The HelioFocus Large Dish Prototype

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Abstract

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HelioFocus is marketing modular solar thermal systems based on a large dish technology. On one of the company's applications, these shall provide high temperature steam to conventional power plants. Schlaich Bergermann und Partner (sbp) were commissioned to develop a large scale parabolic dish for this application. In 2008 a conceptual design study was carried out, by the beginning of 2010 the detailed design of the prototype started.

A large parabolic dish (500 m²) was designed with a solar heat exchanger (volumetric receiver) mounted at the focal point and a special heat transmission system. Via an air-to-steam heat exchanger, steam is generated to be fed into the cycle of a Combined Cycle or coal power plants.

The concentrator is a novel design with 219 mirror facets (1.5 x 1.5 m each) in a Fresnel-like arrangement on a flat supporting structure, bi-axially movable and suspended in a turn table (Fig. 1). The hydraulic drive system comprises innovative pilgrim step actuation and hydraulic accumulators for failsafe function without external power.

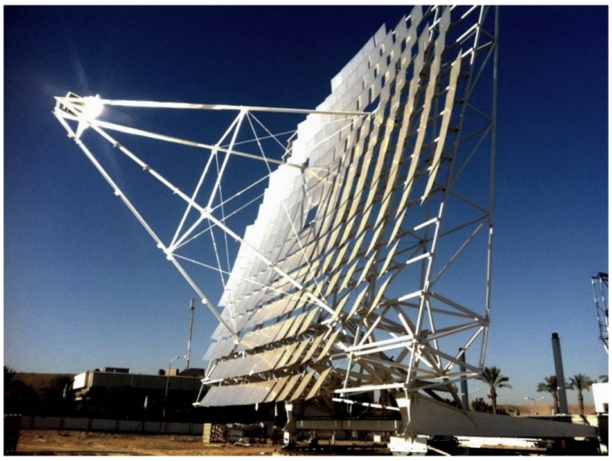

Fig. 1: Prototype dish in operation

1. Introduction

Combined Cycle Power plants upper cycle gas turbine efficiency decreases as a result of ambient temperature increase, with peak levels in summer time. The overall efficiency loss for the steam turbine can reach 10-20 %. Aside of the ability to put back the steam turbine into design point by adding solar generated steam, renewable portfolio standards (RPS) also give incentive to these plants worldwide. Coal plant regulations for pollutants (CO_2/SO_x etc…) emission reduction have turned to be a driving mechanism for solar boosting options as well. Solar steam in this case directly replaces coal burning, thus reducing emissions and yet keeping the same energy output. Per EPRI (Energy Power Research Institute, US, [1]), solar boosting is the lowest cost option for adding solar power to the generation fleet, down to <10c/kWh Levelized Cost of Electricity (LCOE) - a key motivation in setting HelioFocus development focus on such technology innovation.

As power plants with super-critical or ultra-super-critical steam turbines require very high temperatures and pressure (up to 620 °C) for energy feed-in, the know-how of volumetric receivers gained through research at HelioFocus formed one basis for developing a boosting system. Such high temperatures can be achieved only by point-focusing systems, i.e. with the central receiver technology or with dish concentrators. Even though the decentralized structure of a dish plant requires collecting energy from many concentrators, the dish technology was selected due its modularity and highest collecting efficiency.

The main tasks for setting up the new system on the process side consisted in further improving the receiver which was exclusively licensed from the Weizmann Institute of Science to HelioFocus in 2007 and working out the heat transfer system as well as the best feed-in solution for the conventional power plant. The other main job was to develop a suitable dish concentrator. Early investigations at HelioFocus, comprising total cost analysis, led to the conclusion that a large concentrator with approx. 500 m^2 is the way to go. Schlaich Bergermann und Partner were assigned for this mission due to their experiences in developing dish concentrators of different sizes and technologies since more than 25 years.

2. The dish

2.1 Conceptual design

A dish concentrator with a mirror surface of ~500 m^2 is clearly beyond the usual size range for this technology. In 2008, when the concept for the new dish was developed, the only existing design in this scale was the ANU 400 m^2 dish [2]. Such a concentrator, located in Sde. Boker, Israel, was used by HelioFocus for system testing purposes. The next large design is a membrane dish with 227 m^2, two units of which were built in Saudi Arabia in the mid 80s.

Thus there have been little examples for large dish concentrators and it was clear that concepts for smaller concentrators couldn't just be adopted. The size and boundary conditions demand a well adapted design that obviously would be different from the well known and proven solutions. Therefore conceptual design studies have been conducted in 2008 and 2009. A number of alternative structural concepts were investigated and evaluated.

