Hami – The first Stellio solar field

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Hami – The First Stellio Solar Field

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Abstract. The 50 MW molten salt solar tower project Hami in the Chinese Xinjiang province is the first commercial application of the innovative Stellio heliostat. The solar field has been awarded to Dongfang Boiler Group (DBC) who contracted the German-Spanish Stellio Consortium (SC) as technology provider. The Stellio heliostat, solar field, assembly and installation and project implementation are presented.

STELLIO DEVELOPMENT HISTORY

After early stretched membrane heliostat developments in the 90s, schlaich bergermann partner (sbp) decided in 2010 to address the increasing interest in solar tower technology and design a new heliostat. Existing heliostat designs were analyzed and a substantial number of conceptual designs was investigated. Different structural design principles, kinematic systems and drive solutions were studied as well as the heliostat size.

As a result of these comprehensive studies a new heliostat design was concluded, characterized by a medium size of approx. 50 m^2, a structural system with central hub and cantilever arms and innovative kinematics with inclined axes driven by two linear actuators [1].

Based on this fundamental work, a contract was closed with SASOL Technology, South Africa to further develop and design the new heliostat. It was named Stellio, referring to a sun loving lizard domiciled in South Africa. In an intensive effort the concept was advanced to readiness for implementation.

When Sasol withdrew from renewables, the Stellio Consortium (SC) was formed by sbp, Ingemetal Energias, Spain and Masermic, Spain. With their huge experience and knowledge in solar concentrator design, construction and control, SC continued the development on own financing [2]. The first target was to compete for the Redstone project. SC and Stellio were immediately before final contract signature, however the Redstone project was delayed and finally suspended.

Early 2017 collaboration of SC and DBC was established with the aim to participate in the Hami solar field tender which was awarded in September 2016.

Stellio won the SolarPACES Technology Innovation Award 2015 and the CSP PLAZA Technology Innovation Award 2017.

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THE STELLIO HELIOSTAT

FIGURE 1. Stellio Heliostat

The design of the Stellio heliostat combines the most important lessons learnt form the conceptual studies: A pentagon formed by 10 cantilever arms and a central hub results in a more homogenous stiffness distribution compared to rectangular structures and results in a very efficient structural system, i.e. it provides low deformations and thus high optical performance at low specific weight. Its roundish shape reduces shading and blocking and allows for a compact field layout.

The design adapts a well proven solution from parabolic trough technology, the cantilever arm welded from hollow box sections – easy to fabricate and with optimum stiffness per weight. 5 rings of purlins carry the mirrors, made from very cost effective profiled sheet metal with cutting and end confectioning directly in the rolling process. The hub and the parts of the kinematic system are welded from plates. The whole structure is hot dip galvanized to ensure long-term corrosion protection.

10 mirror facets from 4 mm float glass and a central mirror form the 48.5 m^2 reflecting surface. The mirrors are connected to the steel structure by a gluing process which was first applied for the HelioTrough collector and is used also for the Ultimate Trough. Mirrors and structure are joined in a high precision jig which guarantees extremely accurate mirror curvature without any adjustment.

The main advantage of the Stellio kinematic system with two inclined axes is that cost-efficient linear actuators can be used for both axes and that tracking errors due to drive backlash are eliminated for the very most heliostat orientations. The limited range of movement around both axes requires specific axis orientation of every heliostat in the field.

Development and optimization of steel structure as well as drive and kinematic system was based on comprehensive wind tunnel studies and structural analysis coupled to optical analysis, an approach which is well established and further refined for sbp's concentrator design.

THE HAMI PROJECT

Hami is a 50 MW molten salt solar tower project in Xinjiang province near the Mongolian border. It is part of China's first batch of CSP demo projects. China Power Engineering Consulting Group Corporation (CPECC) is the owner, Northwest Electric Power Design Institute (NWEPDI) was awarded the EPC contract. The project has a static investment of about 1580 million RMB. IRR is over 10%.

Hami is a central receiver plant that uses molten salts as heat transfer fluid and as thermal storage system. It consists of solar field and power block. Dongfang Boiler Group Co., Ltd. (DBC) delivers the Solar Field, receiver and steam generator, and they assigned the Stellio Consortium to design the first Stellio Solar Field for this project. Dongfang Turbine Co., Ltd. delivers the turbine. Shandong Jinan Power Equipment Factory Co., Ltd provides the electric generator. The storage system is designed by NWEPDI.

