Status of development of the dish/Stirling systems at Plataforma Solar de Almería

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Abstract:

During the last decade several prototypes of dish/Stirling system have been built and tested in Europe. Based on the SOLO V160/161 engine with a nominal power level of 9-10 kW these systems use either a stretched membrane concentrator or a resin reinforced fiber shell to concentrate the solar radiation and transfer the energy through a tubular receiver into the helium cycle of the engine. This paper describes the different development steps of the units tested at the Plataforma Solar de Almería in Spain, the experiences gained with the operation and maintenance and the test results during long year's tests with more than 35.000 hours of operation.

Introduction

Dish/Stirling systems for solar applications are characterized to be able to deliver electricity in a small scale, i.e. 10 kW up to a few MW. The actual available engine size on the market covers the range of 9-25 kW. Due to their modular layout they provide the capability to be grouped together to power parks, comparable to wind parks. They can either be used in grid-connected mode where they provide clean energy to the electricity grid or in remote applications to supply electric power for desalination, water pumping or rural electrification to help to develop regions where a lack of water and electrical power exists.

The development of the actual systems at PSA lead back to the early 1980´s when a 50 kW dish/Stirling systems was developed by Schlaich, Bergermann and Partner (SBP) that made use of the stretched membrane technology (2 prototypes in Riyadh, 1 unit in Lampoldshausen). These systems used thin stainless steel membranes (17m diameter, 0.5 mm thick) with a slightly evacuated space in between. The front membrane receives its paraboloidal shape by the vacuum and a pre-stressing process during manufacturing.
The Stirling engine used was a United Stirling 4-275 with hydrogen as a working fluid operated at 630°C and 150 bar pressure. The system reached 23% efficiency. For the commercialization of solar powered Stirling engines, SOLO Kleinmotoren (Germany) started in 1991 the manufacturing of a 9 kW Stirling engine based on the V160 concept of United Stirling (Sweden) under the license of SBP. It was the first time combined with a 7.5 m diameter stretched membrane dish at University Stuttgart, Germany for the proof of concept.

DISTAL I

After the successful tests three improved units were erected at the Plataforma Solar de Almería (Spain) in the DISTAL I project in 1992. The stretched membrane dishes of 7.5 m diameter (see Figure 1) consisted of 0.23 mm thin membranes welded and sealed to a 1.2 m high outer ring forming a drum. Thin glass mirrors of 0.9 mm thickness were glued onto the front membrane. A slight vacuum of 35 mbar kept the paraboloidal form. The dish was held in a biaxial tracking system that permits rotation at 15 degrees per hour about the polar axis and allowed the seasonal adjustment of +/- 23.5 degrees. The system was semi-automatic, i.e. the daily tracking was automatic but the mirror had to be start up and shut down manually. An operator was necessary to re-adjust the focal beam position occasionally.

Figure 1: DISTAL I with SOLO V 160

At a mirror reflectivity of 94% the concentrator reached an efficiency of 81%, as illustrated in Figure 2. The power conversion unit (PCU), i.e. a V160 Stirling engine, generator, cooling and Stirling control system, was placed at the focal length of 4.5 m. The Stirling efficiency including the receiver losses was 28 %. The overall system efficiency reached 19.5 %.

