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Modeling and Simulation of the 50 MW Molten Salt Solar Tower Power Plant in Delingha

Real Tower Power Plant Simulation With SAM

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Abstract. As a form of renewable energy, concentrated solar power (CSP) is a stable, continuous and dispatchable renewable energy generation technology. By equipping large capacity molten salt (MS) storage, CSP has many advantages compared to traditional fossil fuel power plant in terms of electricity quality, like grid-friendly production and very low carbon emission during lifetime. In recent years, many developing countries like Saudi and Morocco made ambitious development goals for CSP as well as on of the G20 lands, China. The SUPCON Delingha 50 MW MS ST CSP Plant is one of the first batch of 20 CSP demonstration projects in China. The solar tower (ST) power plant has an installed capacity of 50 MW and includes a 7-hours molten salt storage system. A model of SUPCON Delingha 50 MW MS ST plant was developed with SAM and a simulation took place in order to calculate the annual electrical output performance of the commercial power plant. The simulated result is only 3.6 GWh_e less than the design value. The difference, which is less than 5% between the simulation and design value, is caused due to the lack of information.

Keywords: Solar Tower Power Plant, Concentrated Solar Power (CSP) Simulation, Modelling, Molten Salt (MS), Commercial Power Plant

1. Introduction

The global energy crisis, the environmental pollution, the climate change and the energy transition in many countries are today the most important challenges of humankind. Towards solutions the development and utilization of renewable energy has become a universal consensus in all countries in the world.

As a form of renewable energy, concentrated solar power (CSP) is a stable, continuous and dispatchable renewable energy generation technology. It is one of the most exceptional renewable energy technology with its feasibility and matured development of application and commercialization. According to IRENA, in 2021, the levelized cost of electricity (LCOE) from CSP was 0.114 €/kWh_e, while only 110 MW_e of new CSP plants were commissioned globally [1].

By equipping large capacity molten salt storage, CSP has many advantages compared to traditional fossil fuel power plant in terms of electricity quality, like grid-friendly production, very low carbon emission during lifetime, flexible peak load regulation in large range and fast rampup and ramp-down rate [2]. CSP's predictability, low emissions, compatibility with existing infrastructure, energy storage capabilities, lower long-term operating costs, support for grid resilience, and improved water use efficiency make it a more grid-friendly option compared to fossil fuels. The application of CSP with the use of molten salt as a heat transfer fluid and as a storage medium is described in detailed in [3].

There has been a huge development of CSP in recent decades in Spain and in the United States. In recent years, many developing countries like Saudi and Morocco made ambitious development goals for CSP. Meanwhile also Chinese government proposed similar goals and the installed capacity in 2020 was 5 GW [4].

The SUPCON Delingha 50 MW MS ST CSP Plant is one of the first batch of 20 CSP demonstration projects in China, and has been entitled as National Strategic and Emerging Industry Key Project by the National Development and Reform Commission (NDRC).

2. Description of solar tower power plant and simulation

First in this chapter, the SUPCON Delingha 50 MW Molten Salt Tower Plant is described. Then the simulation approach together with the simulation results are shown.

2.1 Description of solar tower power plant in Delingha

The SUPCON plant as shown in Figure 1 is located in Delingha, Qinghai Province. The construction of the SUPCON Delingha 50 MW Molten Salt Tower Plant started in Mar. 2017, and was commissioned in Dec. 2018. The full-load operation was reached in Apr. 2019 [5]. As heat transfer medium molten salt is introduced. The plant has an installed capacity of 50 MW and includes a 7-hours molten salt storage system.

Figure 1. *Panorama view of SUPCON Delingha 50 MW CSP station (Zhejiang SUPCON)*

The designed electricity production is 146 GWh_e/year. The project can save 46,000 tons standard coal and reduce 121,000 tons of CO_2 emissions.

The receiver used in the SUPCON Delingha 50 MW solar tower plant is external-cylindrical [6]. External receivers suffer from higher radiative heat loss than cavity receivers but have lower convective heat loss [7]. According to [8] the structure is flexible and has minimum impact of thermal stress and fatigue. The material of the solar receiver plates is Inconel Alloy 625 and it has a rated thermal power of 230 MW_{th}, the inlet temperature of HTF is 290℃ and outlet temperature is 565℃.

The HTF transfers the heat to a heat exchanger in order to produce steam, which then expands in a steam turbine. The steam parameters for the steam turbine are 133 bar and 540°C [8]. The efficiency of the power block is 43%. To archive this efficiency, SUPCON applied the project with a 2-stage steam turbine that supplied by Hangzhou Boiler Group [9].