The capacity of the turbine generator is 50 MW, with 43 % thermal efficiency under ambient temperature 19 ℃. The back pressure of air condenser is 8.5 kPa. The thermal efficiency of thermal storage and heat transfer system reaches 99 % in operation. The capacity of thermal storage is 1430 MWh, enough to run the turbine at full output for 12 hours. The annually generated energy is 198.3 GWh.

STELLIO DEVELOPMENT AND ADAPTION TO PROJECT

Prototypes

A first Stellio prototype was built at the Plataforma Solar de Almería, Spain in 2014. It was well equipped with sensors and has been tested extensively. Its outstanding optical and tracking performance was confirmed by CSP Services and CIEMAT.

With lessons learned and further optimizations in structural and mechanical design, electrics and controls as well as assembly tools and procedures, 4 enhanced prototypes were installed at the DLR solar tower test plant in Jülich in 2017. These units have undergone a comprehensive test program and are further operated.

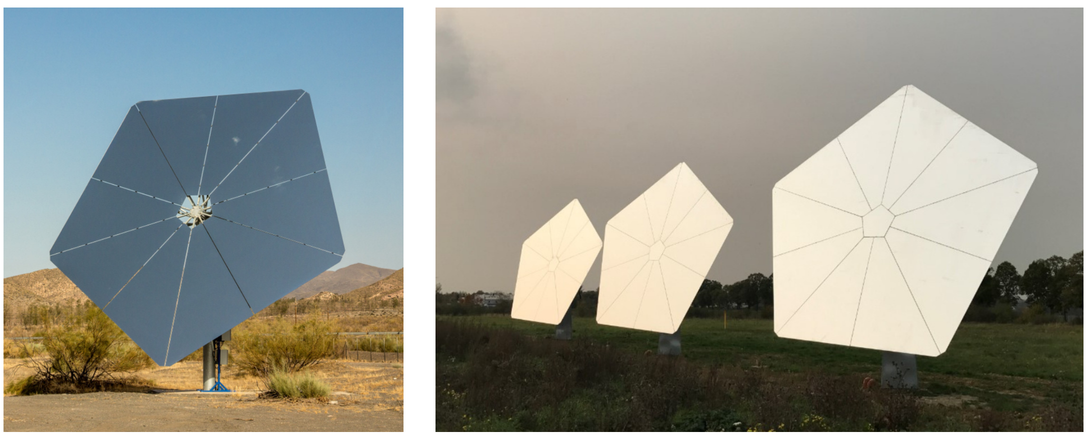

FIGURE 2. Stellio Prototypes at PSA and Jülich

Design Adaption for Hami

For best economy and performance, the Stellio design had to be adapted to the specific requirements of the Hami project site. A statistical wind study was conducted to accurately determine wind loads and correspondingly optimize the steel structure and define loads for linear actuators and bearings.

To safeguard special design details, a considerable number of component lab tests was conducted, including corrosion tests and load, stiffness and deformation testing of structural sections and connections.

Chinese and European suppliers of linear actuators designed products tailored to the Stellio demands. The suppliers conducted a comprehensive test program in their own labs. Important features were additionally performed as 3rd party tests at accredited German test institutes. Environmental testing included water and cyclic dust tightness as well as corrosion resistance. Mechanical testing ranged from positioning accuracy, backlash and self-locking to dynamic load and fatigue. Accelerated cycle tests under high load covered the full actuator service life.

Furthermore the actuators were cycle tested under increased load in a Stellio mockup in the workshop which provides operating conditions close to reality.

For testing the maintenance-free plain bearings and the cardan joint used for connecting the main axis actuator, a dedicated test rig was designed and built. It allows for accelerated cycle testing under controlled conditions including misalignment and dust atmosphere. Bearings from several suppliers have been tested as well as the specially designed cardan joint.

While the original Stellio pylon is a triangular welded design from sheet metal, a specific pylon solution was proposed by NWEPDI, consisting of a standard low-cost pre-stressed spun concrete pipe. The concrete pylon was slightly modified and has been integrated into the Stellio design. The pylons are cemented into drilled foundation holes.