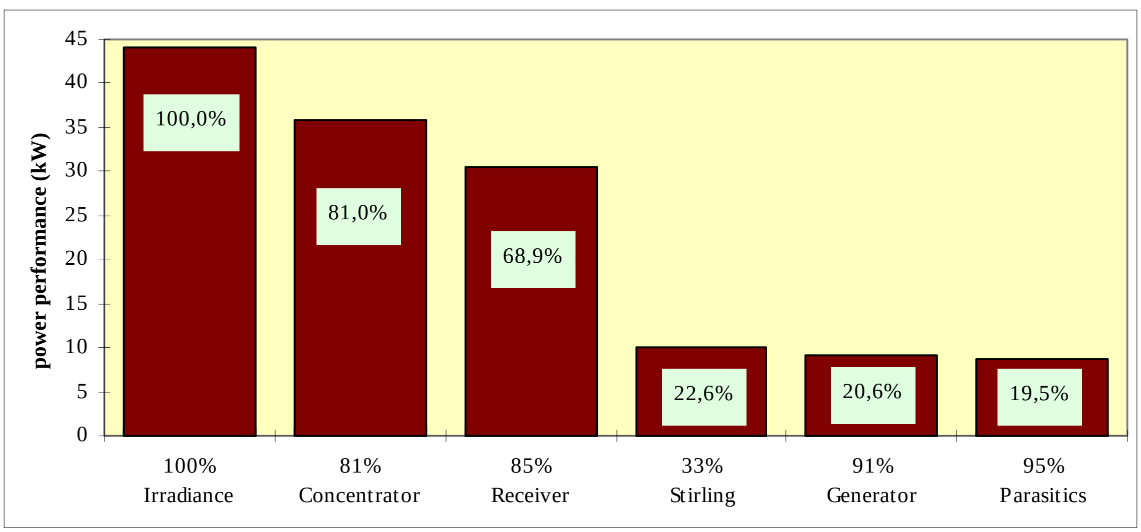

Figure 2: Performance of subcomponents of DISTAL I at 850 W/m²

The system starts generating electricity at the radiation level above 300 W/m². At the end of the DISTAL I project more than 30.000 hours of operation had been gathered. Figure 3 shows an overview over 5 years of operation between 1992 and 1996 [1,2].

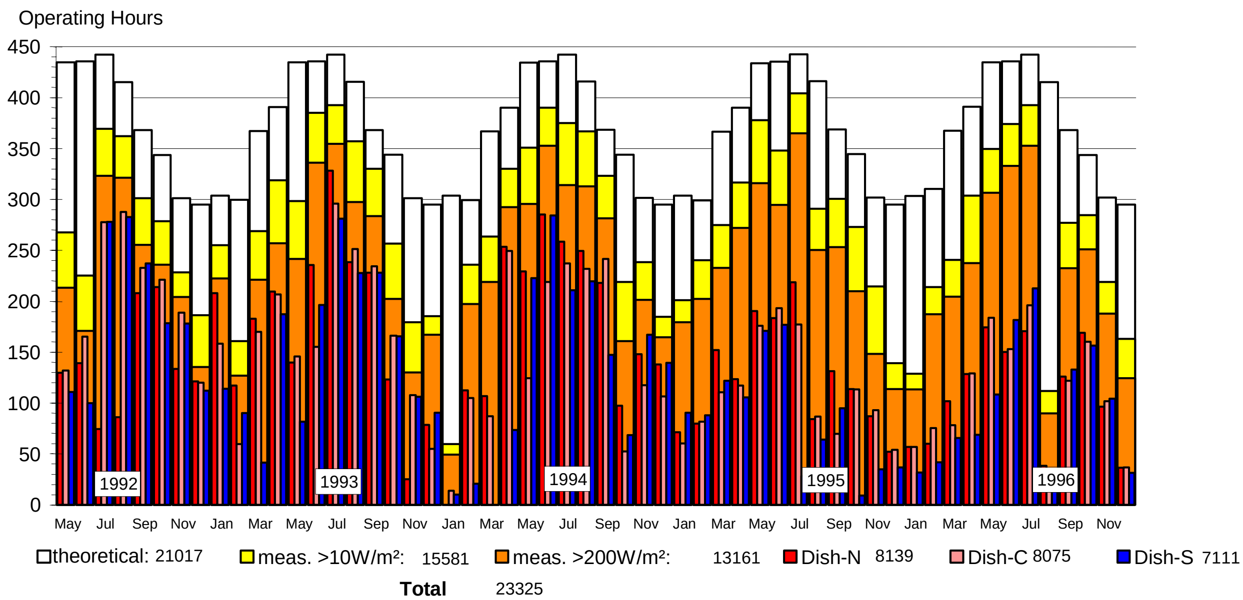

Figure 3: Operation summary of DISTAL I

At the end of the project a short test was conducted to change the heat transfer fluid from helium to hydrogen. It could be shown that the energy output could be increased by approximately 25 % due to the better thermodynamic behavior of hydrogen. But for security reasons in the handling of hydrogen this concept was not followed on.

