Integration of Solar Process Heat into an Existing Thermal Desalination Plant in Qatar


SolarPACES Conference 2015
Cape Town, 13-16 Sep 2015
Overview of Content

1. Solar Resources and Market Situation in Qatar
2. Solar Hybridization Options
   a) DSG: Direct Steam Generation – No Storage
   b) TES: Thermal Oil with 6h Molten Salt Storage
3. Techno-Economic Evaluation of Both Options
4. Feasibility of Solar Only Desalination
5. Summary
Qatar Country Facts

- Peak power demand in 2014: 6500 MW
- Avg. electricity consumer price: 33 US-$/MWh
- Average water consumer price: 1.40 US-$/m³
- Limited land availability
- 4th natural gas producer worldwide
  - Energy supply relies mainly on gas
- 200 MW solar tender announced
Solar Resources in Qatar

Aperture Normal Irradiance: 
\[ ANI = DNI \cdot \cos \theta \]  
(tracking axis south-north oriented)

Annual DNI: 1491 kWh/m²·a

Data Source: Meteonorm 7.1
Ras Abu Fontas Power and Desalination Plant

- Steam network:
  - Saturated steam, 15 bar / 198°C
- Condensate temperature: 80°C
- Desalination steam demand
  - 10% at 198°C (vacuum ejectors)
  - 90% at 120°C (brine heater)
- Auxiliary firing to cover residual steam demand

<table>
<thead>
<tr>
<th>Gas turbines</th>
<th>Desalination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>200 MIGD</td>
</tr>
<tr>
<td>No. Units</td>
<td>24</td>
</tr>
<tr>
<td>Waste Heat Steam Production</td>
<td>4260 t/h</td>
</tr>
<tr>
<td>Steam Demand</td>
<td>4640 t/h</td>
</tr>
</tbody>
</table>
Investigated Solar Field Configurations

- Solarlite SL4600+ collectors
- Storage medium Hitec® salt
  - $T_{\text{freeze}} = 142^\circ\text{C}$
- Techno-economic analysis using greenius

$\rightarrow$ http://freegreenius.dlr.de

<table>
<thead>
<tr>
<th>Property</th>
<th>DSG No Storage</th>
<th>Thermal Oil 6h TES</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Collectors</td>
<td>1080</td>
<td>2160</td>
<td>-</td>
</tr>
<tr>
<td>Solar Multiple</td>
<td>1</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Nominal SF Output</td>
<td>240</td>
<td>480</td>
<td>[MW]</td>
</tr>
<tr>
<td>Aperture Area</td>
<td>570,000</td>
<td>1,140,000</td>
<td>[m²]</td>
</tr>
<tr>
<td>SF Inlet/Outlet Temperatures</td>
<td>80 / 198</td>
<td>220 / 320</td>
<td>[°C]</td>
</tr>
<tr>
<td>Storage Capacity</td>
<td>-</td>
<td>1440</td>
<td>[MWh]</td>
</tr>
</tbody>
</table>
Results – Monthly Solar Field Output

- SF Output - 6h TES [GWh]
- SF Output - DSG [GWh]
- Spec. SF Output - 6h TES [Wh/m²]
- Spec. SF Output - DSG [Wh/m²]

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

0   | 50  | 40  | 30  | 20  | 10  | 0   | 50  | 40  | 30  | 20  | 10  |
Results – Comparison of DSG and TES Option

<table>
<thead>
<tr>
<th>Property</th>
<th>DSG No Storage</th>
<th>Thermal Oil 6h TES</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Solar Steam Production</td>
<td>661</td>
<td>1240</td>
<td>[1000 t]</td>
</tr>
<tr>
<td>Saved Fuel per Year</td>
<td>1.81</td>
<td>3.41</td>
<td>[10^6 MMBtu]</td>
</tr>
<tr>
<td>CO₂ Emission Savings per Year</td>
<td>108</td>
<td>204</td>
<td>[1000 t]</td>
</tr>
<tr>
<td>Mean Solar Field Efficiency</td>
<td>53.0</td>
<td>49.9</td>
<td>[%]</td>
</tr>
<tr>
<td>Solar Share</td>
<td>22</td>
<td>41</td>
<td>[%]</td>
</tr>
</tbody>
</table>

- 6% lower SF output with TES option
- Due to higher operating temperature
- Seasonal variation is relatively weak
Economy: Levelized Heat Cost and Rate of Return

<table>
<thead>
<tr>
<th></th>
<th>DSG</th>
<th>Oil</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX (incl. land cost ≈ 20%)</td>
<td>249 / 435</td>
<td>634 / 555</td>
<td>[Mio $] / [$/m²]</td>
</tr>
<tr>
<td>OPEX</td>
<td>5.9</td>
<td>8.3</td>
<td>[$/m²]</td>
</tr>
<tr>
<td>Levelized heat cost (LHC)</td>
<td>68</td>
<td>94</td>
<td>[$/MWh_{th}]</td>
</tr>
</tbody>
</table>

- LHC of fossil reference about 36 $/MWh_{th} (fuel price: 8 $/MMBtu)
- Costs estimations by experts from QEWC, Solarlite and DLR
- Financing:
  - Discount rate: 10%
  - Equity share: 30%
  - Average debt interest: 2.5%

<table>
<thead>
<tr>
<th>Total Fuel Costs / Opportunity Costs</th>
<th>[$/MMBtu]</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Remuneration Tariff</td>
<td>[$/MWh_{steam}]</td>
<td>16.2</td>
<td>32.3</td>
<td>48.3</td>
<td>64.4</td>
</tr>
<tr>
<td>Internal Rate of Return (DSG option)</td>
<td>[%]</td>
<td>-5.5</td>
<td>4.8</td>
<td>13.1</td>
<td>21.4</td>
</tr>
</tbody>
</table>
Solar Only Operation

- Two desalination units (steam demand: 2 x 175 t/h)
- Minimum part load 80%
- In winter months (Nov – Feb) only one unit operating

Results 24h TES:
- Shutdowns per year : 30
- Capacity factor: 86%
- Dumping: 24%
- Levelized heat cost: +43%
  (compared to 6h storage)
Energy Flows with 24h Thermal Storage

[Graph showing energy flows with various labels: SF Output, Delta Storage, Heat To Desalination, Dumping, Storage Level]
Summary

- Qatar offers challenging environment for CSP
  - Limited solar irradiation potential DNI ≤1800kWh/(m²·a)
  - Limited land availability
- Solar energy as fuel saver becomes attractive (IRR > 5%) for fuel prices > 8 $/MMBtu
- TES with 24h capacity achieves capacity factors of 86%
  - 30 shutdowns per year require flexible desalination technology for solar only operation
- Co-generation of electricity and water not investigated
We gratefully acknowledge the financial support from the German Federal Ministry for Economic Affairs and Energy for the QatDLR project!
Funding Reference: 03ET4008B

THANK YOU for your attention

Contributing Authors:
S. Dieckmann, J. Dersch, D. Krüger
German Aerospace Center (DLR)
G. Krishnamoorthy, M. Aboumadi, A. S. Al-Rasheed
Qatar Electricity & Water Company (QEWC)
Y. Pandian, J. Krüger
Solarlite CSP Technology GmbH
U. Ottenburger
Al Nasr Holding Co. WLL

Corresponding Author:
Simon Dieckmann
German Aerospace Center (DLR)
Institute of Solar Research
51170 Köln, Germany
Simon.Dieckmann@dlr.de