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Progress in heliostat development

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ABSTRACT

Strong efforts are being made to drive heliostat cost down. These efforts are summarised to give an update on heliostat technology comprising: determination of wind loads, heliostat dimensioning, solutions for the different sub-functions of a heliostat, a review of commercially available and prototype heliostat designs, canting, manufacturing, qualification, heliostat field layout, and mirror cleaning. There is evidence that commercial heliostat costs have dropped significantly in the past few years, with commercial suppliers of heliostat technologies now claiming heliostat field costs around 100 USD/m^2. With new approaches even target cost of 75$/m^2 seem to be realistic.

1. Introduction

1.1. Solar tower plants

Concentrated solar thermal (CST) energy is a promising renewable energy technology capable of large scale electricity production and industrial process heating, usually incorporating energy storage. In a solar tower plant, moving mirrors called 'heliostats' track the sun in two axes and reflect the sun's rays onto a 'receiver' at the top of a tower (Fig. 1). The receiver absorbs the radiation and supplies thermal energy via a working fluid at a temperature of typically 300–700 °C. For power towers incorporating energy storage, the working fluid is also a heat storage medium (e.g. molten salt), and is stored in tanks to allow power generation upon demand. Alternatively, the energy received by the solar tower plant may be used for providing heat to a thermochemical process, such as the production of synthetic transport fuels.

A photovoltaic (PV) power plant currently provides electrical energy at a lower cost than a concentrating Solar Power (CSP) plant; however, storage of electrical energy is in general more expensive than storage of thermal energy. Therefore, PV plants are more suitable for power supply during sun hours and CSP plants during the night and in cloudy conditions. A combination of both PV and CSP is seen as a promising solution for future power supply: "The cost of solar technologies are falling so quickly that within a few years the combination of solar PV and solar towers with storage will be able to compete directly with base load fossil fuels" (Padmanathan, 2015). An important advantage of CSP compared with PV is that during construction a high fraction of labour and equipment is sourced locally, which is especially attractive for developing countries.

Examples of industrial processes that could be driven by solar tower plants are cement production (Gonzáles and Flamant, 2014) and enhanced oil recovery (CSP today, 2013b). Solar tower systems can also supply heat to thermal processes at 550 °C or below, although 500 °C have been achieved by some small trough demonstration projects as well. Many industrial processes are designed for higher working temperatures, which are provided

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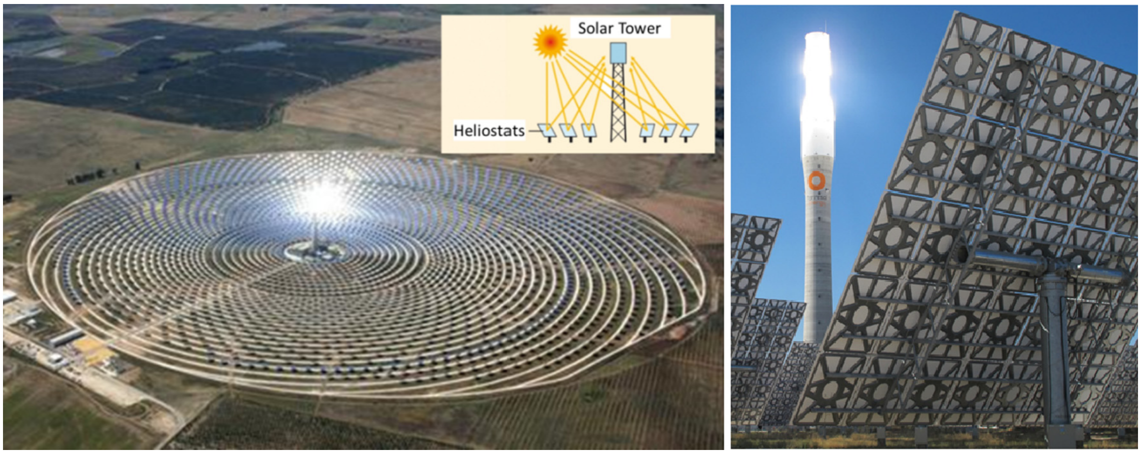

Fig. 1. First commercial power tower with storage using molten salt (Torresol Energy, 2017), (schematic by DLR).

by fossil fuel burners. To incorporate solar input it is sufficient to replace only the burner with a solar receiver and the rest of the plant stays almost unchanged. With further reduction of the cost of concentrated solar systems, applications for solar thermal industrial processes will become economically viable.