Distal II

The major difference of DISTAL II to the former project is the modified tracking system and the increased concentrator size by approx. 25 %. Three 10 kW DISTAL II units were installed in 1996 at the PSA equipped with the SOLO V161 Stirling engine (Figure 4)[3].

To optimize the yearly electricity output the system is oversized during peak load at high insolations over 850 W/m² resulting in better system efficiencies during the majority of operation hours. To avoid over-temperatures during solar peak loads an electrically driven fan cools the receiver down to the temperature limit of 800 °C. This measure increases the number of full load hours by about 25 %. The polar axis tracking of DISTAL I was replaced by a fully automatic turntable concept. System tracking is achieved by using a central computer calculating the actual sun position and transferring these data by a digital field bus to the local drive system, i.e. the azimuth and elevation servo motors. This concept allows automatic system tracking of 16 units by one control PC.
The SOLO V161, a kinematic Stirling engine with a displacement volume of 160 cm³, is the successor of the V160 with a number of improvements, especially towards series production. It is operated at 650 °C helium gas temperature at 1500 rpm and 150 bar pressure. The nominal power level is 10 kW, the power control is managed by varying the mean working pressure.

The system is equipped with a grid connected asynchronous generator and has an emergency DC motor with a battery to shut it down in cases of grid failures.

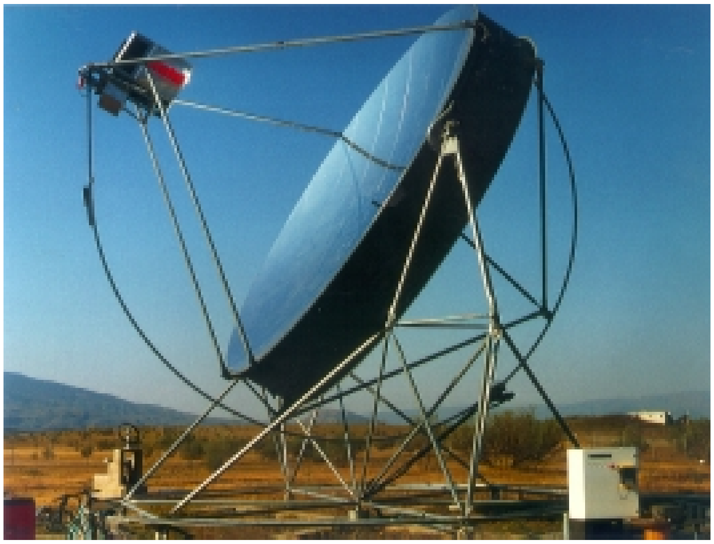

Figure 4: DISTAL II (South dish) with SOLO V 161

The normalized gross power output throughout a day is shown in Figure 5. The input/output characteristic can be seen in Figure 6.

