excellent site for testing CPV system and components, reliability due to its rather aggressive weather conditions. The occurred incidences in the site have led to new solutions aimed to improve the system reliability.

As a result, Isofotón will continue using the site as a test installation of its new technology.

4.1.3.3. CPV Database Experiences, materials, technology and operation

ISFOC is the biggest laboratory in the world for performing field testing of CPV Power Plants in order to support the industrialization of CPV. Currently ISFOC has installed in its facilities up to 1.1 MW of 3 different technologies, with different versions of their products, connected to the grid since 2008. Recently have put into operation additional 1.2MW from other four technologies.

One responsibility of ISFOC in NACIR project has been the creation of a database of worldwide CPV experiences and results of its own tests. Currently, the information contained in the database is covering more than 4 years of operation in the field of power plants from different manufacturers as well as long term measurements of solar resource. The actions at ISFOC allow early detection of failure or degradation modes in any technology and is used as feedback by all CPV community. In the framework of this project ISFOC has developed a management and information system, called GOCPV is focused in the analysis and dissemination of results obtained from the long term operation of CPV plants.

Furthermore, it is important to keep in mind that the ISFOC CPV Plants were installed during 2007 and 2008, becoming the first field for demonstration in the world, using early technology.

The next analysis shows the evolution in time of the averaged energy generated by one CPV Plant (100kW) under averaged irradiance level. This important plot can be also used for unveil a change o degradation of performance.

The difference in the slopes of the regression lines, which better fit the data of each year, should represent the difference or evolution in performance. Comparing the slopes of years 2009 and 2012, it is obtained that the energy generation of the plant has been reduced by a 2% during the four years of operation.

So small variation suggests that there was not any significant loss of power nor degradation with the mature technology available after 2009. The diminution observed in the energy generation during three years is quite small, similar to the one found in conventional PV modules.

Moreover, some conclusions relating the usefulness of the IEC qualification normative to prevent the commercialization of not reliable CPV modules have been obtained along the project. The degradation of a power plant which modules did not adopt the corrections suggested by the IEC 62108 tests showed 13% degradation in 4 years with respect to the same technology with modifications adopted to pass the qualification tests.

ISFOC has been in charge of monitoring the operation of the NACIR stations in Morocco and Egypt. The data have been the first registered in especial location, new for CPVs. The lessons learnt indicates that remote monitoring must rely on the cooperation of the local operators, this is the partner ONE and his associated University (AUI) at Ifrane.

Five partners of the project are active members of the IEC-TC82, the international organization responsible of the PV standardization. In this frame the experience and results obtained in the project are crucial for the development of CPV standards. The Power Rating, indoor and outdoor, of CPV modules and the rating of large CPV plants at STC are contributions of NACIR to creation of CPV normative. UPM is also responsible for the definition of solar simulator characteristics for CPV modules.

The forecast of the energy production expected from CPV power plant has required the thermal characterization of the modules arrays including simpler methods for defining the module temperature (CNOCT: Concentrator Normal Operating Cell Temperature) and monitoring the performance with respect to the spectral distribution of the light (using Tri-band Heliometers). It has been shown that reliable results are obtained if the valid testing conditions are limited to high irradiation levels and mild ambient temperatures. These research activities have been covered by the long term thermal characterization of CPV modules and systems and the solar spectrum recording network carried both under this project in collaboration between ISFOC, IES-UPM and Fhg-ISE. It is observed that the values obtained present a linear trend, with some exceptions related to wind influence.

From that 'plot the module temperature at "Concentrator standard Operating Conditions" can be calculated The error in the determination of the module temperature is 2.5°C, what results in an uncertainty in the power determination of $\pm 0.4\%$.

Both, IES-UPM and Fhg-ISE have developed Tri-band Spectro-heliometer.

This equipment measures the equivalent direct normal irradiance for each component cell.

The IES-UPM Tri-Band Spectro-Heliometers are installed at ISFOC and IES-UPM in Spain and also at the locations of the project, Ifrane in Morocco and Wadi el Natrun Egypt. The Fraunhofer Tri-Band Spectro-Heliometers are installed at Fraunhofer in Germany and ISFOC in Spain.

It can be observed a big period around midday with blue rich spectrum where the middle component cell is limiting the current generation, and two red rich periods at the morning and at the evening where the current is limited by the top component cell. The matching points of both component cells are where the spectral distribution of the direct normal irradiance is equivalent to the reference spectrum AM1.5D.

Date 3j-DNI DNI

06/08/2011 -0.51% -5.25%

20/09/2011 2.98% 3.43%

13/10/2011 -0.52% 3.08%

09/01/2012 -0.47% 2.25%

13/02/2012 OUT OF THE STUDY

14/03/2012 -1.76% -3.52%

These results are being shared with the WG7 of the IEC-TC82 committee looking for the standardization of the rating methods for CPV technologies.

