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Influence of different operation strategies on transient solar thermal power plant simulation models with molten salt as heat transfer fluid

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Abstract

One of the advantages of solar thermal power plants (STPPs) with molten salt as heat transfer fluid is the direct storage system. This means that the thermal energy collected by the solar field and the electric power generation can be fully decoupled. The plant operator must therefore make the daily decision when to start-up or to shut-down the power block (PB). Normally, the solar field of these STPPs is overdesigned which leads to dumping of solar energy during days with high solar radiation, due to the inability of the hot tank and the PB to consume all the collected thermal energy. The PB must therefore start as soon as possible to prevent excessive dumping of solar energy. Contrarily, on days with low solar radiation, the PB should not start too early to prevent a second start-up on this day, because of a low hot tank level. In order to operate within these counter bounds, a fixed and a dynamic operation strategy are proposed. The so-called solar-driven strategy serves as a reference. Using this strategy, the PB operates whenever the solar field is online. The two proposed operation strategies are compared to the reference strategy by means of a transient STPP simulation model. Using the dynamic operation strategy, the annual unnecessary PB start-ups and the auxiliary heater thermal energy for anti-freeze protection are decreased, whereas the annual net electricity is increased.

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1. Introduction

Most solar thermal power plants (STPPs) that are currently being run, harvest solar energy by parabolic trough collectors (PTCs). The energy is then transferred via synthetic oil to the thermodynamic steam cycle. The use of

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Nomenclature		
DNI	Direct normal irradiance (W/m ²)	<i>Abbreviations</i>
j	Control variable from 0 to n (-)	
E	Energy (J)	
\dot{m}	Mass flow (kg/s)	
Q	Specific energy (J/m ²)	
\dot{Q}	Power (W)	
r	Ramp up factor (kg/s/s)	
t	Time (s)	
z	Hot tank level (-)	
<i>Greek letters</i>		
η	efficiency (-)	
<i>Subscripts</i>		
D	at the design point	
dyn	dynamic	
e	electrical	
fix	fixed	
hl	heat losses	
th	thermal	
AH	Auxiliary heater	
BOP	Balance of plant	
CF	Cold feeder	
CH	Cold header	
HF	Hot feeder	
HH	Hot header	
HT	Hot tank	
HTF	Heat transfer fluid	
IS	Indirect storage	
LCoE	Levelized cost of electricity	
MM	Mass multiplier	
OPS	Operation strategy	
PB	Power block	
PF	Profile	
PTC	Parabolic trough collector	
PTR	Parabolic trough receiver	
SF	Solar field	
SEGS	Solar Energy Generating System	
STPP	Solar thermal power plant	

oil as heat transfer media has some drawbacks. The limitation to higher process temperature is regarded as the major drawback for efficiency improvements and, thus, lower electricity costs.

Molten salts as an alternative heat transfer fluid (HTF) for parabolic trough systems show a potential for lowering the levelized cost of electricity (LCoE). Kearney et al. [1] described a possible reduction of LCoE between 14.2 to 17.6% depending on the salt mixture. Turchi et al. [2] approved the LCoE reduction potential, as he published reductions of 6 to 15% depending on different solar field (SF) sizes. Kelly et al. [3] showed that for the case of changing the HTF to salt and the PTC to a more suitable 8-meter aperture, LCoE reduction of 25% are realistic. Kolb and Diver [4] approved this figure. In Wittmann et al. [5] the influence on storage size, high and low process temperature, and employed salt have been assessed. It was demonstrated that further optimization potential can lead to further LCoE reductions.

In STPP energy yield calculation an operation strategy (OPS) which represents the power plant operator has to be defined. Most of the calculations are conducted by using the so-called solar-driven OPS, as described in Eck et al. [6]. It means that the operator's goal is to synchronize the plant to the grid whenever the current solar irradiation situation and the thermal storage charge allow the operation. In reality, the operator does not only use the current state as basis for any operational decision, but also the weather forecast. By looking to the future, the operator is able to reduce non-reasonable power block (PB) starts and stops, and therefore enhance the electricity output.

Lippke [7], and Cerni and Price [8] were the first to publish research on the impact of operational strategies on the SEGS power plant's electricity output. Lippke evaluated the optimal operational SF temperature under different operating conditions. Cerni and Price [8] introduced weather forecasts in order to set up the daily operation schedule. They intended to increase the annual energy generation through more prudent use of the limited natural gas allotment, and through improved maintenance planning. Wittmann et al. [9,10] used mathematical optimization in order to raise the revenues of commercial STPPs under uncertainty of weather and price forecasts. Powell et al. [11] also based their optimizations on weather forecasts. Regarding the classification according to Hirsch et al. [12] the mentioned three works are classified in the high quality level models. García-Barbarena et al. [13] showed the influence on gas consumption of the auxiliary heater (AH). All authors mentioned in this paragraph assessed STPPs

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