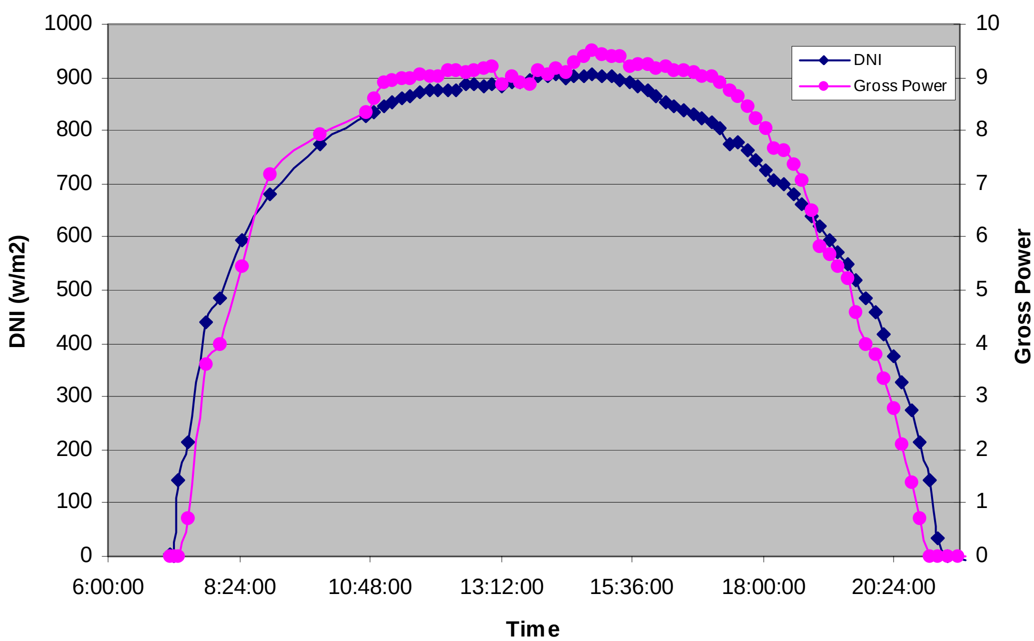

Figure 5: Normalized daily gross power at DISTAL II

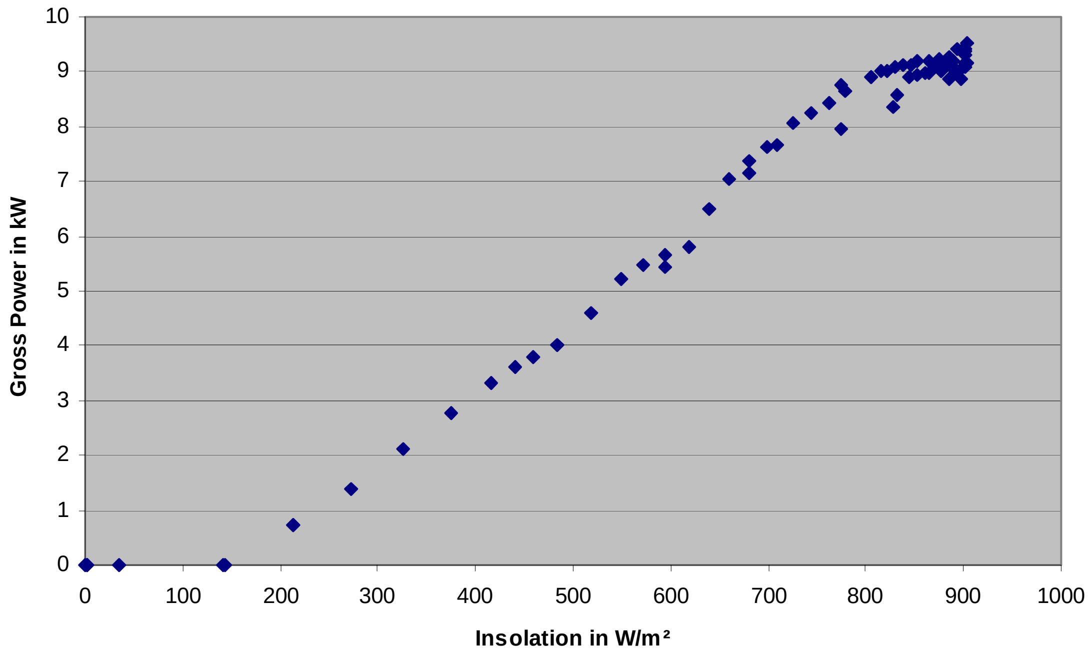

Figure 6: Gross power vs. insolation

Since DISTAL II is a solar only system that cannot meet the supply demand during the evening hours efforts had been made to hybridize the engine. Two projects follow this path to a future 24-hour supply. Both are conducted in the DISTAL II facility, which serves as a test bed for component test in the following mentioned projects.