One significant task included in the NACIR project is the indoor round robin test performed with Soitec modules, a highlight without precedent in CPV. Eight modules have been measured at FhG ISE, were sent to Spain to IES UPM and ISFOC and sent back to FhG ISE. Measurements with indoor sun simulators for CPV modules were performed at each location. Comparatively large deviations were found, especially when different sensors were used for the determination of the irradiance level.

It could be also be demonstrated that deviations can be minimized when the same irradiance sensors are being used (see upside down triangle "ISE mono module"). In summary the main outcome of the round robin activities within NACIR are lessons learnt and recommendations for future CPV module round robins, which rules are currently under preparation.

The main recommendations are:

- define the irradiance sensor - if possible also include a mono-module as part of the shipment
- take temperature of the primary optics into account
- include isotype/component cells in the activity for monitoring the spectrum

4.1.3.4: Technology development: improvement of modules, manufacturing, new products and testing requirements.

4.1.3.4.A Technological development for improving current performance of FLATCON module at Fraunhofer and SOITEC SOLAR.

Further work topic at FhG ISE was the support in the development of silicone on glass CPV modules with secondary optical elements (SOE). The work within NACIR was focussing on refractive secondary optics and there especially on manufacturing issues. Typically SOEs are positioned on the solar cell assembly, i.e. a CPV cell bonded to a carrier. The positioning of refractive SOEs however can correspond to a challenge especially for vision systems that are used for identifying optimum positioning of the SOE and also for the positioning of the solar cell assembly with SOE on

the bottom plate. Hence an alternative approach was investigated within the NACIR project. Here the idea was to directly cast the SOE onto the solar cell assembly. At FhG ISE a prototype for the proof of concept has been realized where a single SOE can be casted directly onto one solar cell assembly.

After successful demonstration of direct casting of silicone SOEs onto solar cell assemblies and analysis of test modules the technology has been transferred to full size Soitec modules. The working principle of the prototype was not directly transferred to Soitec in order to avoid the necessity of positioning of solar cell assemblies with SOEs. Thus a method for direct casting of SOEs on fully assembled bottom plates was developed. The principle idea is to have metal plate with the same number of moulds as solar cells on the bottom plate. The moulds are filled with silicone and the bottom plate - with mounted solar cell assemblies is put upside down onto this metal plate. The method has been demonstrated successfully at Soitec.

Soitec was involved in two key aspects of the project. The first one was the development of a new module generation with a secondary optics. The second one was the setup of the first stand alone CPV system in the desert.

Module development at Soitec

The well proven CPV modules of Soitec Solar, was originated from the FLATCON module technology, very simple and compact, made at Fraunhofer-ISE. It consists of two rectangular parallel glass sheets closed by stainless steel perimeter walls. The top side glass, facing the sunrays, is a Fresnel lens made with the called Silicone on Glass (SoG) moulding process.

The lenses concentrate the light on small MJ solar cells, each mounted on an individual square metallic spreader, which is glued on the bottom glass.

The thermal conductivity of glass and the small size of cells are sufficient for reaching a convenient dissipation of heat.

The chromatic aberration associated to refractive concentrators limits the available concentration level of this module solution. Soitec has reached a good compromise between sufficient light concentration, moderate acceptance angle and excellent tracking accuracy. The SOITEC power plants have demonstrated yearly top energy efficiency in the field.

However the possibility for improving the module characteristics, this is more concentration and wider acceptance angle, is a significant target to investigate at SOITEC. The research on this subject became one Work Package in NACIR project.

From the beginning of the project a new CPV module design using a secondary optics has been developed. The following goals were defined in the project layout.

Target Result achieved

Geometrical concentration of 1000x With the new module design, with secondary, optics a geometrical concentration of 820x was achieved

Acceptance angle $\pm 0.9^\circ$ With the additional optical concentration an acceptance angle of $\pm 0.53^\circ$ was achieved

In order to cost effectively integrate the secondary optic an overall cost-optimized redesign of the module was necessary in order to reduce the part count per watt.

The following improvements have been additionally included:

- Primary lens area increased by factor of 2
- Increase of concentration level of the primary optic to 460X
- Better utilization of solar cell wafers
- Change of heat sink and module frame bulk metal for cost reduction

This module design has been certified and put into production.

Another important foreground is the progress made in understanding of the silicone-on-glass Fresnel lens. A new Fresnel lens design has been developed, that reduces the dependence of optical efficiency on lens temperature and the performance peak has been moved to the desired value of 35-40°C.

The new module design was used as basis for the secondary integration. Silicone optics are used and directly molded on bottom plate, allowing for very low cost.

