Combined Solar Thermal and PV Power Plants – an Approach to 24h Solar Electricity?

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Solar Thermal Technology for Heat and Electricity

Optics and Material Science	Solar Thermal Collectors	Solar Thermal Systems Engineering
■ PVD coatings	■ Collector development	■ DHW and heating
■ Surface analytics	■ Certified TestLab	■ Process heat
■ Vacuum technology	■ Heat transfer	■ Solar thermal power
■ Micro structuring	■ Concentrator optics	■ Thermal storage
■ Degradation	■ Structural mechanics	■ Water treatment

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- Definition of Case Study
- Results
  - CSP Power Plant without PV
  - Combination of CSP with FPV
  - Combination of CSP with CPV
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Introduction

Advantages

- CSP: Dispatchability using Thermal Energy Storage (TES) allows a generation of electricity in high-load situations, even at night time
- PV: Strongly decreased investment cost due to the large market growth lead to much lower LCOE compared to CSP
- Combination of CSP + PV might lead to low cost dispatchable solar power

Developers have taken up recently the approach to combine CSP and PV:

- Copiapó 130 MW CSP-150 MW PV Chile (Solar Reserve)
- Redstone 100 MW CSP-75/97 MW PV South Africa (ACWA, Solar Reserve)
- Complejo Atacama 1+2, 110 MW CSP-100 MW PV Chile (Abengoa)

Introduction

Possible integration approaches for combining CSP and PV

- Use of PV in order to operate CSP plant (pumps, controls etc.) during daytime
  - Reduce difference between gross and net electricity generation of CSP

- Use of PV for generation during daytime and CSP with TES for generation during remaining time
  - Solar field sizes may be decreased
  - Operation hours of turbine are reduced

- Use of PV for generation during daytime and CSP with TES for supplementing the generation (day and night)
  - Solar field sizes may be decreased
  - Operation hours of turbine are high

Description of Methodology

- Annual performance calculation
- Quasistatic steady-state approach
  - Comparable with Greenius, TRNSYS, SAM,…
  - Hourly time-step
  - No detailed transient effects
- High flexibility of model

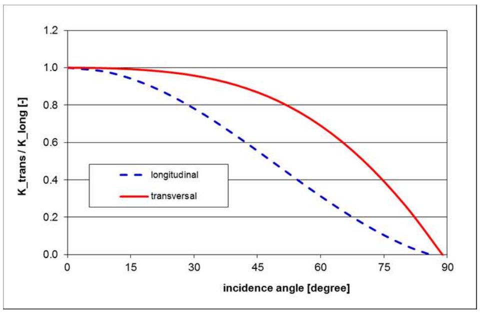
- Comparison with same weather data for all technologies
- Cost assumptions for cost categories
  CSP cost: Reference data from presentation this conference

  W.Platzer, F. Dinter: A Learning Curve for Solar Thermal Power – how can we learn from Photovoltaics? SolarPACES 2015, Thursday 16:55h

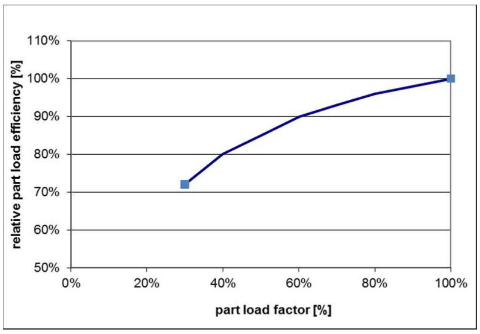
Description of Solar thermal power plant

Performance simulation

- Collector model for linear concentrating collectors
  - 2D incidence angle modifier
  - Receiver loss (T_{abs})
  - Coll. Eff. Factor F'=0.95
  - Thermal loss piping 21 W/m²
- Two-tank storage model
- Simple one-phase heat transfer fluid
- On/off controller logic
- Power block: Efficiency curve
- Direct normal irradiation and ambient temperature



Example IAM curves



Partload efficiency power block

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Description of PV power plant

Flat-plate PV

- Tilted modules
  - Row shading neglected
  - 30° tilt towards equator
  - ASHRAE incidence angle modifier
  - Temperature effects by simple model of Kratchovil
- Global irradiation on tilted plane with diffuse sky and ground radiation

Concentrator PV

- Fully tracked modules
  - Constant average efficiency 28%
- Direct normal irradiation DNI

Source: Soitec Solar, 2013

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Cost assumptions

Analysis period	25a
Insurance cost	1.0%/a
Capital cost (WACC)	8.0%/a
Operation and maintenance	1.5%/a