Hyhpire

In 1998/1999 a hybrid receiver test was conducted with a sodium heat pipe receiver that allows reliable power generation independent of solar radiation. This receiver replaced the conventional tubular receiver and was equipped with a propane gas supply system. The heat pipe used conventional spot welded screen wick structures with arterial webs. Due to the very good heat transfer characteristics of the heat pipe, only a low temperature drop between heated surface and the engines helium was observed from the gas as well as from the solar heated side. Beside the receiver a low emission, high efficiency and high-density combustion system had been developed and the control system had been modified to allow for automatic power control between solar only, gas only and hybrid mode. The gross efficiencies for solar only operation were measured to be up to 18 %, in gas only mode up to 17% and in hybrid mode up to 16 % [4].

After finishing this project an alternative hybrid receiver development project has started at PSA making use of new developments in ceramic materials. The receiver will be made of carbon fiber reinforced SiC ceramics that has sufficient strength to resist the high helium pressure. Another advantage compared to metallic receivers is a better heat conductivity and a less thermal expansion leading to a better temperature distribution and less stresses. A similar test procedure as for the heat pipe will be applied to the ceramic receiver showing its performance in solar only, gas only and hybrid mode.

Eurodish

The EURODISH project had the goal to reduce the system costs evaluated after the DISTAL projects of approx. 11.000 € per kWe to 5500 € per kWe. Since the stretched membrane concentrator technology requires welding specialists and special tools for erection on site a potential decrease cost wise was expected by reviewing the type and composition of the concentrator. This lead to four different promising alternatives of which the design with one shell of resin reinforced plastics mounted on a ring truss showed the best performance/cost relation. The concentrator shell is composed of a sandwich of thin reinforced sheets with polyurethane foam in-between, having a total thickness of 22 mm. A reinforcement rib at the backside stiffens the shell during mounting and handling. The total weight is decreased to 1.8 tons (47 % reduction) compared to the stretched membrane design. The turntable concept of DISTAL II is generally maintained, but the drive system is significant cheaper in manufacturing. The control is realized through a digital field bus, which is tracking up to 16 units by an industrial PC that is located in the control cabinet. Remote access to data and control is implemented and the system is fully automated (see Figure7) [5].

