FIELD TEST RESULTS OF THE ARCHIMEDES PHOTOVOLTAIC V-TROUGH CONCENTRATOR SYSTEM

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ABSTRACT: A new photovoltaic concentrator system with passive tracking has been developed and tested (EU Joule III Project ARCHIMEDES). It is based upon irradiation enhancement in the module plane by flat plate mirrors in V-trough configuration and elimination of losses from off axis incidence using a maintenance free solar tracking unit, the thermohydraulic actuator (THA). The new ARCHIMEDES system is designed for highly efficient and long term reliable water pumping and can offer up to more than 40% cost advantages compared to conventional fixed flat plate systems. Prototypes are installed since summer 2000 in Germany, Spain and on Crete. The field test results confirm the concept. Effective concentration factors of more than 1.8X are reached under clear sky conditions. The operation temperature is comparable to conventional non concentrating systems. An annual energy harvest of 3000 – 3500 kWh_{dc} per installed kW_p can be reached for Southern Europe.
Keywords: Concentrator – 1: Tracking – 2: PV Pumping - 3

1. INTRODUCTION:

PV V-trough concentrator systems with passive tracking for medium to large central power stations have been developed and demonstrated formerly [1-4]. The ARCHIMEDES project exploits now passive tracking and V-trough concentration also for small decentralised systems, as PV pumping, through a modular and integrated design of the PV receiver.

In contrast to PV concepts with higher concentration, the ARCHIMEDES system can use standard one sun technology.

Structural and tracking requirements are relaxed due to the high acceptance angle of the V-trough concentrator and allow thermohydraulic passive tracking. Therefore the ARCHIMEDES system can fulfill all requirements for low cost series production and reliable long term system operation.

The ARCHIMEDES project included the development of system components, manufacturing of prototypes and subsequent field tests. Two systems are installed in Widderstall, Germany, one prototype operates with a pump and an inverter for irrigating orchards on Crete island, one prototype is tested in Madrid, Spain, in combination with different pump technologies.

This presentation describes the concept and the realisation, discusses the field test results and gives performance estimations for the application of the ARCHIMEDES system in different climatic regions.

2. THE ARCHIMEDES CONCEPT:

- Heat dissipation needs to be managed in order to avoid decreasing system performance due to excessive cell temperatures under concentration.
- A tracking accuracy of about ± 3 deg is sufficient for V-trough concentration.
- The V-trough geometry is equivalent to 2X geometrical concentration which implies that half of the aperture area is covered with PV modules.
- The effective concentration is a little lower than 2X due to the imperfection of mirrors (reflection < 100%) and additional Fresnel reflection losses on the front glass of the PV-laminate from the higher incidence angles of the redirected sunlight (> 60°).
- The ARCHIMEDES system accepts direct and diffuse irradiance, but only the direct fraction is concentrated. Therefore the effective irradiation enhancement of the system is about 1.5X to 1.6X depending on the site specific fraction of direct solar irradiance.
- Polar-axis tracking in Europe increases the irradiance in the module plane of flat plate systems by a factor of 1.25 for Central Europe to 1.35 for South Europe depending on the fractions of direct and diffuse solar irradiance.
- In total the specific annual array yield (in kWh per installed kWp of PV modules) of ARCHIMEDES is about twice that of a conventional fixed tilted system. The actual value is expected between 1.8 and 2.2 depending on the annual diffuse irradiance portion.

3. ARCHIMEDES SYSTEM:

The V-trough collector has been designed as a modular system with separate elements. PV modules fit into the bottom of DELTA shaped profiles which are connected with the carrier frame and contribute to form a system with high mechanical stability. Thin glass mirrors with high reflectivity are glued onto the sides of the profiles. All rays reflected from the mirrors reach the solar cells embedded in the PV module (Fig. 1).

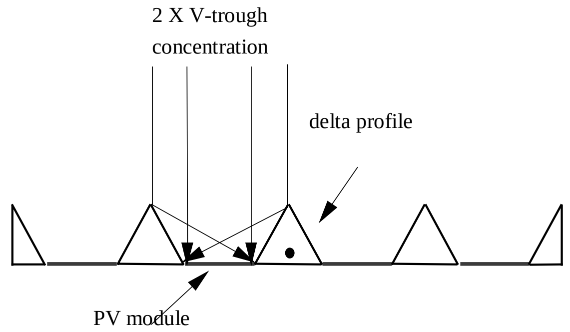

Fig. 1: Principle scheme of the ARCHIMEDES structure.