The concentration ratio has been increased to 820X at an acceptance angle of $\pm 0.53^\circ$. It was shown that this design is UV proof by exposing one prototype to sun for 1.5 years. All other climate chamber tests according to the IEC certification have been successfully passed. The process has been transferred to pilot production. The efficiency of the module with secondary optics has reached 28.4% compared to a module efficiency of 25% at the beginning of the project.

The progress made during this project has led to a production capacity increase from 25 to 70 MWp/a for the Freiburg production site. Soitec has secured its position in the CPV sector and has become the world-leading company. New markets in the Mediterranean region, South Africa and the US have been entered. This success has led to expanding the production to the US with the build of a 280 MWp/a factory.

4.1.3.4.B. Technological development at Isofoton

The technological work at ISOFOTON has been focused in the design of a new generation module, its qualification and to prepare/modify the manufacturing line for reaching quality and high throughput with this new CPV module. The tests carried out at UPM have helped to optimize the design and provide accurate specifications in STC and SOC.

New module

A new design of RESET module has been carried out in order to upgrade the former RESET_Ver01 module in power efficiency, less water and humidity penetration and reduced UV degradation: The reduction of the number of components per unit of energy was the target orienting the new design.

Six highly efficient MJ triple junction solar cells, shunted each by a Schottky diode, are used in these concentration modules. Concentration module RESET_Ver02 is based on two step optics: Primary element is an acrylic square Fresnel lens which focuses light directly to the entry surface of the SOE, consisting of a glass prism.

Production line and Improved throughput

Isofoton is a pioneer company producing CPV modules. In consequence, it owns a large variety of manufacturing machines, like die bonder, pick and place, fluid dispenser or rack storing for manufacturing the first generation of Isofotón CPV module (RESET_Ver01). All this equipment needed to be modified for being adapted to the new RESET_Ver02 technology. The efforts for carrying out this plan and reach high throughput is the aim of Isofoton in this section of NACIR.

The mentioned and many others machines need such adaptation for using them with the new module version.

The drastic variation of cell area, from 1,32mm² in Ver01 to 1cm², affects many steps of the production line: the modifications affect the following equipment:

Cell bonding- New curing oven

This oven model is able to maintain vacuum while controlling temperature and nitrogen concentration in order to obtain an optimum soldering.

- Pick and Place machine: It was adapted to new size and shape of receivers.

- Die bonder: It is a two steps machine. The first step consist picking the solar cells chip from the wafer expensor, Then dispense a solder paste over the substrate and place each solar cell onto the corresponding pcb that will be assembled to the module. The second stage is used to make the wire bonding between the solar cells and the PCB.

- Receivers sorter: It makes possible to test each receiver before sealing the module housing. The modifications have been significant because the large variation of the cell output power, from mA range to 5 A.

- Silicone dispenser for module sealing and top glass placing
This machine automatically covers the final steps of the assembling process increasing the production rate The main steps performed here are: back plate alignment, silicone dispensing for frontal and back covers of the housing and frontal lens parquet.

This machine has been recently installed in our facilities and is working properly after the corresponding set up and configuration.

- Module tester and sorter: The automatic system for module measurements "SAMMOD" consists of an electronic rack with the corresponding voltage source, electronic charge, control PC, a double face module-holding system and a flashing light system consisting in a controlled flash light and a parabolic mirror to collimate the light onto the modules.

Throughput and production results:

The current production capability of our factory has achieved the 2000 modules per month, and it could be improved as to achieve maximum of 4000 units' month by just adding replicas of some of the available machines. These values are equivalent to a production 2-4 MW/year. Two installations based on the new modules have been recently installed: One in Golmud (China) and the other one in Sicily (Italy). These are result of the development inside NACIR and an evidence of the degree of confidence reached which the new generation of modules. The Chinese installation is located in the desert Tibetan plateau, characterized by high radiation and low temperatures consist of 8 trackers.

The installation of Italy is also a 100kW one but requires only 7 trackers of a new type. The radiation and temperature conditions of this location are less extreme but assure 1800kWh/m². per year

Modules Characterization at UPM

The Partner UPM, at IES has developed a deep study on our RESET_Ver02 module looking for its optimization and characterization. The analysis was developed not only with complete modules of our production line but also with individual elements as a necessary step towards optimization of the optical subsystem.

Experimental setup

The measurements were performed indoors and outdoors. For the indoor measures the CPV solar simulator UPM-Helios 3198 was employed. Collimation and spectrum are well controlled: in addition the UPM can operate this test locating a single optical element inside a thermal cabinet which allows testing at any temperature. The optimization of a CPV module was carried checking out experimentally the variation of the focal distance with temperature, the maximum power vs. with the focal length, the short circuit current vs. the spectrum across the optics and finally the efficiency with the DNI level. The outdoor measurements of modules were carried out continuously on a tracking system with 0.1 degree accuracy. The result of the optimization and measurements yield the following specifications at 850 W/m², AM1.5D, 25°C.

