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Parametric Simulation and Economic Estimation of Thermal Energy Storage in Solar Power Tower☆

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Abstract

The alternative for fossil fuel generated energy is energy from solar plants. A solar power tower system, which is a type of concentrating solar power (CSP), is simulated with the SAM (System Advisor Model) to help in decision-making on whether or not to include a storage system in it. Addition of thermal storage in a solar power tower system brings sustainability and dispatch ability of the power produced. Since solar power tower systems require high investment costs to be established, the percentage contribution of Thermal energy Storage (TES) on the installation costs are found. In this paper, different locations are chosen from India, Germany and Mediterranean countries to simulate a solar power plant of 100 MWe capacities. Initially, the excel sheet with pre-built functions of SAM are custom modified. Then the parameters related to the direct costs and installation costs are determined, which are then used as input in the SAM software to do a parametric simulation.
The dependence of the following are estimated with the help of SAM and customizing the SAM excel model:

- Dependence of turbine gross output on total installed costs
- Dependence of thermal energy storage hours of two tank storage system on total installed costs
- Dependence of thermal energy storage hours of latent heat storage on total installed costs

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Keywords: Solar Power Tower, Thermal Energy Storage, Economic evaluation, Parametric simulation

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1. Introduction

A Solar power tower (also called a central receiver system) is a type of concentrating solar power (CSP) system that consists of a heliostat field, tower and receiver, power block, and optional storage system (Figure 1). The field of flat, sun-tracking mirrors called heliostats focus direct normal solar radiation onto a receiver at the top of the tower, where a heat-transfer fluid is heated. Then it is pumped to the power block. The power block generates steam that drives a steam turbine and generator to convert the thermal energy to electricity. This is one of the key technologies used to generate electric power in the recent past. The power tower uses a Thermocline storage tank or a two-tank system to store the heat energy generated. The thermal energy stored is dispatched at required intervals to generate electricity. This thermal energy storage (a two-tank system or a latent heat thermal storage system) influences the cost of the construction of this solar power tower plant. Since solar power towers are highly cost intensive investment, it becomes important to get knowledge about the impact of a storage system economically on the plant before even venturing in to the project. In this paper, the total installed costs and the dependence of the storages is estimated to help understand the contributions of each one of them in the costs.

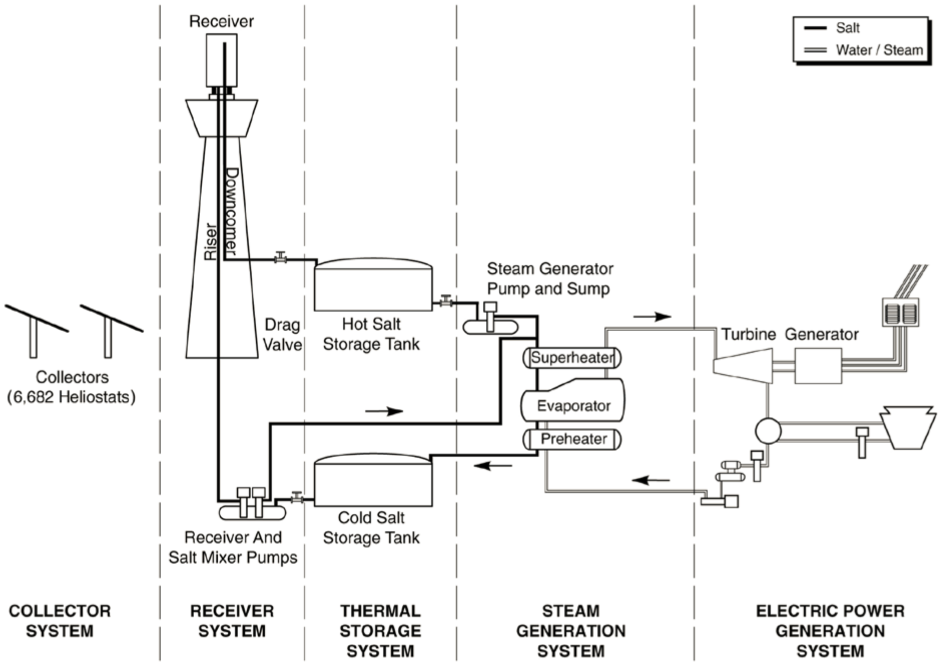

Figure 1 Schematic of a molten salt power tower showing major sub-systems [1]