The dimensions of the V-trough array are determined by the required power and voltage level and the size and electrical parameters of the used photovoltaic cell technology . In the actual project the Saturn cell technology of BP Solar is used.

Shading losses for the front contact and bus bars of the Saturn cells are typically optimised for one sun irradiance. At 2X concentration the current is twice that of one sun operation and the power losses increase by a factor of four. By cutting the cell in half the current under concentration is identical to the current of a full size cell under one sun irradiance. Cutting the cell in half also benefits the efficiency of the device with a maximum at approximately two suns.

A single PV V-trough module (3.35 m length, approx. 252 mm width) is subdivided into 2 units each consisting of 25 half cells connected in series. In this way the voltage of the array can be adapted to the required level in 12.5 V steps. Ten rows of PV modules are combined to form the V-trough array with dimensions 3.47 m length, 2.65 m width (Fig. 2).

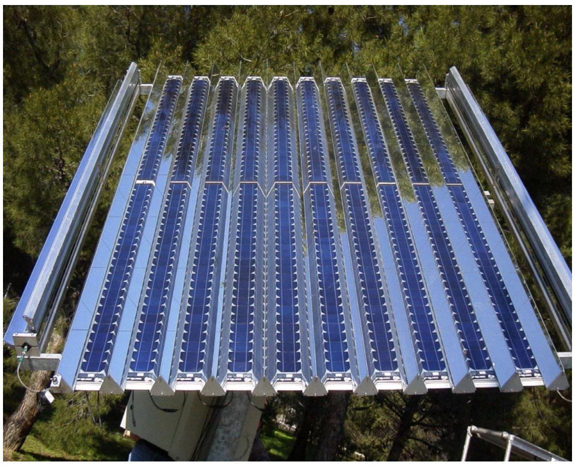

Fig. 2: Frontal view of the ARCHIMEDES concentrator tracking system.

The absorber tubes with the tracking reflectors of the passive thermohydraulic tracker are used as an integral part of the support structure and contribute to the mechanical stiffness of the array (see Fig. 2).

Increasing cell temperature reduces cell performance. In order to avoid excessive operation temperatures under concentration an aluminium back with fins was used to facilitate passive cooling (Fig. 3).

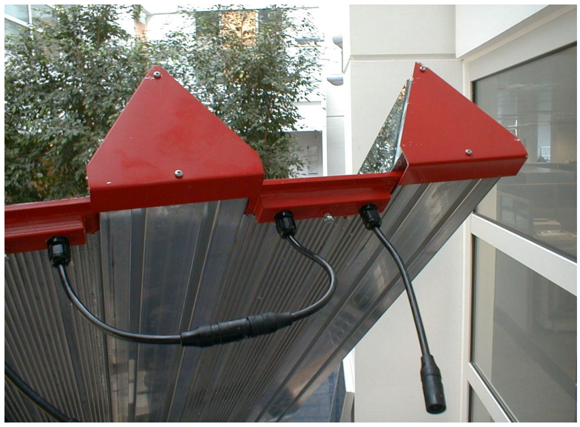

Fig. 3: Rear side of the ARCHIMEDES structure.

4. RESULTS:

A small plateau at about 1000 m altitude on Crete has been selected to test the ARCHIMEDES system in a typical user application. There are orchards and a few houses. The location is remote from utility grid and the pumped water covers needs for plant irrigation and drinking water supply.

For data acquisition a data logging and remote transmission system has been installed at the test site. All relevant meteorological data and the system data are continuously sampled in 20 sec. intervals and recorded as 10 minutes averages.

The ARCHIMEDES system has been installed in August 2000 (Fig. 4). The pumped water was immediately used for irrigating orchards at the test site.

Fig. 4: The ACHIMEDES concentrator after erection on Crete.

A thermohydraulic solar drive is used for solar tracking of the Archimedes PV-V-trough concentrator system. ZSW developed a sun sensing reflector unit for improved tracking accuracy.

Figure 5 shows the typical tracking behaviour on a sunny day with low wind velocity. Immediately after sun rise the system is oriented to the east position and locks to the sun's path within an error interval of less than ± 1°.