A concentrator with the given size is subjected to the rule that structure mass increases more than proportional when scaling up. Besides of the height profile of wind speed in the atmospheric boundary layer, with velocity increasing with height, this is due to the fact that dead weight and wind forces go up linearly with increasing surface, but moments follow the cubed radius. On the other hand, large structures have a lower part count per m^2 and cost-effective hydraulic drives become attractive.

Post mounted solutions were ruled out from the beginning as the load and drive moments cannot be taken up efficiently by a post and associated drives. Therefore, all alternatives were based on a turn table.

In a valuation and down selection process, an unusual structural concept was finally decided upon. The concentrator is formed as a flat supporting structure with the mirror facets arranged in a Fresnel like way (Fig. 2). It is installed on a turn table with the elevation axis close to the concentrator's lower edge. This causes a large imbalance on one hand, resulting in high dead weight forces to be overcome by the elevation drive system. On the other hand it allows for a relatively low stow position (mirrors facing up) and for supporting the concentrator not at its outer rim but at 4 points along the elevation axis, which is very helpful for such a large span structure. The flat concentrator main structure can be made simpler and more economic than the common curved design.

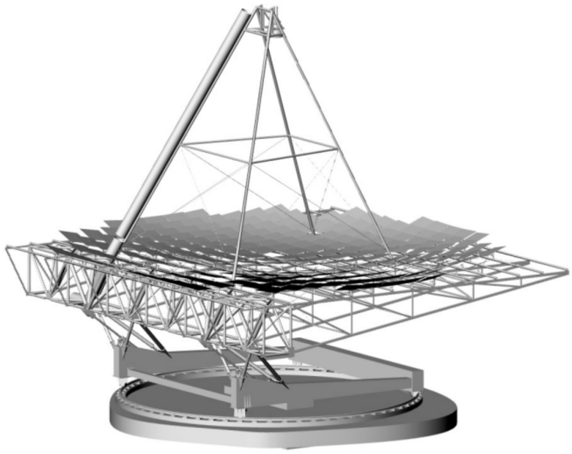

Fig. 2: Overview of dish structural design

2.2 Structural design

In the beginning of the project, a detailed design started, based on the selected concept.

The concentrator's overall dimensions are 26.5 x 25 m. It is a simple and stiff framework design from hollow profiles with a flat top face. The "backbone" of the concentrator is a rigid torque box along the lower edge of the concentrator. The receiver support is made up of four main beams with transverse and diagonal stiffening, transmitting the dead weight loads of the receiver, located at the focal plane above the mirrors, and the air pipe to the cantilever arms resp. the torque box.

The turntable main structure consists of two side beams, the front beam and the rear beam, the latter being used as a counterweight at the same time. The hollow box side beams are welded from plates, with the trunnion bearings for the elevation hydraulic cylinders integrated. They are partially open on the top side to allow the cylinders diving into them. Structural performance was calculated for a considerable number of load case combinations of dead weight and wind loads. Wind tunnel testing was performed to obtain precise wind loads for the global system as well as for the individual mirror facets.

For an economic structural design that also satisfies the optical performance needs, ray tracing analysis was carried out in parallel to the structure development. A well proven simulation tool, developed at sbp, was used for this analysis. Based on the deformed structure from the FEA under different load cases, the optics simulation delivered detailed data on intercepted power, losses for every facet etc.

2.3 Mirrors

~220 mirrors form the concentrator's reflective surface with an overall area of ~500 m². The Fresnel-like arrangement of the mirror facets results in gaps between the mirror rows when viewed from the top. The used facet pattern minimizes blocking effects on the reflected sunlight while maintaining compact outer dimensions.

The mirror facets are supported on four outer points and a central one, using glued ceramic pads (Fig. 3). Via an adjustment system, the dead weight and wind forces are transmitted to the so-called frog fingers which in turn are attached on the concentrator structure. The adjustable supports allow for individual and precise alignment of the mirrors.

Fig. 3: Mirror facets and supporting system

2.4 Drive system

The drives of such a large concentrator have to withstand high loads from wind and dead weight and therefore do also require non-standard solutions and a careful design. Hydraulic actuators are well suited for high forces and slow motion and were selected for the drives.

The turn table is supported on 4 bogies. A ready-to-use wheel block system from crane industry is employed, with ductile iron wheels. The wheels roll on a circular heavy crane rail supported on rail chairs, which are designed to allow for thermal expansion of the rail ring.

