Next-CSP

High Temperature Concentrated Solar Thermal Power Plant with Particle Receiver and Direct Thermal Storage

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Deliverable D7.1

WP7 – Preliminary Design of the Future Utility-Scale Commercial Plant

Deliverable D7.1 – Report on the Preliminary Design of the Future Utility-Scale Commercial Plant

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Executive Summary

The Next-CSP project aims at developing a demonstration 1.2 MW_e Concentrated Solar Power plant that uses solid particles as both heat transfer fluid and storage medium. The project also paves the way towards commercial developments of this technology by studying its scale-up to industrial size. To this end, this report (D7.1) describes the preliminary design of a typical 150 MW_e plant to be built around 2030. We chose a solar-only plant (i.e. without supplementary firing) as a result of the detailed study performed in Deliverable D6.2 (Work Package 6).

CSP plants operate in well-irradiated areas that face steep variability of the net demand, including high power generation (sometimes over-generation) during daytime. Consequently, only peaker or mid-peaker CSP plants make sense, and even more so in the future. The dispatch strategy chosen for our plant consists of 5 full load equivalent hours of power generation during the evening. This dispatch strategy corresponds to a thermal power output of the solar island of 320 MW_{th}, taking all heat losses into account.

The receiver technology developed in Next-CSP (Upward Bubbling Fluidized Bed) limits the thermal power to about 40-45 MW_{th} per receiver due to technological constraints regarding the tube height. Besides, a cavity receiver is mandatory in order to mitigate the radiative thermal losses. We prefer to install only one receiver per tower. Consequently, the plant features eight towers, each one with a cavity receiver and a North field (for a plant located in the northern hemisphere).

The simulations were performed with a direct normal irradiation and a latitude corresponding to Tucson, AZ (USA) or Ouarzazate (Morocco). A tower height of 93 m was chosen as the result of a trade-off between optical efficiency and reasonable parasitic power consumption to lift the particles to the receivers. The resulting dimensions of the solar field are approx. 600 m x 600 m (max. North-South tower-heliostat distance and East-West width of the solar field).

Since the plant does not generate power during daytime, the thermal storage corresponds to a full day of solar collection. In order to simplify the conveying network, four particle hoppers are used: two containing the hot (~819°C) particles and two containing the cold (~609°C) particles. Each hopper contains 15 000 tons (7 500 m^3) of particles. The design of the hoppers aims at limiting their total height in order to limit the parasitic consumption required to lift the particles above them: their internal diameter and total height are respectively 30 m and 16 m.

In order to limit the conveying distances, an "H" configuration of the conveying network was chosen. Further to extensive discussions between EPPT and EDF, the most appropriate solutions for both horizontal and vertical handling of the particles were selected, and reported upon in Deliverable 1.5 (EPPT leading partner):

- To convey the particles between the storage and the towers, apron conveyors were chosen because of their continuous operation, their moderate power consumption and their heat losses that can be mitigated. Slopes up to 30° are possible and simplify the design of the conveying network.
- Rather than being dropped from the receiver to ground level, the hot particles slide downwards in successive inclined vibrating chutes, thereby avoiding attrition and limiting the length of the apron conveyors.

- In order to lift the particles to the receivers, bucket elevators were chosen because of their quasi-continuous operation. Thanks to inclined apron conveyors, the buckets are loaded 35-40 m above ground. Each tower features four elevators (2 in series x 2 in parallel).

The auxiliary consumption of the whole conveying network is reasonable and takes place mainly during daytime: it can be supplied in a cost-effective way by a small photovoltaic farm equipped with a limited amount of batteries. On the other hand, the thermal losses that occur during the conveying of the particles penalize heavily the plant efficiency. They were roughly estimated at ~9.5%; more accurate calculations and an optimized design should reduce this figure by at least a quarter.

Unlike the gas turbine of the Next-CSP pilot plant that works in open cycle with an additional firing, the power cycle of the scaled-up plant is a combined cycle gas turbine whose heat input is 100% solar. As shown in Deliverable D6.2, the resulting low Turbine Inlet Temperature (TIT = 780°C) requires a double reheat on the gas turbine to ensure a net cycle efficiency of 48.6%. No significant hurdle exist to build such a gas turbine, other than convincing a manufacturer to do it.

Gas turbines in general are extremely sensitive to pressure drops and our particular turbine struggles with a low TIT. Therefore, the particle-to-air heat exchangers must fulfill two antagonist criteria: low pressure drop and low temperature difference. This results inevitably in bulky (thus costly) heat exchangers. However, preliminary calculations (not displayed in this document) showed that a set of exchangers of reasonable size and cost can be devised. This will be studied in more detail in Deliverables D7.2 and D7.3.

The thermal inertia of the heat input in the event of a turbine trip is a critical issue that must be dealt with in Deliverable D7.2.

A Process Flow Diagram of the power cycle (including the set of particle-to-air heat exchangers) was established. It is appended to this document.

To conclude, this study shows that:

- A scaled-up solar tower based on the Upward Bubbling Fluidized Bed concept is feasible, but only with a muti-tower configuration that requires several km of particle conveying;
- In order to allow the plant to be significantly more efficient than a molten salt tower, specific attention must be paid to further mitigate the thermal losses of the conveying network;
- If very cheap particles prove appropriate for our use, they would allow for a much bigger storage that could provide extra value to the electrical grid.

This report was prepared by EDF R&D (lead partner of WP 7) further to a previous general assessment with all partners during the progress Next-CSP meetings, and to more detailed discussions with EPPT (as reported in Deliverable 1.5).