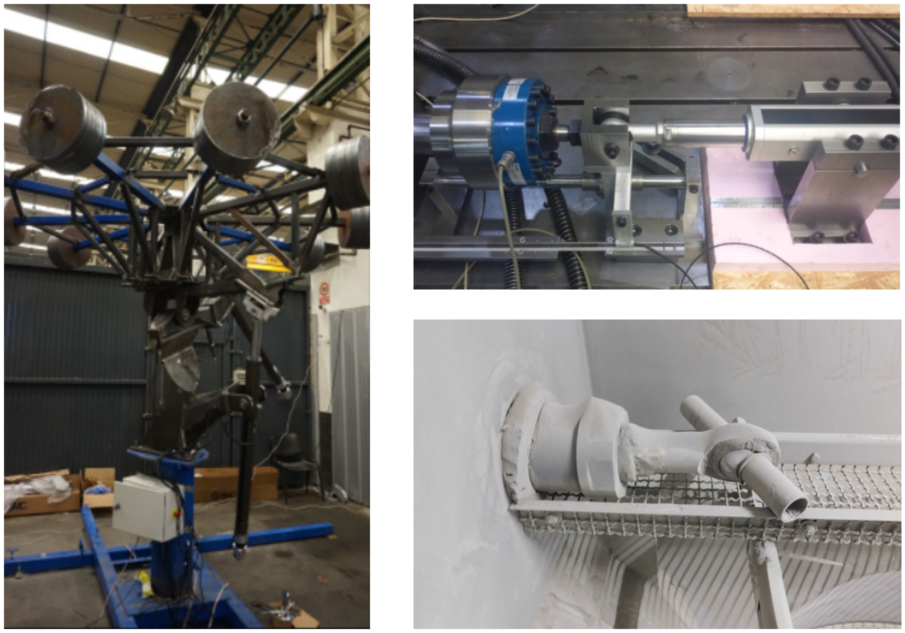

FIGURE 3. Stellio actuator testing: Mockup with ballast weight, mechanical and dust test

SOLAR FIELD DESIGN, ASSEMBLY AND INSTALLATION

Solar Field Design and Optimization

For design and optimization of the Solar Field layout, sbp in-house developed tools were used, incl. the ray-tracing tool sbp**RAY**. Taking receiver limitations into account already during the layout process minimizes the heliostat count to reach the requested annual production. More detailed information can be found in [3].

The site terrain is favorable with good flatness and just a slight overall slope. Therefore, a regular staggered field could be applied. In a comprehensive approach solar field performance was optimized while considering additional requirements like washing vehicle passage, roads and heliostat installation and replacement. Another part of the design effort was determination of optimized axis orientations for all heliostats.

Finally a surround field with 14’500 heliostats has been developed.

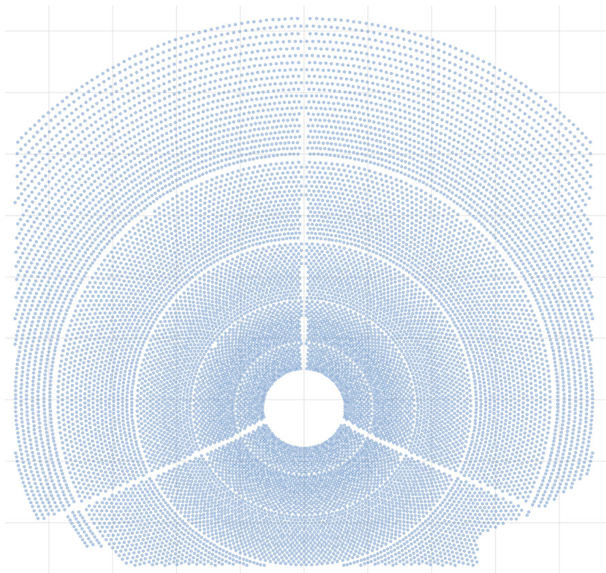

FIGURE 4. Hami Solar Field

Electrical and Control System

The Stellio electrical and control system was adapted to the projects boundaries and requirements and to Chinese regulations. It has a clear topology and uses both specifically developed components and industry standard parts [4].