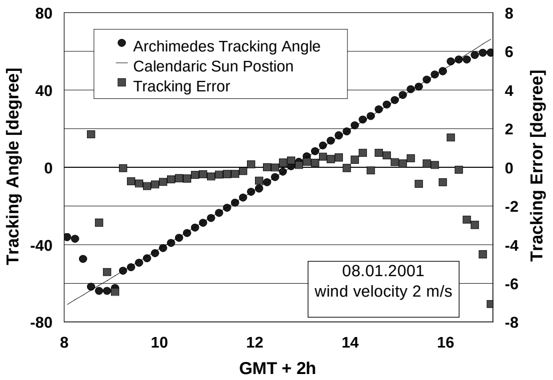

Fig. 5: Accuracy of the ACHIMEDES concentrator tracking system at wind speed of 2 m/s.

Even under higher wind load of around 8 m/s, the tracking accuracy remains in the order of ± 2° (see figure 6).

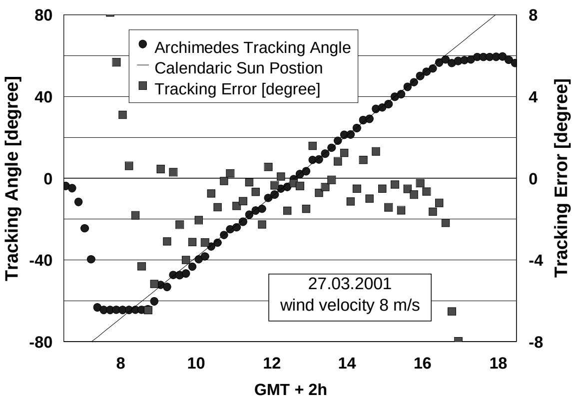

Fig. 6: Accuracy of the ARCHIMEDES concentrator tracking system at wind speed of 8 m/s.

Due to its high acceptance angle the V-trough concentrator is not sensitive to such small deviations from the ideal tracking angle. Therefore the systems operates with optimum performance for irradiance levels above 500 W/m².

On extreme days gusts of wind above 20 m/s can temporarily displace the array by 10° to 20°.

Figure 7 shows the irradiance profiles of two days in March 2001. The global horizontal irradiance has the typical sinusoidal profile of a fixed system. Solar tracking results in a nearly constant profile. This effect is of benefit especially for pumping systems with a certain threshold power level for the start of pumping.

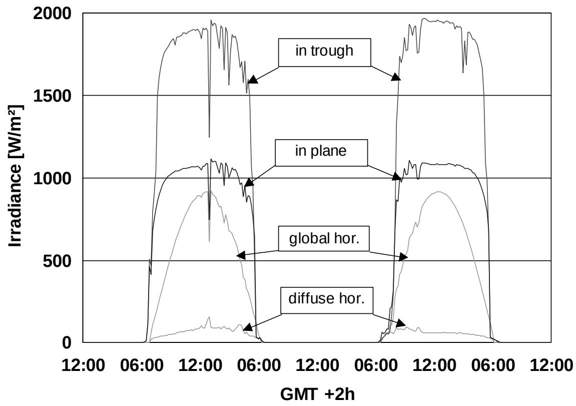

Fig. 7: Comparison of irradiations.

V-trough concentration boosts the in plane irradiance level by a factor of 1.6 to 1.9, dependent on the fraction of direct to diffuse radiation.

Despite of the enhanced irradiation level in the V-trough of nearly 2000 W/m², the excess temperature (module temperature – ambient temperature) is comparable to conventional fixed tilted system under one sun. This is mainly due to the aluminium cooling fins on the back tray of the module (see Fig. 3). Fig. 8 demonstrates the strong influence of wind velocity on this temperature effect.

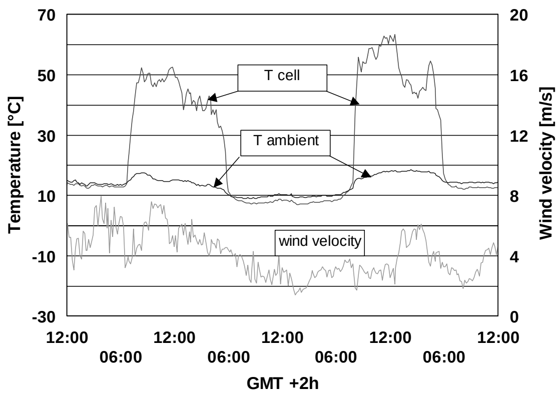

Fig. 8: ARCHIMEDES module temperature.