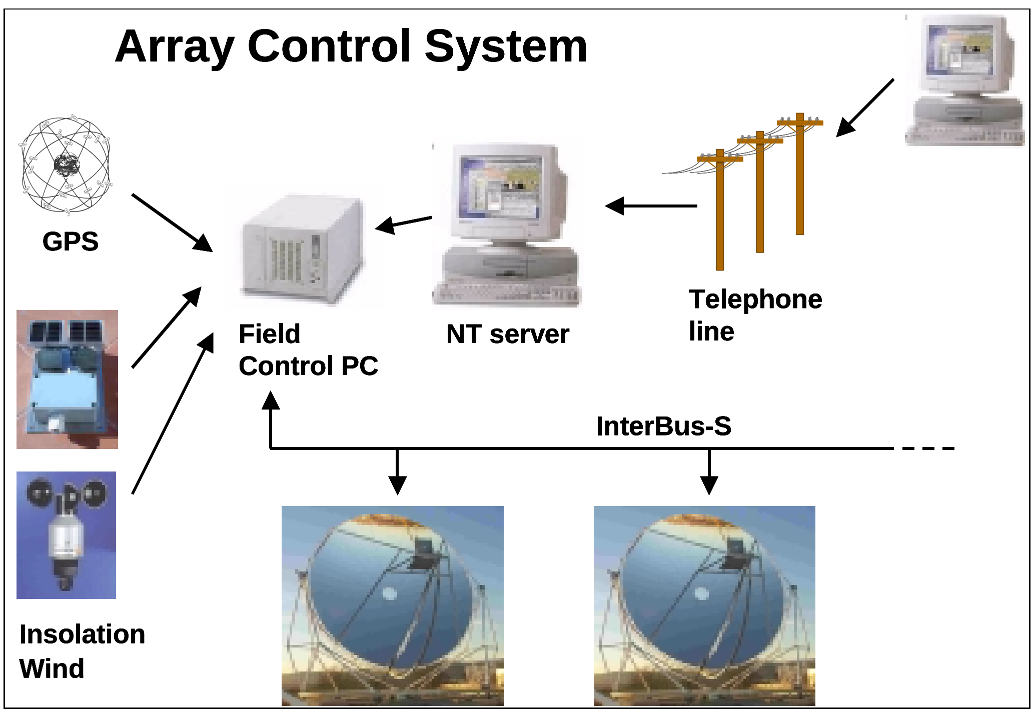

Figure 7: Schematic of control system

During the component tests more than 5000 operation hours were gathered on the engine components.
Two prototypes of the system were erected at the PSA between December 2000 and June 2001 (see Figures 8,9). During the erection process it was demonstrated that the mounting effort is reduced drastically compared to the stretched membrane concept. Preliminary test results during the first 300 hours of operation show a good system behavior, which will be reported shortly.

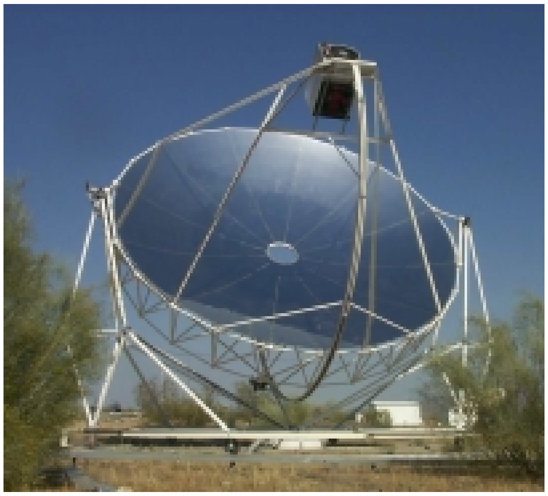 

Figure 8: Front and side view of the EURODISH system

 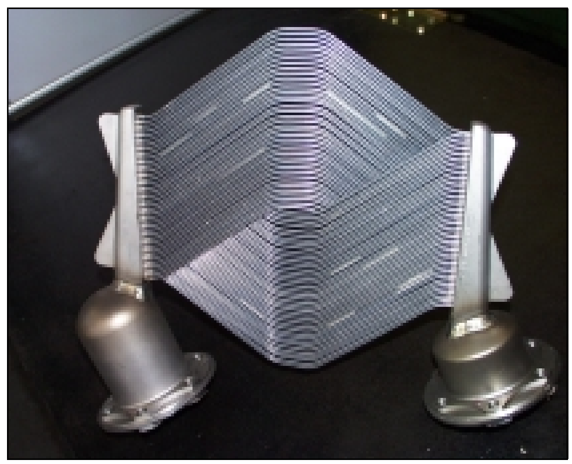

Figure 9: SOLO V161 Stirling engine (left) and metallic, tubular solar receiver (right)

Conclusions

Since the first setting up of dish/Stirling units at the Plataforma Solar de Almería in 1992 three generations of systems have been built and intensively tested. More than 35.000 operation hours on sun had been accomplished. The engine was since then significantly improved due to the gathered experience, mainly with respect to lifetime. The tubular metallic receiver stands several thousand hours. Two different hybrid dish/Stirling options had been or will soon be investigated. With the two new Eurodish prototypes and its technical maturity combined with the accomplished cost decrease a first market introduction is expected to start soon. A small series production, some minor component developments and a field test with the gathering of more operation and maintenance experience are now necessary to broaden the data basis and thus minimizing the risk for both manufacturer and customers with respect to reliability and liability.

ACKNOWLEDGEMENTS

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