The thermal energy storage (TES) system of SUPCON plant includes 2 storage tanks designed to store 10,093 tonnes of HTF which consists with 60% $NaNO_3$ and 40% KNO_3. The heliostat field of SUPCON plant consists of a heliostat field of 27,135 pieces of 20 m^2 waterproof reflective mirrors resulting in an aperture area of 542,700 m^2.

2.2 Simulation approach

For the simulation of the heliostat field a configuration of plant in CAD as shown in Figure 2 was prepared.

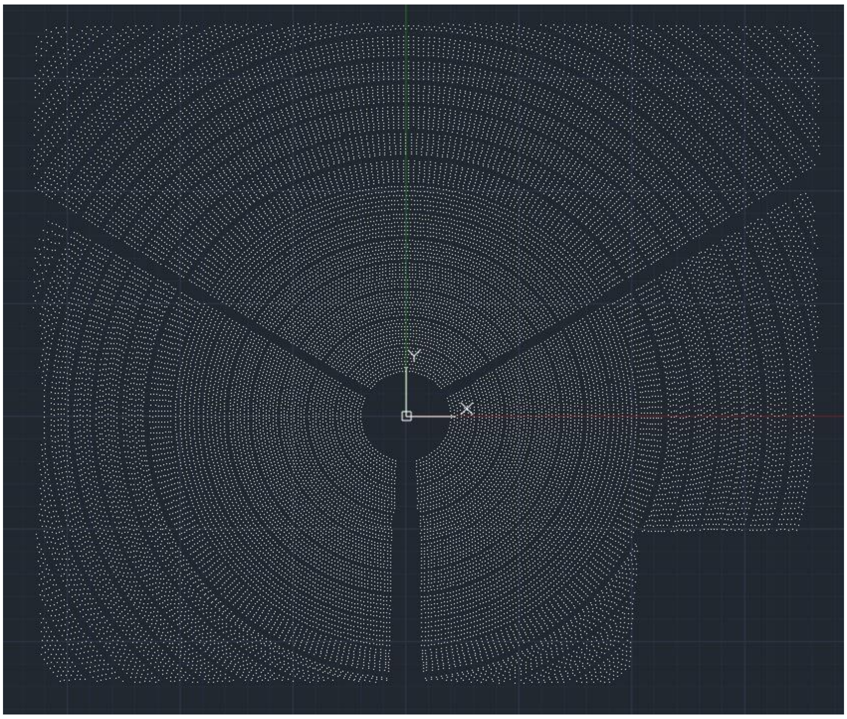

Figure 2. *Shortcut of CAD – Configuration of plant in CAD [9]*

Afterwards, the two-dimensional array coordinates data of all 27,135 points was exported and imported into the System Advisor Model (SAM) for further simulation.

SAM is a techno-economic computer model designed to facilitate decision making for people involved in the renewable energy industry [10]. To model a solar tower project in SAM, the authors choose a performance model to represent the project, and assign values to input variables to provide information about the project's location, type of equipment in the system, and operating the system. A financial model use and the consideration of cost of installing and financial and incentives assumptions are not in the focus of this paper.

In the technical assessment, a simulation of the electrical output is computed with the hourly-based direct normal irradiance (DNI) source data of the project location in Delingha from Solar and Wind Energy Resource Assessment (SWERA) in the SAM software tool environment.

2.3 Simulation results

A model of SUPCON Delingha 50 MW MS ST plant was developed and then a simulation took place in order to calculate the electrical output performance [9]. The simulations depend on the weather data of the location and set parameters.

As one of the simulation results, a monthly system power generation is simulated by SAM and shown in Figure 3. In this figure, SAM gives the daily working status of each month of the plant.