Table C2.1 RESET_Ver02 module specifications: Optical and electrical main characteristics at 850 W/m², AM1.5D, 25°C

Focal distance 253 mm Cell active area 1 cm²

Primary lens side 240 mm Peak power (P_m) @ 85 W

Geometric concentration 570 X Open circuit voltage (V_{oc}) 17 V

N° of receivers 6 Short circuit current (I_{sc}) 5,5 A

Optimization techniques based on indoor tests.

The results of extensive and intensive measurements at UPM has allowed to generate the plot which defines the optimal focal distance at each lens operating temperature, which is a key for the efficient use of the SOG primary optics. This technique is a must for the optimization of the CPV modules based on SOG lens concentrators.

The other key dependence of this concentration technology is related to the radiation spectrum. The triple junction solar cells are designed for a standard spectrum AM1.5 D. But the optics and the meteorology modifies that spectrum during normal operation of CPV systems. The definition of Equivalent Spectrum and the parameter SMR have been improved and consolidated during NACIR at UPM, ISOFOTON and Fraunhofer. SMR becomes higher than 1 for bluish spectrum and less than 1 for reddish ones.

Outdoor measurements

Outdoor tests along a large period provide the best information about the expected energy generation.

The data were collected at 5 minutes interval without filtering with respect to ambient temperature nor spectrum. However, the results are not too disperse, just +/- 4%. From other side the objective of efficiency proposed in the project has been reached as 24% at STC. The goal is satisfied and demonstrated moreover when this is a randomly chosen module of our production, not the best we have manufactured.

In addition to this result, the continuous testing outdoor has provided the variation of Voc with the ambient temperature, which is an useful parameter for refining any energy forecast. The obtained value is $V_{oc}(T) = -0,0235 \text{ mV}/^{\circ}\text{C}$ for the module which corresponds to $4\text{mV}/^{\circ}\text{C}$ per cell.

4.1.3.4.C. Development of a new Concept for CPV modules - Fluidreflex- at UPM.

Introduction and Scope

The technological activity of UPM in NACIR has been devoted to the development up to pre-industrial module level of a new PV concentrator concept. This novel concentrator concept consists of a single reflective stage immersed in an optical fluid. The presence of the fluid entails significant advantages. Not only it allows a high system optical efficiency and increases the attainable concentration but it also enhances the heat dissipation from the cell. In addition, the electrical insulation is improved and simplified and the problem of water vapour condensation inside the module is avoided. Among the experimental results, it stands out a measured optical efficiency of 83.5% for a concentration of 1035X. The full development and verification of the initial premises and the development of a pre-industrial prototype are the tasks carried out in the project.

Description of the new concept and its advantages

The new concentrator, named FluidReflex, is based on a single optical stage immersed in a dielectric fluid. Previous experiences at low concentration ratios using optical fluids were carried out at the IES-UPM with successful results but, to the knowledge of the authors, this is the first attempt to used fluids benefits in a high concentration module. The FluidReflex elementary unit consists of a parabolic mirror which acts also as the rear face of the module, a high efficiency MJ solar cell placed in its focus at the inner side of a transparent front face and the dielectric fluid filling the volume between the mirror and the front face. Square elementary units are placed in a grid, composing an array of elements that constitute the module.

FluidReflex uses only reflective optics to concentrate light, avoiding the limit in concentration caused by chromatic aberration in refractive systems. When using a single mirror the solar cell must be placed between the sun and the optics, so if a cooling element were added next to the cell it would cast shadow reducing the system efficiency. An common solution to this problem is to add a secondary mirror to redirect light through a hole in the primary mirror to a solar cell on the back surface of the module. The drawback of this configuration, known as Cassegrain, arises from the fact that the light is now reflected twice and, as reflection is not ideal, light losses become more significant and optical efficiency decreases. On the contrary, in FluidReflex concept, the fluid presence improves the thermal management within the module avoiding the need of external cooling fins and enabling the use of a single reflective stage. Moreover, the fluid enhances the optical efficiency by reducing Fresnel losses in several interfaces and it increases the concentration-acceptance angle product as it is explained in detail later.

The heat concentrated in the solar cell is transported to the module walls by convection (natural or forced) and conduction in the fluid.

From other side the water condensation inside the module is impossible because the Fluid fills the internal space. In addition, once the fluid

has been proven to be harmless to the cell and the rest of the module components it acts as an encapsulate protecting the components inside the module from degradation.

Verification of the Fluidreflex suitability for reaching the objectives
Optical characterization of the elementary unit

Several elementary unit prototypes were built to measure FluidReflex optical performance. They were composed of the same circular parabolic mirror (58 mm in diameter) manufactured by diamond turning and cells with different sizes obtaining different concentration ratios.