Nomenclature

TES	Thermal Energy Storage
LHTES	Latent Heat Thermal Energy Storage
SPTP	Solar Power Tower Plant
MWe	Megawatt electricity
SAM	System Advisor Model
LCOE	Levelized Cost of Electricity
CEPCI	Chemical Engineering Plant Cost Index
PPI	Producer Price Index
DC	Direct Cost
EPC	Engineering Procurement Construction

2. Simulation and economic estimation

The project plant data and the indices are initially fed in to the excel functions of the SAM (Figure 2). The labour costs, CEPCI and PPI are taken from various sources for the year 2015. Custom modification of the SAM excel functions would yield the total direct and indirect costs of the plant (Table 1& Table 2) which are later fed in to the SAM software for a parametric simulation.

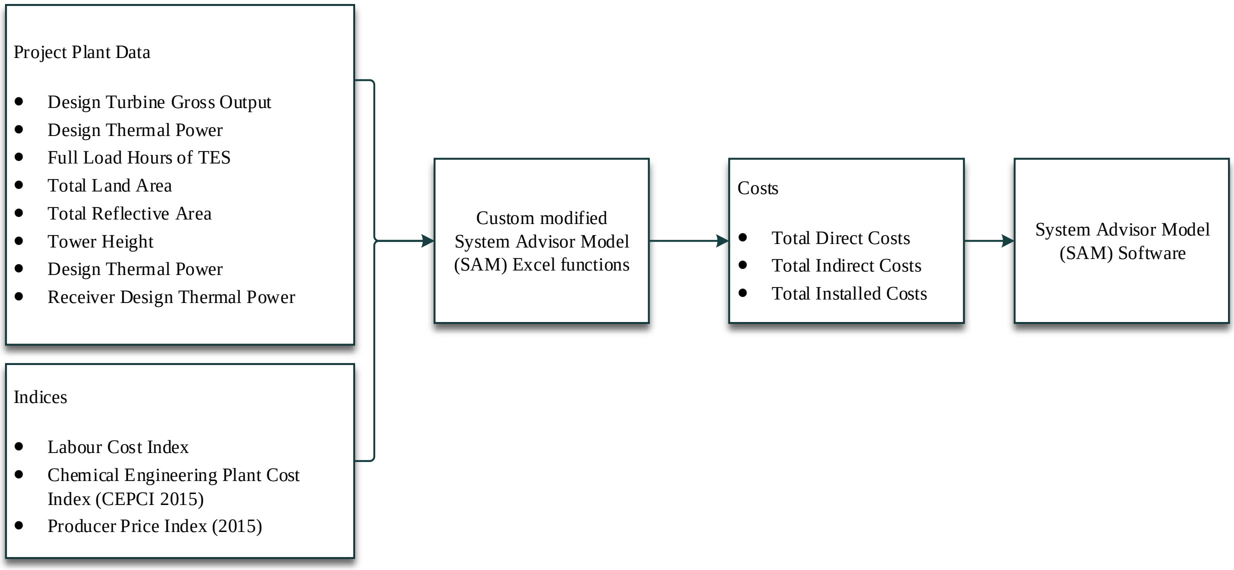

Figure 2 Inputs for the simulation

Table 1 Direct capital cost summary

Direct Capital Cost Summary	Parameters to SAM	Units
Site Improvements	15	$/m2
Heliostat Field	181	$/m2
Tower		
Receiver	116	/kW-t
Thermal Energy Storage	26	$/kWh-t
Fossil Backup	0	$/kWe
Balance of Plant	365	$/kWe
Power Plant	1234	$/kWe
Contingency	7.0	%