The heliostats represent 40–50% of the cost of a power tower plant, so they must be relatively low cost for the cost of energy from the plant to be competitive with that of fossil fuels (Mancini et al., 2000). It was shown by Gary et al. (2011) that to achieve a levelised cost of electricity (LCOE) of 0.10 USD/kWh the heliostats must cost no more than 120 USD/m^2. The heliostats must cost about 75 USD/m^2 if the target LCOE is 0.06 USD/kWh (Gary et al., 2011). To achieve these targets, innovative designs and solutions regarding the complete heliostat concept and its components, are needed. Furthermore, the dimensions of heliostats must be selected to minimise manufacturing and installation costs. This requires accurate estimation of the wind loading on both operating and parked heliostats to allow structurally efficient heliostat designs to be developed with good optical performance characteristics, while avoiding structural failure.

1.2. Previous heliostat reviews

Mancini et al. (2000) collected data from eight different commercial heliostats that were available on the market. They presented a general description of heliostats and their cost structure based on the information provided by the manufacturers of the heliostats.

In July 2006, a two-day workshop was held at the National Solar Thermal Test Facility (NSTTF) in Albuquerque, New Mexico, to discuss heliostat technology and to identify solutions for technology improvement. Approximately 30 heliostat experts and manufacturing companies from the United States, Europe, and Australia participated in this workshop. After the workshop a team of six experts developed a price estimate for current heliostats and evaluated the price-reduction potential solutions for the future heliostats. The results of this study were published in a SANDIA report (Kolb et al., 2007).

Pfahl (2014) presented an overview of 48 approaches for heliostat cost reduction in a tabular form and discussed their main advantages and disadvantages, giving example reference cases. The review was intended to serve as a base for the development of new low-cost heliostat concepts.

One of the objectives of the European project STAGE-STE is the development of a low cost heliostat. At the commencement of the program, the state-of-the-art of heliostat technology and the specifications were discussed and published (Téllez et al., 2014). The report presents potential solutions for cost reduction consistent with the required functional specifications, and a review of heliostat deployment worldwide.

Similarly, the Australian Solar Thermal Research Initiative (ASTRI) carried out a Heliostat Cost Down Scoping Study (Coventry et al., 2016; Coventry and Pye, 2013) as a first step in a heliostat cost-reduction project.

In the following sections, the current level of knowledge in heliostat technology about different aspects of heliostat design and manufacturing will be discussed. This review paper is arranged according to the following topics:

1. Static and dynamic wind loads.
2. Heliostat dimensioning.
3. Heliostat components.
4. Heliostat designs.
5. Canting.
6. Manufacturing and assembly.
7. Qualification.
8. Heliostat field layout.
9. Mirror cleaning.
10. Cost.

2. Wind loads

2.1. Relevant wind properties

Heliostats are exposed to the atmospheric conditions prevailing on the field. They experience aerodynamic forces caused by wind that can lead to a mechanical failure if they are not accounted for in the design. At extreme wind speeds, the loads can lead to a failure by exceeding the maximum stress that the heliostat structure is designed to sustain. In addition, fluctuating wind forces may result in fatigue failure due to flow-structure interaction and resonance.

Emes et al. (2015) showed that there is a strong dependence between the cost of the heliostat field and the design wind speed. For example, they showed that lowering the design wind speed by 9 m/s from the maximum 22 m/s measured wind speed at Alice Springs in Australia yields a 0.3% lower capacity factor for the solar tower power plant but it reduced the LCOE by 18%. In addition they showed that with an increase in the average wind speed the heliostat size preferably should be decreased.

To determine the mean and peak loads, normalised load coefficients that depend on the shape and orientation of the heliostat