For the best-performing elementary-unit prototype an optical efficiency of 83.5% at 1035X was measured. Furthermore, efficiencies higher than 80% were measured for concentration ratios up to 1500X. According to that and the cell state of the art a total CPV system conversion efficiency of higher than 31.5% is predicted.

Angular transmission curves at different concentrations were measured illuminating the concentrator with collimated light using the Helios 3198 solar simulator which allows the accurate deviation of the concentrator from the incident light beam.

Additionally, cell positioning tolerances have been determined as part of this optical analysis because the required assembly accuracy will have a large influence on the trade-off between module performance and assembly costs. The system lose 10% power output when the cell is displaced ± 0.6 mm from ideal XY position or ± 0.4 mm in X Z direction, at 584X. It is clear from these results that the FluidReflex concept will require relatively high assembly accuracy, though well within the level achievable with robotic placement tools

About the fluid

The presence of a dielectric fluid is the major novelty of the new concentrator so its optical performance was studied. Transmittances of many fluid candidates were measured from 350-1700 nm for a 5 nm interval. Due to its low cost, reliability and high transmittance, paraffin oil seems one of the best candidates. A consideration when designing a fluid-filled concentrator is related to the refractive index variation across the fluid when temperature is not uniform. A non-homogeneous refractive index bends rays from their original design paths and enlarges the spot size reducing attainable concentration. The results of modelling were experimentally confirmed by observing the evolution of the normalized optical efficiency, and the solar cell temperature, when the FluidReflex prototype is measured outdoors.

The normalized optical efficiency remains almost constant during the time period in which the cell and the fluid temperature significantly vary.

About AR Coating optimization

When designing the ARC over the solar cell several important aspects were considered. First, the angular distribution of light over the MJ solar cell was taken into account. In this case, FluidReflex compact design illuminates the cell with a wide-angle ($\pm 65^\circ$) cone of light.

Manufacturing of concentrating optics

Prototype mirrors for FluidReflex concentrator were manufactured by plastic injection as this is a promising low cost technology that may, in a future, enable the fabrication of the complete module rear wall (including the array of parabolas) in a single injection. Later, the injected pieces were mirrored by evaporating aluminium or silver. Silver is preferred for its major reflectivity but is unstable in contact with air.

In FluidReflex modules silver mirrors are immersed in a fluid so, once it has been proven to be innocuous, the fluid may avoid the mirror corrosion showing an extra benefit from its presence. The long term reliability is currently under study. Regarding adherence both materials showed a good behaviour when evaporated over PMMA.

The reflectance measurements were made with the samples surrounded by air. However, in FluidReflex concentrator mirrors will be surrounded by a fluid whose refractive index is higher than one. Therefore, a decrease in reflectance of approximately 2 absolute points is expected for both materials when they are immersed in fluid.

About Plastic injection for Fluidreflex optics

Plastic injection is considered a very promising technological option for CPV manufacturing by several reasons. If sufficient optical quality is attained this process could translate into a significant cost benefit compared to, for example, glass mirrors. More importantly, it may be possible to fabricate the FluidReflex whole module rear wall by a single injection in which all the parabolas are simultaneously obtained. EE is defined as the amount of total energy contained in a circle of a certain radius. The three injected mirrors samples show a very similar curve to the EE of the spot casted by a diamond turning machined mirror, differences being within the experimental error. The machined mirror can be considered as the highest attainable optical quality so consequently, the injected mirrors show a high optical quality with a low cost. For all the injected mirror samples measured, 90% of the energy is contained in a spot with 1.4 mm diameter.

Superimposed EE predicted by ray-tracing simulation with solar simulator ($\pm 0.4^\circ$) and real sun ($\pm 0.265^\circ$) collimation angles. The differences between the machined mirror and the injected piece which seems to perform better are within the experimental error.

The spot casted by each mirror is photographed using a CCD camera. The light of each mirror is cast inside each cell, although some deviation is observed.

The parabolic mirror casts a non-uniform irradiance profile over the cell, which worsens the cell performance as compared to uniform illumination. Unlike refractive concentrators, reflective ones produce the same spectral distribution throughout the cell, thus avoiding additional losses due to spectral non-uniformities. The masks method described in detail in previous works by UPM has been applied to estimate cell-efficiency worsening due to non-uniform illumination. The measurements indicate that, for two out of the three manufacturers analyzed, MJ solar cell technology losses due to non-uniformity are in the range of the experimental error (± 2) for uniformity factors as low as.

Prototype modules

Many prototypes have been made and tested. The alignment of the mirrors and the cells has been a very difficult task while made by manual procedures. However we have reached 26.6 % efficiency modules with cells 35-36% efficient using just some aids to manual mounting. The precession with robots for cell positioning and the use of 40% cells assures 30-31 % module efficiency.