According to the constant irradiance profile also the dc-array power remains nearly constant and allows the pump to operate during the whole day at optimum power level (Fig. 9). So the typical losses of fixed tilted PV pumping systems after sun rise and before sun set can be avoided.

Fig. 9 shows the performance of a Grundfos (centrifugal) pump at an efficiency of around 27%. This pump technology has been compared with a positive displacement pump (Mono Pumps, Australia). Preliminary results of very recent measurements have demonstrated at least the same quantity of pumped water at half of the generator size. Therefore pump efficiency is expected to be well above 54%!

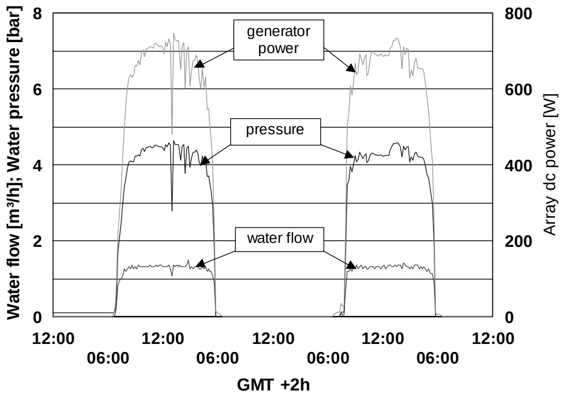

Fig. 9: ARCHIMEDES system performance.

5. EVALUATION

In order to determine the annual system performance for different climates, irradiance simulations have been performed for Central- and South-Europe on the basis of meteorological data from Widderstall and Livadi/Crete. The simulation program considers tracking as well as V-trough concentration. Therefore the in-plane irradiance and in-trough irradiance can be obtained with high precision.

Input parameters like optical efficiency (reflectivity), and the performance ratio of the pv generator have been determined and validated with the field test results. The results are summarised in figure 10.

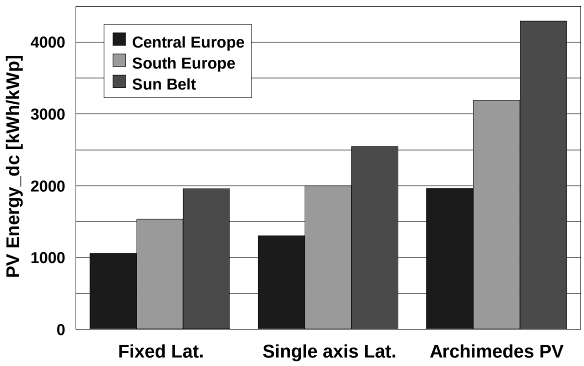

Fig. 10: Energy generation under various climates.

It turned out that tracking gives a surplus of 25% - 30% over fixed tilted systems, dependent on direct to diffuse fraction, as expected. V-trough concentration gives another surplus of 60% to 80% respectively. In total pole-axis tracking combined with V-trough concentration can rise the energy generation of conventional PV cell technology by 80% to 120%!

To turn energy gain into economic advantage certain boundary conditions for the area related system costs as structure, concentrator and tracker have to stay within certain margins. For this Archimedes PV concentrator system a cost estimate gave approx. 170 €/m² cost for the tracking structure, including V-trough and tracker.

Based on these assumptions the Archimedes concept will be up to 40% more cost effective than fixed tilted systems at todays module costs of approx. 3.5 €/W_p. Even at tomorrows module costs of 1 €/ W_p there will be a cost advantage of about 10% to 15%..

6. NEXT STEPS

Large scale demonstration for:

- Extended proof of concept
- Component design refinement
- Long time component testing under more extreme environments
- Investigation of the upscaling potential for larger systems

7. CONCLUSIONS

- Four Archimedes systems are sucessfully in operation in Germany, Greece and Spain
- Passive cooling of the PV module
- Thermohydraulic tracker accuracy 1°- 2° under clear sky condition
- PV array yield is 3000 - 3500 kWh/kWp with standard cells (in South Europe)

ACKNOWLEDGEMENT

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