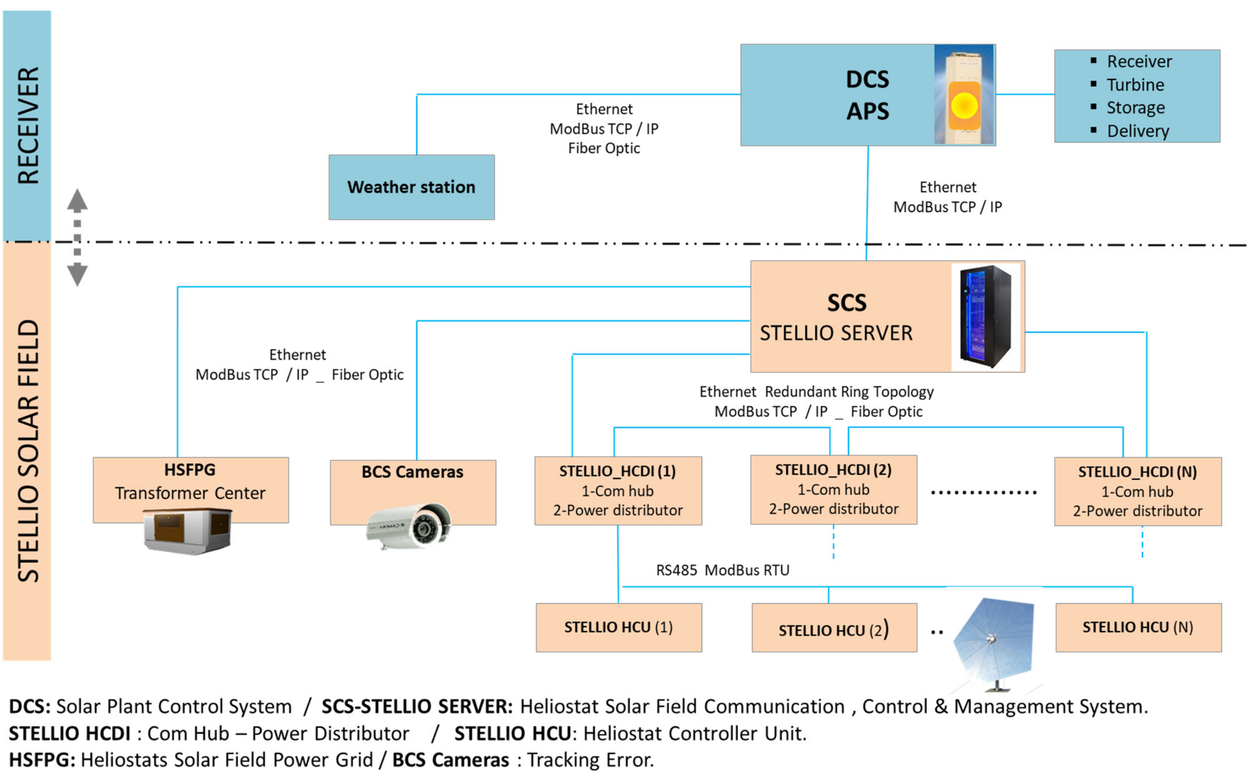

FIGURE 5. Stellio Solar Field Control Architecture

Stellio Heliostat Control Unit (HCU)

The Stellio HCU is an autonomous heliostat tracking control system with I/O for sensors, com ports and DC motor drivers for actuators. It was developed and is fabricated in compliance with automotive standards and guarantees. Heart of the HCU is the EUT15 state-of-the-art microcontroller, integrating the heliostat automation and communication system as well as the power drivers for reliable and efficient Stellio actuators management.

Maximum power consumption per heliostat is 190 W, which significantly simplifies solar field power grid architecture. Average tracking power consumption per heliostat is below 16 W. Due to the option to power-off the solar field when out of operation, night time average consumption below 1 W per heliostat is achieved.

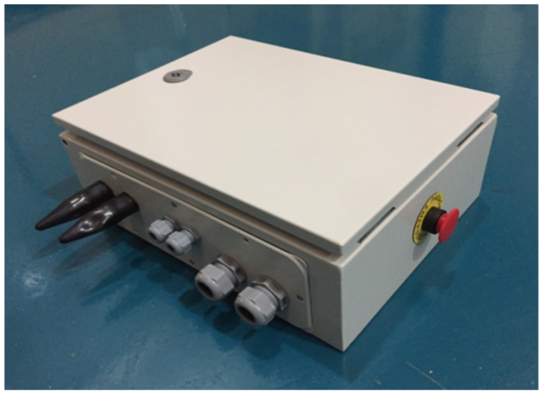

FIGURE 6. Heliostat Control Unit (HCU)

Stellio Server, Solar Field Control and Management System (SCS)

The Stellio Solar Field Central Control and Management System with the Stellio Server (SCS) as its core, performs real-time and history data and events monitoring. It commands the heliostats and exchanges data with the receiver control system and with the aim point control. Further tasks are meteo data processing, heliostats operational data traceability, equipment maintenance management, HCU remotely firmware updating, SF data monitoring: alarms, heliostats current status, SF communications data etc.