Conclusions and future research lines

An extensive set of experimental results prove that there is no fundamental reason that prevents the practical realization of the concept. The high optical performances predicted by theory were shown to be attainable in practice. In particular a high optical efficiency of 83.5% at 1035X was measured simultaneously to a $\pm 0.92^\circ$ acceptance angle. Since this new concept seems very promising as a means to obtain cheap photovoltaic electricity, future work will be directed towards translating the concept into an entire module. In addition, accelerated degradation experiments must be carried out to guarantee the long term reliability of the materials, or their combinations, that have never being used in photovoltaics before.

parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

Potential Impact:

4.1.4. Potential impact, dissemination activities and exploitation of results.

4.1.4 1. About potential impact

The Project has already demonstrated an evident impact in the areas of new applications of CPV, development of testing methods for concentrators, creation of normative and technological development, according to the objectives stated in the EU call and in the Grant Agreement.

The work developed in Egypt is the one with clearer socio-economic impact. From one side it is the first stand-alone CPV power plant, which in addition has the double aim of checking the performance in desert areas and simultaneously to develop an irrigation plant absolutely based on PV solar energy.

The experience of the Egypt partner, the NWRC in capture of underground water wells, pumping from deep water level, desalination storage and irrigation has allow to achieve demonstration level results just with the execution of a pure R&D work.

The new application has required more dedicated work than provided from Fraunhofer in order to optimize an ambitious management of CPV energy at the irrigation and fresh water supply station.

The Wadi El Natroon stand-alone power plant is operating as an island AC grid. This allows operating the site with conventional AC loads combining simultaneously Diesel generators, windmills, etc. in the same grid. The station is an example not only for CPV but also for PV in the region. The professional execution of the whole system and the good orientation of the project was documented and spread, at worldwide level, with the documentary "The Photovoltaic Oasis" produced by Euronews channel.

With the results obtained here, Soitec has verified and confirmed the high reliability of this system and unveil the sources of failure in desert areas. Now Soitec is ready for the occupation of the niche of activity related with the crop irrigation and fresh water supply.

The interchange of information with local partner has been significant and very positive for all parts. The keys for operating in the Middle East markets are currently better known thank to the cooperation with NWRC.

Along the four years of the project, Soitec Solar (formerly Concentrix Solar) has passed technically from modules Gen 2 to Gen 5. From the commercial and industrial points of view, passed from producing few MW to hundreds of MW per year, becoming the number one CPV company.

The cooperation between NWRC (Egypt), Fraunhofer and Soitec has been so satisfactory that the company will continue developing work at the station of Wadi el Natroon after the end of the project. Such decision should increase the opportunities for the spreading of the NACIR results in the region.

In conclusion, we can say that the new application has found solid base and is going to solve real needs. The technology is ready for electricity generation (Soitec), energy management (Fraunhofer) and water supply engineering (NWRC).

Isofoton, the other manufacturing company involved in NACIR is a pioneer in CPV. The company was born manufacturing bifacial cells, previously developed for concentrators. Its research and development activities in concentration have been continuous from the 90's.

A Call for Proposals aiming to promote the CPV technology at worldwide level was opened by ISFOC funded by Central Spanish Administration, Isofoton and Soitec applied and were awarded with the compulsory and stimulating conditions for starting a real production of more than 300kW. Isofoton started a real production for installing a 400kW Power plant in Puertollano (Spain).

Isofotón has been exporting up to 60 countries from its foundation in 1981.

The opportunity for exploring the performance and reliability of its CPV system in remote areas defined its role in NACIR.

A combination of circumstances suggested Morocco as the ideal partner due to the stability of this Country and because the Kingdom is planning and executing large PV electrification as well as expensive experiments in renewable (solar thermal electricity) and wind.

The partnership was established necessarily with the only utility in Morocco; ONE (Organisation National d'Electricite) who become ready for share the CPV experience and rules for grid connection. Although the grid connection is not a "new application", the particularities of the grid, the remote site, the climate, the need for remote control under week communications became the task a true challenge and novelty. In addition, for compensating the experiment in the sands and glazy sky of Egypt, in Morocco was selected a high altitude site (1.700 m. altitude), with extreme low temperature, wind and high radiation (+high UV)

In addition to the lessons learnt about exportation and logistics in North Africa the continuity of power injection in the grid has been a challenge due to grid instability and lack of protection for the long power line in a region with frequent lightning.

The continuity of communications has been also difficult to maintain resulting in response slower than expected.

The ONE invited the International Al Akhawayn University (AUI) for contributing to the project providing location, support and infrastructure as well as researching attitude and capacity.

The presence of the University in NACIR opened educational and disseminating opportunities. With respect to education, the course about CPV management to the researcher and engineer technical staff given by Isofotón paved the way for improving the cooperation and the resolution of small problems during operation.