Table 2 Indirect capital cost summary

Indirect Capital Cost Summary	Parameters to SAM	Units
EPC and Owner Costs	11.1	% of DC
Land	10000.0	Land cost per acre
DC's Sales Tax	78	applied to % of DC

The tables show the constituents of the direct and indirect costs. During, the whole simulation, CEPCI cost index is used for all the countries and dollar is used as the currency to make the prices comparable. In this summary of the costs, the plant is simulated without a fossil back up. Hence, its value is set to be zero. The cost of contingency is also assumed as 7% of the total direct costs. All these value determined are the output of the excel functions that are ready to be given as input in the SAM software for further simulations.
Initially, seven different cases of solar power plant are simulated from seven different locations. These locations are from in Mediterranean region, Germany and India. The best case in terms of high capacity factor and least LCOE is chosen of all those cases. The chosen best case is used for the parametric simulation. Before beginning with the parametric simulation, the weather file of the best case is taken from the library of SAM.
In the parametric simulations, the input variables of design turbine gross output (MWe) and full load hours of TES are varied to determine the capacity factor and the total installed costs. SAM-excel functions break down the total direct and indirect costs in to its contributors. For the corresponding input, the SAM-excel also give the contribution of TES (Two-tank system).

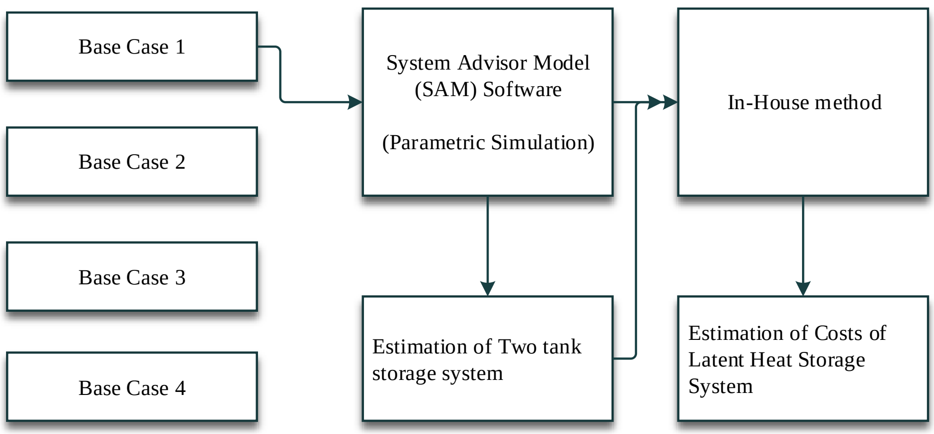

Figure 3 Economic estimation

Using this percentage contribution for every load hours of TES (Two-tank system) from the SAM excel, the corresponding contribution to the total installed costs is estimated (Figure 2). Data from literature are used to build a simple in-house excel tool to estimate the equivalent cost of a latent heat storage system in place of the estimated Two-tank system. In this in-house method, there is an assumption made as per [2]. That is, the cost of latent heat thermal energy storage is assumed to cost 40% of the two-tank system.

3. Results and discussion

The parametric simulation generated the total installed costs of the solar power tower plant for various turbine output in MWe. The full storage hours is also varied from 0 to 10 hours. The results are plotted in Figure 4. The total installed costs increases with increase in the turbine output. Until the 40 MWe mark, there is not a much difference between the total installed costs for different full load storage hours. The difference is clearly visible after the 40 MWe. Considering the fact that all the intermediate values between full load hours of 2 and 10 would fall in-between the two lines in the graph, the difference is too close. There is a small inflection point in-between 30 MWe and 50 MWe. This inflection point is simply the outcome of the SAM excel function. Because, of the same characteristics being in all the lines in-between full load hours of 2 and 10 hours.