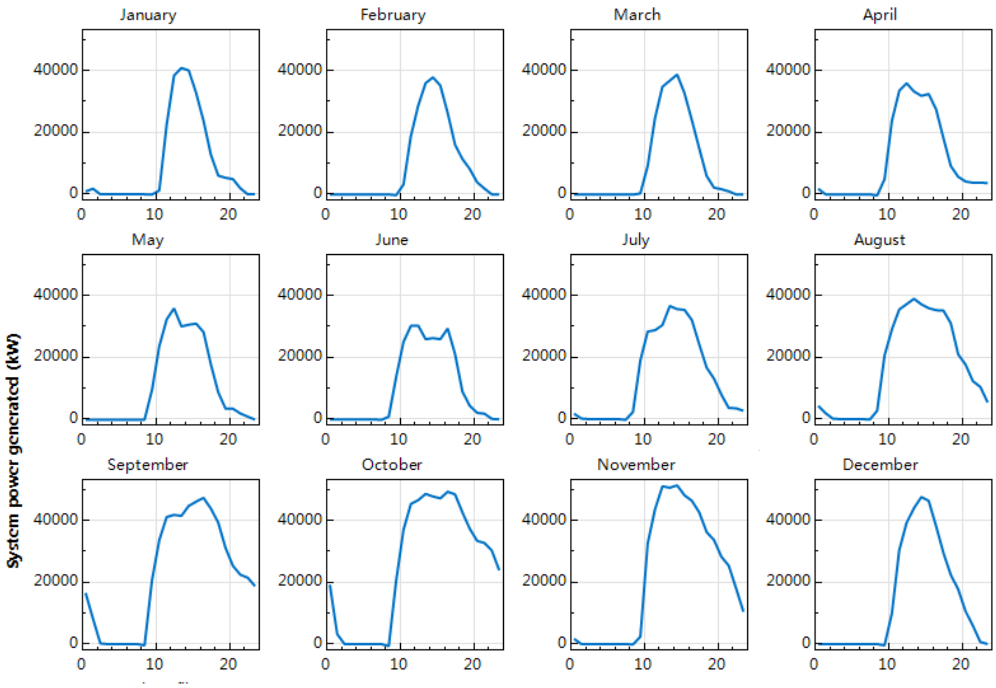

Figure 3. *Simulation by SAM – Monthly System Power Generation*

It is obtained that the plant normally works from 08:30 to 23:00, by when the sun rises and sets in Delingha and after sun set the energy is further supplied from the TES system. Delingha has better weather conditions in spring, especially from September to November.

Unfortunately, it was not directly possible to use real operation data of the system from both commissioning and actual testing phases, as well as the operation data. Nevertheless, the results of the simulation model were validated. The authors compared the computed output with the actual electrical output during the operation period from October 2019 to February 2020, which were released by the plant operator.

An electrical outcome is simulated and the result is accumulated below in Table 1. The result indicates 142.4 GWh_e annual power generation and 125.7 GWh_e of the gross output is delivered to the grid, which marks an annual average of 88.3% of delivery rate.

Then the simulated result is analysed by a comparison to the design value. As mentioned in [9] SUPCON announced an annual output of 146 GWh_e, the simulated result is only 3.6 GWh_e less than the design value. The difference, which is less than 5% between the simulation and design value, is caused due to the lack of information.

In the subcomponent of Power Cycle, the steam cycle blowdown fraction and ambient temperature at design cause a huge impact on the simulation outcome and is missing. Due to lack of information for the power block, the simulation for this part is also applied with the default setting of a Rankine cycle parameter. In addition, the weather data applied in the simulation might have a slice difference as well. The missing data about the solar tower power plant and the DNI difference caused the difference in the final simulation result [9].

Table 1. *Monthly Performance Simulation of Delingha 50 MW MS ST Plant by SAM [9]*

Month	**Power Generation [GWh_e]**	**Delivered to Grid [GWh_e]**
January	8.0	7.0
February	7.1	6.1
March	7.9	6.8
April	9.1	8.0
May	8.9	7.7
June	8.2	7.1
July	11.1	9.8
August	14.2	12.6
September	18.0	16.1
October	21.0	18.8
November	17.3	15.5
December	11.7	10.4
Total	142.4	125.7

Therefore, a difference of 2.4% is considered within the tolerance and thus the simulation result is acceptable.

3. Outlook

In the present work, the simulation model of SUPCON Delingha 50 MW solar tower plant was developed on SAM. The analysis showed that this is easy-to-use yet detailed and precise model to describe such a system.

The simulation model of the solar tower power plant will be continuously improved, its functionality extended, and, ideally, the parameters used will be adjusted if data from Cosin Solar will be available.

Furthermore, it is planned to perform simulations with SAM of other commercial installed and operated solar tower power plants in China.

Data availability statement

The detailed and extensive amount of data supporting the results of this paper is only (and even only) in parts accessible.

Underlying and related material

There exist no other material, which supports the findings of the paper except of the bachelor thesis [9] which was done at the FH Aachen University of Applied Sciences.

Author contributions

G. Chen: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization

S. Alexopoulos: Conceptualization, Formal Analysis, Investigation, Methodology, Software, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing;

Competing interests

The authors declare no competing interests.

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