The UPM has the opportunity for presenting a short course to the AVI students and professors.

In addition the influence of NACIR has induced the creation of a MASTER in "management and economics of new energies" which will be directed, in

principal, to future decision makers in Morocco and other African countries, because the high prestige of this Anglophone University.

And last, but not the least, the proposal of NACIR management board for organizing a Workshop at AUI (Ifrane) with occasion of the semester meeting on January 2012 become a reality exceeding all imagined,. It became an open Conference called RETEM 2012, which joined very relevant Morocco authorities, from the National Research centers, from Ministries of Industry and Science, and the Director of MASEM, which is the center contracting and installing renewable energies at multi-megawatt levels, etc.

In addition, scientist of Morocco Universities presented their works sharing the sessions with the NACIR partner leaders and other invited speakers.

Isofotón has learned about the tracker defects early unveiled in the conditions of Ifrane, where it has withstood snowing, lighting and winds over 100 Km/h. The feedback from the extreme conditions of the two sites in North Africa (Mediterranean) was one objective of the project

The power plant of 30 KW peak, as rated by the partner ISFOC, after the grid problems and internal failures were identified the system is injecting regularly the grid.

Additional education and scientific contribution of the AUI consisted of the analysis of the CPV module materials evolution under the high UV content of the irradiance at 1700 m. and about the freezing conditions found in winter.

The lessons learn by Isofotón with the installation at Ifrane have decided, as did Soitec in Egypt, to continue using the site installing new generation modules in order to take advantage of the "accelerating" conditions of operation in the ONE-AUI site.

The need for normative and techniques for rating the CPV power, testing components, defining standards and forecasting energy production determined the second block of activity in the project.

The commercial activity requires standards for the mutual protection of manufacturers and customers in economic, business, safety, financial risks, etc.

Conventional PV took 25 years for creating a quasi complete normative around IEC-TC82 Committees.

The CPV technology, in some aspects more complicated than conventional PV, must demonstrate to the market its reliability based on consistent standard assuring energy generation for reaching the necessary bankability.

In such task, several partners of the project are fully and directly involved writing and developing testing programs on module power rating, field testing, solar simulators for CPV and energy production forecast.

For contributing to this line of activity, the first round robin of CPV modules has been carried out in the project.

Secondly, it has been demonstrated the consistence for relating the output power of modules and systems to the available irradiance separated into spectral bands coincident with the absorption of the used MJ cells.

UPM and Fraunhofer developed separately tri-band spectral heliometers. A network registering spectral irradiance in Freiburg, Madrid, Puertollano, Ifrane and Egypt are registered.

After the Tri-band technology developed in NACIR has been transferred to a company there are 10 additional sensor around the world (included NREL) which suggest a possible increase of the spectral network in the near future

ISFOC has prepared the data management system called GOCPV, which generates reports from the data obtained from the NACIR sites, recorded by different equipment (from Soitec, NWRC, Fraunhofer, Isofotón, UPM) in any site. The harmonization of data system and recording rate has been solved at ISFOC.

The CPV database stored in ISFOC is the world most valuable because includes data from seven different technologies in power fields of significant size.

Among such series is important to point out that the degradation CPV systems installed in Puertollano, all made with early generation of modules and trackers is practically negligible, similar to conventional PV plants. This is a conclusion of principal socio-economic information for the progress of CPV, which has become a technology led by Europeans.

The third block of activity in NACIR is devoted to technological progress of the principal components of CPV industry, the modules and de BOS, which is a key for cost reduction and assured performance.

Soitec has industrialized the FLATCOM technology defined by Fraunhofer. They have work together in NACIR for exploring several ways for improving the efficiency and optical performance of current (by 2008) modules.

The FLATCON module technology is one on the most simple, both in number of elements and materials. It uses Silicone on Glass Fresnel lens technology and Multi-Junction cells mounted on simple metallic substrates, which are glued to a back module substrate, also made of glass.

The use of just one refractive optical step provides a low CAP (concentration x acceptance angle product) and consequently a very accurate tracker array and to trim the parallelism of modules mounted in a tracker platform.

Although this one significant difficult Soitec has solved reasonably the problems derived from the low CAP.

The immediate technical solution is to use two-stage optics, but the preserving reliability simplicity and low cost of the module is not immediate. The efficiency cannot be degraded and the new modules must pass the hard IEC62108 qualification test to assume credible reliability.

Fraunhofer and Soitec have solved the inclusion of a secondary in a brilliant way with a solution which did not reduce efficiency and passed the IECG2108.

A pilot manufacturing has been developed conforming that Soitec has already an alternative module with higher CAP. The evolution of the MJ cell prices will recommend adopting the two-stage optics module of just to increase the size of cells looking for better acceptance angle at constant CAP.