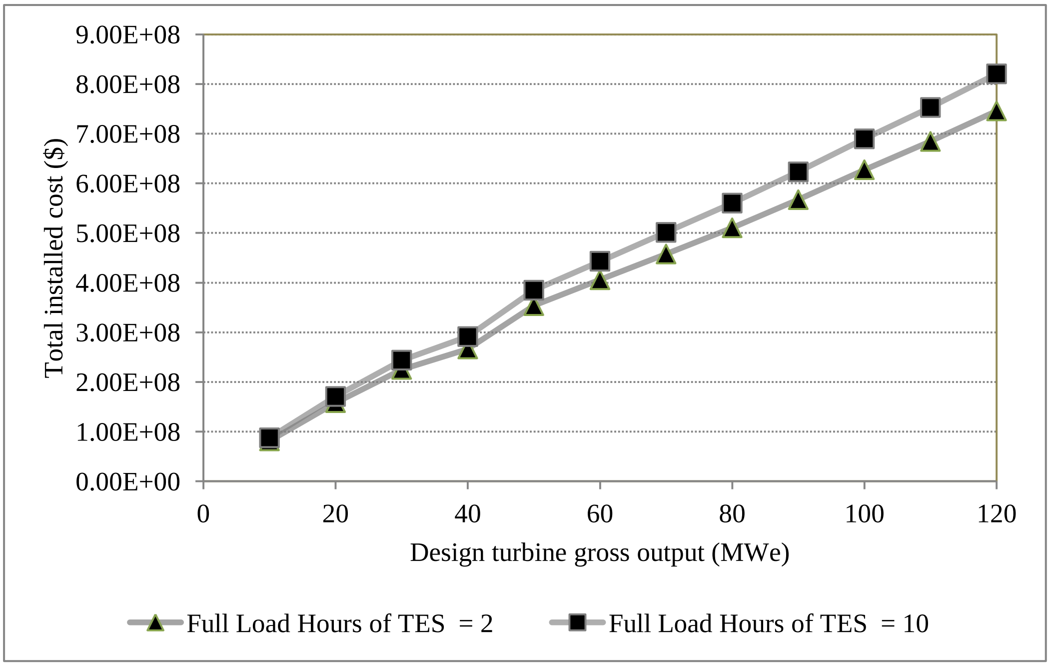

Figure 4 Dependence of turbine gross output on total installed cost

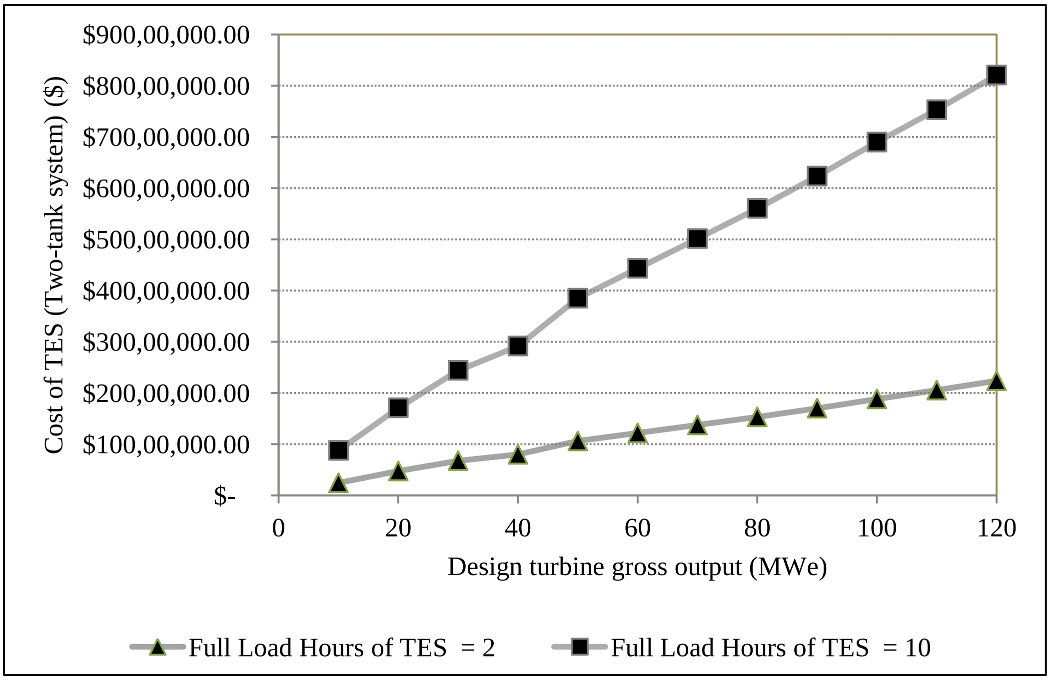

Figure 5 Dependence of turbine gross output on cost of thermal energy storage (Two-tank system)

The cost of thermal energy storage (Two-tank system) is a part of the total installed cost. To understand the contribution of two-tank system for the total installed cost, the SAM excel is modified to find the thermal energy storage as a function of the total installed cost. The results are plotted in Figure 5. The same way, the dependence of the latent heat storage is also estimated and are plotted in Figure 6. The values are plotted only for the full load hours value of 2 and 10. The lines of the in-between values fall in the graph within the plotted two lines. Again, there is a small inflection point between 30 MWe and 50 MWe. This is a virtue of the SAM excel functions estimation. Moreover, the pattern of the curves in both the Figure 5 and Figure 6 are identical. In both the figures, the cost of the TES falls flat for the lower full load hours of the TES. The slope of the curve increases as the full load hours increase as well. This infers the demand for higher costs as the full load hours of thermal energy storage increases. That too, for a higher design turbine outputs, the cost of TES reaches the maximum in both the thermal energy storage (Two-tank system) and in the thermal energy storage (LHTES)-

However, the pattern of the figures may be the same; still there is a difference in the values between the two-tank system and latent heat storage system. The latent heat storage system is far cheaper than the two-tank system. The reasons for this could be factors such less construction costs, lesser material costs etc for a latent heat storage system. Before the decision making process of whether or not to add a thermal energy storage system of latent heat storage, the approximate dependence of it has to be estimated. To give a clear idea of how much possibly a thermal energy storage (LHTES) costs in the total installed cost, the percentage contribution of the thermal energy storage (LHTES) at various full load hours are plotted in Figure 7

