Minimizing Water Consumption of a CSP Plant, by Using an Optimization Algorithm for Cooling Operation

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Introduction

Complex hybrid cooling systems require optimized operating plans

- Water – a precious and valuable resource
- Water often scarce at CSP locations
- Wet cooling causes over 90% of water consumption
- Cooling system’s complexity rises
- Hybrid cooling systems combine advantages
- Dry cooling → performance loss
- Demand for optimized operating plans
- Cooling operation optimization

Agenda

- Hybrid Cooling Systems
- Optimization Problem
- Cooling Operation Optimization Algorithm
- Simulation Results and Discussion
- Conclusion
Hybrid Cooling Systems
cooling systems using multiple cooling mechanisms

ACC and WCT in parallel  WCT or DC in parallel with cTES

ACC: Air Cooled Condenser  CT: Cooling Tower
SC: Surface Condenser       cTES: Cold Thermal Energy Storage
WCT: Wet Cooling Tower  CWP: Cooling Water Pump
DC: Dry Cooler  SCP: Storage Charging Pump
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Optimization Problem
minimize water consumption and maximize electrical yield

\[
\max_x f(x, y) = \sum_{t=0}^{t_N} \left[ k_{el} \cdot W_{el,netto}^{t} = k_w \cdot V_{ew}^{t} \right]
\]

apply weights

min. water consumption

max. generated electricity
Optimization Problem
transform search space from manipulative quantities to operating states

operating state 1:
Use ACC 100% and WCT 100%

operating state 2:
Use ACC 100% and WCT 50%

operating state 3:
Use ACC 50% and WCT 50%

operating state 4:
Use ACC only

\[ \max_{x} f(x, y) = \sum_{t=0}^{N} \left[ k_{el} \cdot W_{el,netto}^t - k_w \cdot V_{ew}^t \right] \]
Optimization Problem
consider equality and inequality constraints in definition of operating states

**operating state 1:**
Use ACC 100% and WCT 100%

**operating state 2:**
Use ACC 100% and WCT 50%

**operating state 3:**
Use ACC 50% and WCT 50%

**operating state 4:**
Use ACC only

if $p_{\text{cond}} < p_{\text{cond, min}}$ then reduce WCT load

if $p_{\text{cond}} > p_{\text{cond, max}}$ then reduce Power Block load

... 

$a > b$

$a = b + c$

equality and inequality constraints
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Cooling Operation Optimization Algorithm

The optimization algorithm is applicable to a power plant model as a black box.
Cooling Operation Optimization Algorithm
development of an \textit{Ant Colony Optimization} variant

\begin{align*}
\max_x f(x, y) &= \sum_{t=0}^{t_N} \left[ k_{el} \cdot W_{el,netto}^t - k_w \cdot V_{ew}^t \right] \\
\Delta t &= 2h \\
W_{el,3,7}, V_{ew,3,7}, \tau_{3,7}^n, \psi_{3,7}^n
\end{align*}

operating state 1

operating state 2

optimized operating plan

simulate \( K \) paths

update path weights

Deamon activities

find new best path

convergence

\begin{align*}
\max_x f(x, y) &= \sum_{t=0}^{t_N} \left[ k_{el} \cdot W_{el,netto}^t - k_w \cdot V_{ew}^t \right]
\end{align*}
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Simulation Results and Discussion
cooling optimizer finds a better solution

Electrical Yield and Water Consumption

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16 000 000 possible operating plans

![Diagram](chart.png)
Repeated Optimization Runs

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16,000,000 possible operating plans

Simulation Results and Discussion
cooling optimizer finds the same optimum every optimization run

Repeated Optimization Runs

- 50 MW Parabolic Trough Power Plant
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Repeated Optimization Runs

- 50 MW Parabolic Trough Power Plant
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- late summer day
- over 16,000,000 possible operating plans
Simulation Results and Discussion
cooling optimizer is sensitive to water and electricity weights

Parameter Variation of Weights

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16 000 000 possible operating plans

→ decreasing water consumption with increasing weight of water
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Conclusion

Max. 1500 m³

Cooling Operation Optimization Algorithm

Optimized operating plan

Operating state 1

Operating state 2

04:00 08:00 12:00 16:00 20:00 24:00

OS 1

OS 2
Sources

• Craig Turchi, Michael Wagner and Chuck Kutscher. „Water Use in Parabolic Trough Power Plants: Summary Results from WorleyParsons’ Analyses“. In: Contract 303 (Jan. 2010). doi: 10.2172/1001357


• Matthias Loevenich. “Entwicklung eines Einsatz- und Betriebsoptimierers für ein hybrides Kühlsystem mit Kältespeicher zur Wassereinsparung und Ertragssteigerung in einem CSP-Kraftwerk”. June 2021
Thank you for your attention!

Q&A

„Essentially, all models are wrong but some are useful.“
George E. P. Box