Solar Field Communication Network (SFC)

The solar field communications protocol is based on the industrial redundant Ethernet MODBUS TCP/IP – MODBUS RTU. The updating time of solar field monitoring status is approx. 2 s, remote updating of the HCUs firmware for the whole field is accomplished in less than 5 min. Time/date synchronization is achieved with a precision of less than 10 ms.

Heliostat Solar Field Power Grid (HSFPG)

The HSFPG features a power grid distribution divided in various sectors. All sectors have the same power grid architecture which is synergic with the communication network architecture. 4 transformer centers are located in the solar field, each of them equipped with battery-backed UPS. The optimized heliostat power consumption allows operation of the whole solar field at the same time.

Meteo data and Now-casting

Several meteo stations measure DNI, wind speed and other data incl. sun shape. CSP Services' now-casting solution Wobas with 4 sky cameras is implemented to provide data for solar field and receiver management for optimized performance and receiver load under transient solar conditions.

Aim Point Strategy

The aim point strategy (APS) is being developed by sbp in collaboration with DBC and realizes synergies by cooperation of solar field and receiver experts. Static and dynamic field and receiver models were used to simulate flux distributions, tube and salt temperatures and thermal losses under constant and transient conditions. Several aiming approaches were investigated and optimized to find the best suited strategies for different conditions and operation states.

Beam Characterization System

A beam characterization system (BCS) as part of the tracking calibration solution is needed to characterize and optimize tracking quality of each heliostat. It is based on the classic target aim shot principle with some new solutions. Instead of dedicated flat targets, a sector of the cylindric tower shaft is coated white and used as target. 8 cameras are installed in the solar field to take images of the beam spots.

The BCS works together with APS and SCS to manage heliostat assignment for calibration and to direct them to the target. A large number of images is continuously evaluated by the BCS server which automatically performs calibrations and corrections. It calculates beam centroids in real time and provides the data to the SCS.

Heliostat calibration

Calibration technology of the Stellio heliostats is one of the key factors for their excellent performance. The calibration procedure consists of 3 main steps:

- Step 1 (recording DNA) is carried out in the assembly hall. After assembly, the geometry of the kinematic system of each heliostat is precisely measured in a semi-automatic procedure. The resulting data set is individual for the specific heliostat and is denoted its DNA.
- Step 2 (initial calibration) is performed in the solar field in automatic operation mode. Using the DNA data, tracking accuracy of a new heliostat is good enough to focus its beam on the calibration target below the receiver. The beam position is captured by the BCS and registered tracking error data are applied for tracking correction.
- Step 3 (continuous calibration) is an ongoing process and is regularly repeated during its full lifetime. Similar to Step 2, tracking errors for each heliostat are recorded to further improve tracking accuracy and compensate any changes, e.g. due to foundation settlement.

Assembly and Installation

Efficient and accurate heliostat assembly at the construction site is one of the key cost factors for the Solar Field. Ingemetal gained vast experience with parabolic trough assembly and developed the Stellio assembly line. Automatization and manual work as well as component pre-assembly at suppliers and site assembly are well balanced. Complete heliostat quality assurance is integrated.

Specific transportation and installation tools for pylons and heliostats were designed and a detailed installation sequence has been worked out.

PROJECT IMPLEMENTATION AND TIMELINE

Collaboration between Parties

The split of tasks between the involved parties was defined according to the project requirements and boundaries. The complete Solar Field is designed by Stellio Consortium (SC). Civil works incl. tower construction as well as pylon and heliostat installation are performed by NWEPDI. The assembly line is provided and supervised by Ingemetal and operated by DBC. Commissioning is under DBC responsibility with SC support.

Project Timeline

Ground breaking at Hami site was in October 2017, main construction works continued after winter break in April 2018. Construction shall be completed in January 2019; grid-connected power generation is foreseen in May 2019.

By mid of August 2018, the main power building has been completed. The design of Solar Field has been completed by 90 %. The tower has reached a height of 94 m and is expected to be completed at the end of September. The design of the receiver has been finalized; it is now being manufactured and will be delivered in October.

In the solar field area the concrete pylons are being installed; due to severe frost these works have to be interrupted from mid November to March. The storage tank foundations are under work. 70 % of the assembly workshop has been built and completion of assembly line is expected in early October.

Main components of the Solar Field have been ordered (actuators, steel structure etc.), suppliers intend to begin delivery in early October. First assembly of heliostats is scheduled for October.

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