In the elevation axis, four spherical and maintenance free plain bearings are used. The azimuth bearing has to accommodate the large air pipe, therefore a custom design with a hollow shaft and maintenance free plain bearings is used. The hollow shaft is anchored to the central foundation, which also has a hollow shaft to pass the air pipe and the rotary joint.

Two large double-acting hydraulic cylinders are used to lift the concentrator and rotate it in the elevation axis. The cylinders are mounted on the turn table side beams; a trunnion pin design allows for improved buckling resistance of the piston rod. The rod ends are equipped with maintenance free spherical bearings.

An innovative pilgrim step drive solution was developed for the azimuth movement: two hydraulically actuated rail brakes are connected to the turn table main structure via hydraulic cylinders. By alternatively closing and opening the brakes while extracting and retracting the cylinders, the drive forces are transmitted to the rail by one of the brakes at a time. In standstill, both brakes are activated and can thus transmit high survival wind loads.

The hydraulic unit was specifically developed for this application and offers some special features. A hydraulic accumulator was added, thus increased motion speed is provided for limited time, allowing for use of a smaller pump with lower power rating. Furthermore, this enables completely autonomous emergency lowering of the concentrator in case of power blackouts. This even works with a complete control system outage.

3. Receiver, heat transfer system and steam generation

The volumetric solar heat exchanger (receiver), located in the focal plane of the dish, can generate pressurized hot air up to 1000 °C. The hot air is transferred to the heat exchange system in a closed loop, using a piping system developed specifically for this application, including special rotary joints for crossing azimuth and elevation axis. Via an Air-to-Steam heat exchanger (Fig. 4), steam is generated to be fed into the steam cycle of a Combined Cycle or coal power plants (HelioBooster™).

The receiver and the complete heat exchange system were designed and tested through several design generations. Testing was conducted both in the 400 m² Big Dish of the Ben Gurion University and in the Solar Tower test facility of the Weizmann Institute of Science.

Fig. 4: Heat exchange system and maintenance tower

4. System erection and test

The steel construction for the prototype unit was fabricated in Israel and assembled on the test site at Rotem Industrial Park near Dimona, Israel. A simple mirror alignment method was applied for the first time and the mirrors were installed. The drive and control systems were commissioned and after some initial issues, full functionality and performance for tracking, fast movement and emergency were achieved. Precise tracking could be achieved even without a closed loop focus control system. The pilgrim step azimuth drive worked as expected from the beginning and the emergency functions based on the hydraulic accumulators could successfully be proven.

For determination of intercepted power, cold calorimeter measurements were conducted. Then receiver and air piping were installed and connected to the heat exchange system. In the test setup, the complete heat exchange system is realized and tested including steam generation.

5. Further development steps and applications

In parallel to erection and testing of the prototype unit, an improved version of the dish was developed for the next project. Four dishes will be installed at a power plant in Israel and deliver steam into a combined cycle for the first time (project 'Stardust'). System installation is expected for the end of 2012. Further projects already entered the design and planning phase. The main target for the next development steps is working out a fully commercial version of the dish which includes specific market adaptations and operational perspectives to enable adequate assembly and calibration processes.

The first market aimed at with the newly developed technology is the boosting of existing power stations. In the boosting application, the system utilizes a heat exchange system that creates steam at exactly the same conditions as the power station’s heat recovery steam generation system. Steam is introduced into the turbine’s different pressure levels as needed. The steam supplied to the turbine is stable and always maintains pressure and temperature as needed by the cycle. A heat capacitor (short time storage) is being used to gap short time sun blocking.

The ability of the technology to work at high temperature (high concentration ratio) enables the highest solar peak efficiency (direct normal radiation to electricity), and the "real dual axis tracking" system gives the highest annual kWh electricity output per kW installed. Various future stand-alone applications (centralized steam turbine, gas turbines and distributed micro-turbines) are under development utilizing the new dish. A typical size of a stand-alone system is 50 - 100 MW. The fact that the technology is modular has the benefit to use the solar field in multiple power generation opportunities.

Furthermore, HelioFocus is working on development and integration of a microturbine mounted at the dish focal spot. An additional application is a hybridized microturbine system, which will have the advantage of solar generated electricity together with full capacity and availability. Such a system can provide an attractive opportunity to utilities under specific renewables rate usage targets (e.g. California's target of 33 % renewables by 2020) with reduced cost in the bottom line of Levelized Cost of Energy (LCOE).

Other applications like combined heat and power (CHP), coal drying etc. are also potential future fields of use. HelioFocus is working with associates on a CHP system that can leverage the system advantages in rural areas mainly and provide a cost efficient CHP application.

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