Also after the inclusion of the secondary optics (SOE) the Soitec module is the most simple all CPV market.

In parallel to the adoption of a secondary optics, the appreciable problems associated with the dependence of the SoG Fresnel lens with temperature have become negligible modifying the manufacturing process for better adaptation to module operating temperature in the field.

Soitec was using modules of Generation 2 at the beginning of the project but commercializing today Generation 5. This is a demonstration of the fast learning curve promised by CPV technology in its beginning.

Soitec has been celebrated and received several prices for its innovation and industrial developments. SOITEC took the opportunity offered by the ISFOC call for consolidating its manufacturing technology and field deployment expertise. It continued with NACIR.

Isofotón was a world pioneer using GaAs solar cells into high gain concentrators using the ultra compact TIR technology. Later TIR optics has been used with MJ cells of very small size.

The NACIR project has contributed directly to the continuity of the CPV line in Isofotón, due to the opportunity of the grant negotiation with the change of company owners in 2008: TIR technology needed to be substituted because it was not the best suited for the new MJ cells and the new prices of module components.

Isofotón has carried out in NACIR the development of a new module with larger cells (100 cm²) and consequently larger focal distance.

The principal effort has been devoted, not only on the module design, but also to adaptation of manufacturing capability and instruments to the new size and two-stage optics architecture. This was already provided in the proposal and included as main tasks in the Grant Agreement.

The new module uses the state of the art cells and Fresnel lenses made of SoG with a pyramid glass secondary.

This classic configuration has achieved 24-25% efficiency in the first prototypes while the manufacturing line is ready for 2-4 MW throughputs.

NACIR has restored the confidence of Isofotón headquarters on CPV and the deployment of two demonstration installations, in China and Italy, are positive pre-commercial steps based on the new module developed within the NACIR project.

The adoption of a new tracker, with less expensive components and true reduced cost is reinforcing the return of Isofotón to the CPV world market again.

The visibility obtained with NACIR has contributed to gain such confidence. As stated in the project proposal in 2007, Soitec and Isofotón are still the two leading CPV European companies.

Finally, the technological activity in NACIR has supported the development of a new concentrator module based on reflexive optics at UPM.

The mirrors, which operate with the simplest optical principle, reflection, combine the highest concentration level within compact focal distances. In addition, reflectors do not cause chromatic aberration, which still improves their comparison with lenses.

However the practical solutions adopted classically, present in the current market are made of two mirrors, with a glass sheet in the top, with secondary, insulating cell on carrier and supporting water condensation inside.

UPM decided to eliminate all problems affecting the reflexive CPV modules, using an old experience of the Instituto de Energía Solar who used a fluid as optical element and heat remover.

The called Fluidreflex technology was proposed promising to give 1000X, 1.2° acceptance angle, less than 80°C cell operating temperature and module efficiency at the state of the art using MJ cells.

The space between the mirror and the cell must be filled with a transparent insulating, stable head conductive and low cost liquid which will carry the heat from the cell to the front and back module surfaces.

Although on the paper the proposal looks excellent, the task scheduled in NACIR was to prove that achieving all required characteristics is possible and compatible with long-term operation, reliability, high efficiency and cost.

As can be seen in previous reports all steps have been demonstrated and the technical solutions achieved, with several Fluidreflex prototypes assembled and tested indoor and outdoor.

Prototypes are passing the IEC 62108 qualification test.

Two patents have been issued. High level of dissemination has been carried out on Fluidreflex with five conferences and three papers in SCI journals.

Conversations with companies are already in course in order to start a pilot line and deploy a demonstration.

This work has contributed to high-level education of young scientists with the preparation of their thesis.

It is a case of success from the theoretical "revolutionary" proposal of a CPV structure to a real operating module.

4.1.4 2. About dissemination of NACIR Project activities and achievements

The dissemination of the whole project has been above average, and circumstantially had the opportunity to be presented to more than 80 press agents at the Shanghai Expo 2011 as the "only" European PV project included in the "Europe-China Technical Week". We can combine the satisfaction for the high dissemination with the pride of representing world leading PV European science and industry.

The dissemination will continue presenting results at the PV conferences and writing articles not only in scientific journals but also in industrial magazines. The patents issued will be also object of publicity.

4.1.4.3. About Exploitation plans.

The new generation of Soitec modules is already in commercial exploitation at MW level.

Isofoton is commercializing its new module and tracker.

ISFOC is offering consulting on field-testing and software for Data exploitation.

UPM has transferred the technology of the Tri-band heliometers to a company for industrialization and commercialization (seven equipments are already sold).

The Fluidreflex technology and achievements are currently offered to a couple of companies for starting a demo program.

List of Websites:

<http://www.ies.upm.es>