Next-CSP Concept with Particle Receiver Applied to a 150 MW_e Solar Tower

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1. Context – Dispatch strategy of the plant

The Next-CSP project aims at developing a pilot-scale 1.2 MW_e Solar Tower 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. This paper describes the preliminary design of a typical 150 MW_e plant to be built around 2030. Regarding its power cycle, we selected a solar-only, externally-heated gas turbine in combined cycle configuration (the gas turbine of the Next-CSP pilot plant works in open cycle with an additional firing).

CSP plants operate in highly 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. Therefore, the dispatch strategy chosen for our plant consists of 5 full load equivalent hours of power generation during the evening, which corresponds to a thermal power output of the solar island of 320 MW_{th}.

2. Main design features of the plant

2.1. Solar island and storage system

The direct normal irradiation, latitude and temperature of the reference site correspond to Ouarzazate (Morocco). See level barometric pressure is considered. The nominal thermal power of the receiver technology developed in Next-CSP (Upward Bubbling Fluidized Bed) is currently limited to about 55 MW_{th} per receiver due to technological constraints to maintain good solid-gas hydrodynamics along the full height of the receiver tubes [1]. Besides, a cavity receiver is mandatory in order to mitigate the radiation thermal losses. We chose to install a sole multi-tube receiver per tower. Consequently, the plant features six towers. Their height – 126 m – is the result of a trade-off between optical efficiency and constraints regarding the vertical particle uplift. The hot particles are stored at about 815°C, the cold ones at 600°C. Since the plant does not generate power during daytime, the thermal storage corresponds to a full day of solar collection, hence implying a storage of approx. 30 000 tons of particles. In order to limit the conveying distances, various configurations of the conveying network were compared. The chosen layout is shown in Fig. 1 below. Each black dot is a tower, connected by a particle conveyor to the storage and power block located in the center.

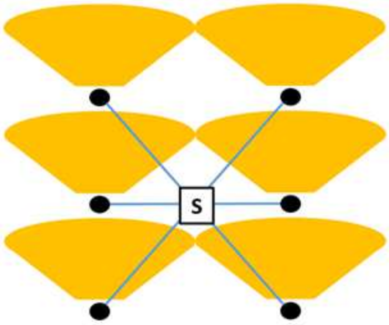

Fig. 1: Layout of the six tower solar island.

2.2. Horizontal and vertical conveying of the particles

To convey the particles between the storage hoppers and the towers, apron conveyors were chosen because of their continuous operation, their limited power consumption, and their moderate heat losses that can be mitigated. In order to lift the particles to the receivers, bucket elevators were chosen because of their quasi-continuous operation. Inclined apron conveyors limit the required final vertical lift of the bucket elevators. Rather than being vertically discharged from the receiver to ground level, the hot particles exiting the receivers slide downwards in successive inclined vibrating chutes, thereby avoiding attrition and limiting the length of the apron conveyors.

The auxiliary consumption of the whole conveying network takes place during daytime: it can be supplied by a cheap photovoltaic farm equipped with a limited amount of batteries. On the other hand, a first estimate showed that its thermal losses can be carefully mitigated to be kept below 5%.

2.3. Power cycle

Because of its low Turbine Inlet Temperature (~780°C), the gas turbine requires a double reheat layout to ensure a net combined cycle efficiency of 48.6% [2]. No significant hurdle exists to build such a bespoke gas turbine, other than convincing a manufacturer to do it. The particle-to-air heat exchangers must fulfill two antagonist criteria: low pressure drop and low temperature difference. This results inevitably in bulky and expensive heat exchangers [3]. However, preliminary calculations showed that a set of exchangers of reasonable size and cost can be devised.

3. Conclusion – Key takeaways

The main conclusions of this study are as follows:

- A scaled-up solar tower based on the Upward Bubbling Fluidized Bed concept developed in Next-CSP is feasible, but only with a multi-tower configuration that requires several kilometers 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 mitigate the thermal losses of the conveying network;
- The design of the utility-scale receiver has raised several challenges such as achieving a satisfactory compromise between low spillage, low thermal losses and well-controlled flux map while limiting particle attrition or agglomeration. However, these risks can be mitigated through proper R&D and engineering practices.
- If very cheap particles with appropriate heat capacity prove applicable for this specific set-up, they would allow for a much bigger storage than commonly practiced with molten salt towers, which could provide extra value to the power generation and stability to the electrical grid.

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