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IMPACT OF SALT-TO-STEAM HEAT EXCHANGER FAILURE RATES ON LIFETIME PRODUCTION OF CONCENTRATING SOLAR POWER TOWER PLANTS

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ABSTRACT

Heat exchangers in the steam generation system (SGS) of concentrated solar power (CSP) plants are unique in their functionality. Consequently, equipment replacements have long lead times. A typical CSP plant using an organic Rankine cycle has one or two salt-to-steam trains (SSTs) within the SGS. When one heat exchanger in the SGS fails, the individual SGS fails. We use an existing framework that combines simulation and optimization models to assess the impacts of irrecoverable failures on long-term production. The methodology provides an optimized dispatch with the integration of unplanned simulated failures over a thirty-year period. Our work shows a system of two trains provides resiliency and reduces downtime of a plant by six to eight times compared to a single train. The gross revenue increases by 31% and 11% for single and two trains, respectively, when the expected lifetime increases from five to 10 years.

1 INTRODUCTION

Most dispatch optimization models that prescribe production scheduling for an energy system assume that components have 100% reliability. This can lead to overestimation of long-term production. In a concentrated solar power (CSP) plant, there are typically one or two salt-to-steam trains (SSTs) within the steam generation system (SGS), each of which is comprised of four heat exchangers. Molten salt absorbs sunlight directed to a receiver, then exchanges heat with water producing steam for electricity. Failures in the SGS are a leading cause of maintenance issues and outages in CSP tower plants (Price et al. 2021), and because the heat exchangers in an SST operate in serial, when one heat exchanger fails, the entire SST fails. The lead time for an unrecoverable failure can cause long-term impacts on the productivity of the plant. A prior power sector study cites lead times of 6-26 months for large components (Pauschert 2009). We use a model developed in prior work to estimate the effects of long leads times on long-term CSP plant production, using industry-informed component lifetime distributions in a simulation and optimization framework that schedules daily operations decisions at hourly fidelity over a rolling short-term decisions over a rolling horizon for a 30-year period (Wales et al. 2023).

2 METHODOLOGY AND CASE STUDIES

We use a simulation and optimization model where the goal is to maximize gross revenue:

$$\text{maximize} \sum_{t \in \mathscr{T}} P_t (1 - \eta_t^c) \dot{w}_t \tag{1}$$

where, in time period, t, P_t denotes the electricity sales price [\$/kWh$_e$], η_t^c denotes the ambient temperature-dependent condenser efficiency in time t, and $\dot{w}_t$ represents the gross electrical production at time t [kW$_e$], i.e., we do not account for operations and maintenance costs or electricity consumption for internal operations. The model is constrained by system requirements in both the receiver and power cycle (Wagner et al. 2018). Optimized dispatch schedules serve as input to the simulation model. The simulation model tracks component lifetimes and failures, which, in turn, may cause a failure in the system; when one occurs, the dispatch optimization is resolved starting at the time of failure. The simulation model uses an exponentially distributed repair time with a mean of 12 months when there is an irreparable failure for the evaporator. During the repair, the capacity of the CSP plant is reduced to 0 if there is no train available and to 50% if one of two trains is still operational.

Our case study is a notional 120 MW_e CSP plant in Daggett, California with 15 hours of thermal energy storage and a pricing signal scaled to 13.5 cents/kWh, which is the average power purchase agreement for a CSP plant in Tonopah, Nevada. We look at cases that have one and two trains. In addition, we look at SGS train life cycles of 5, 10, and 30 years. Other component failures that impact plant capacity, such as salt pumps and the turbine, also incur failures in the simulation and have the same impact on plant capacity and efficiency as in the predecessor paper (Wales et al. 2023).

3 RESULTS

Our results, seen in Table 1, show the following for gross revenue, gross power generation, and days down given our different case studies. The days down for the SGS include failures besides the evaporator.

Table 1: Case studies for varying expected evaporator lifetimes and number of SGS trains.

Trains	**Expected Lifetime**	**Revenue ($B)**	**Energy Generation (GWh_e)**	**Days 0 Production**
1	5 years	2.072	15,733	4199
1	10 years	2.719	20,644	2165
1	30 years	3.083	23,415	1012
2	5 years	2.675	20,305	545
2	10 years	2.984	22,655	597
2	30 years	3.050	23,159	319

There is a 31% gross revenue increase for life cycle changes from five to ten years in a single train and a 10% increase for two SSTs. The presence of two SSTs generally reduces downtime by a factor of 3 to 8 depending on life time compared to a single train.

4 CONCLUSIONS AND FUTURE WORK

Our model shows the impacts a long lead time for equipment can have on operations, which is a common issue for CSP plants where it can take more than 12 months to replace a critical piece of equipment. In addition it shows, how having resilient systems with multiple trains can impact operations along with the importance of equipment longevity. This allows for future work in inventory models with long lead times. Even with the redundancy of two SSTs, significant impacts to production and revenue are present when the SGS components are replaced multiple times over the life of the plant; the revenues in Table 1 would be further reduced if production levels were not sufficient to maintain an existing power purchase agreement. This, along with the impact on currently operating plants from the report (Price et al. 2021), suggest that investigating dispatch and startup policies that extend the lifetime of these heat exchangers is an opportunity for future research that can impact long-term CSP plant profitability.

REFERENCES

Pauschert, D. 2009. "Study of Equipment Prices in the Power Sector". *ESMAP Technical Paper* 1(81725). World Bank Group. http://documents.worldbank.org/curated/en/952421468330897396/Study-of-equipment-prices-in-the-power-sector.

Price, H., M. Mehos, D. Kearney, R. Cable, B. Kelly, G. Kolb, and F. Morse. 2021. "Concentrating Solar Power Best Practices". In *Concentrating Solar Power Technology*, 725–757. Elsevier.

Wagner, M. J., W. T. Hamilton, A. Newman, J. Dent, C. Diep, and R. Braun. 2018. "Optimizing Dispatch for a Concentrated Solar Power Tower". *Solar Energy* 174:1198–1211.

Wales, J. G., A. J. Zolan, W. T. Hamilton, A. M. Newman, and M. J. Wagner. 2023. "Combining Simulation and Optimization to Derive Operating Policies for a Concentrating Solar Power Plant". *OR Spectrum* 45(1):119–150.