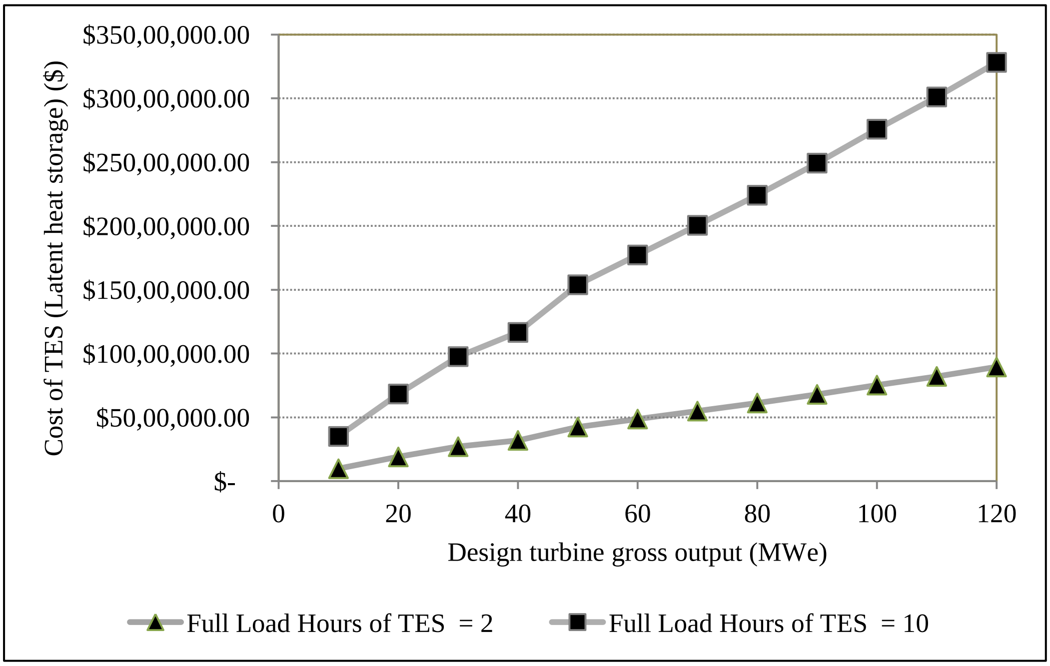

Figure 6 Dependence of turbine gross output on cost of thermal energy storage (latent heat storage)

As in Figure 7, even at the maximum value of 10 full load hours, the LHTES costs only 4% of the total installed cost of the plant. This is cheaper than the thermal energy storage (two-tank system) that costs around 10%. After the 6th hour, the percentage cost of LHTES increases linearly. Until the 6th hour from the beginning, it forms a curve. This is similar to the inflection points in the previous graphs, which are the results of the SAM, excel.

Hence, the contributions of the two storage systems are estimated through a parametric simulation.

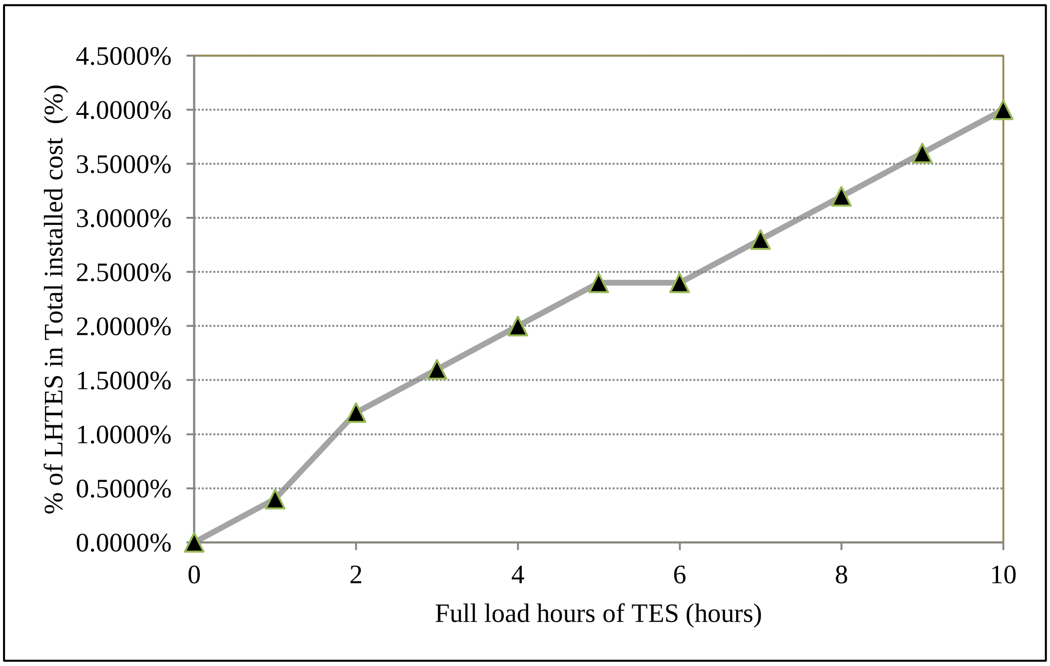

Figure 7 Dependence of LHTES full load hours in Total installed costs.

4. Conclusion

Due to the varying cost index with the location, time and the market, the estimates of many of these values may vary with respect to time. But the intention of producing such a simulation is to give firsthand information on decision making before the construction of a plant. The dependences of the thermal energy storage on the installed cost would help in decision making whether or not to include in an upcoming construction.

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