Flat plate PV	1000 €/kW
Concentrator PV	1400 €/kW

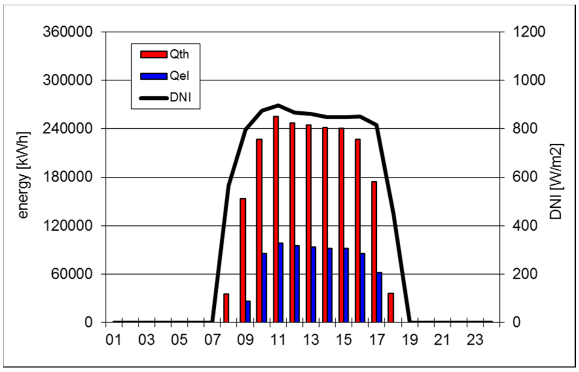
Subsystem	Reference@3 GW
Solar field (incl. Rec./HTF/pip)	254 €/m2
Thermal storage	40 €/kWh
Power block and BOP	762 €/kW
Civil and site works	35 €/m2

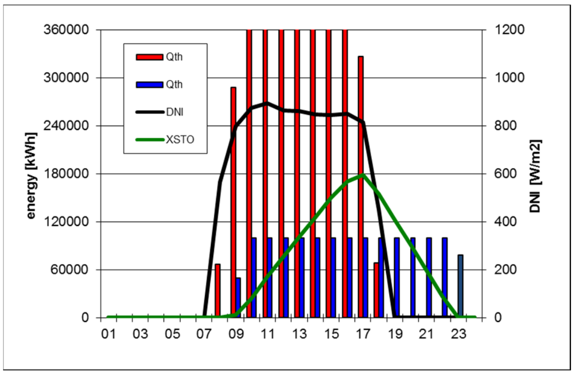
Results

CSP Power Plant without PV as Reference

Molten salt Fresnel power plant 100 MW with direct 2-tank storage

Upington, South Africa





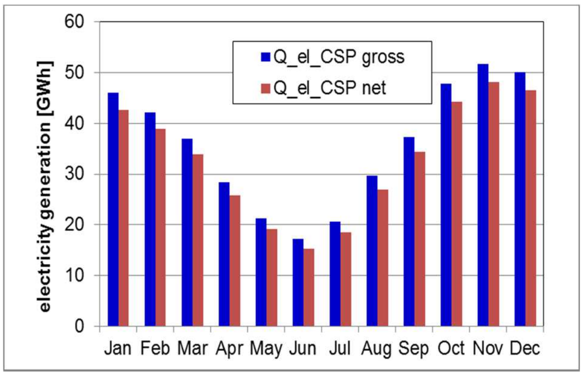
Hourly DNI (black), produced thermal energy Q_{th} (red) and generated electricity Q_{el} (blue) for the case SM=1.48 w/o TES (left) and SM=2.78 with 9h TES (right); the green curve XSTO shows the filling level of the hot storage (1000 on the right axis equivalent to 100%)

CSP Power Plant without PV as Reference

Aperture area	1000 m²	614	960	1152	1382.4	1536
Solar multiple	SM	1.48	2.31	2.78	3.33	3.7
Storage cap.	h	0	6	9	12	15
Q_{el} (gross)	GWh/a	205.6	353.7	429.8	517.2	571.5
Q_{el} (net)	GWh/a	187.6	324.7	394.9	475.2	524.9
Op. Hours	h	2980	4018	4693	5517	5979
Cap. Factor CF	%	21%	37%	45%	54%	60%
CAPEX	€/kW	3043	5018	6072	7260	8181
LEC	€/kWh	0.192	0.183	0.182	0.181	0.185

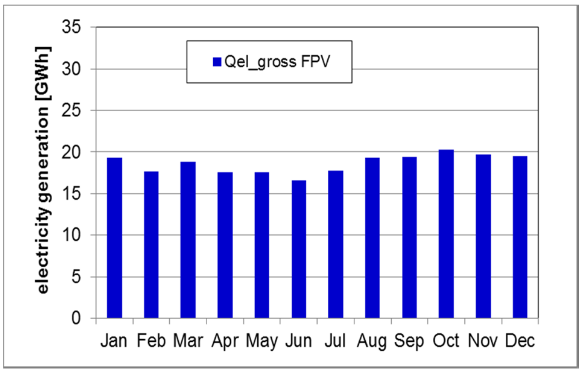
CSP Power Plant with Flat-plate PV-modules (FPV)

Comparison Linear Fresnel Collector (LFC)



Monthly electricity generation (gross and net) for the 100 MW LFC plant with SM=2.78 and 9h TES

Flat-plate PV 30° tilted



Monthly electricity generation for a 100 MW FPV plant, Upington, South Africa

CSP Power Plant with Flat-plate PV-modules (FPV)

Aperture area	1000 m2	2112	1920	1728	1536	1344	1152
Q_{el} (gross)	GWh/a	802.5	775.1	742.9	707.8	665.7	614.6
Q_{el} (net)	GWh/a	735.8	712.8	685.3	654.9	617.7	571.9
Op. Hours	h	8113	7963	7783	7576	7350	7044
CF	%	84%	81%	78%	75%	71%	65%
CAPEX	€/kW	10800	10134	9468	8802	8137	7471
LEC	€/kWh	0.172	0.166	0.162	0.157	0.154	0.152

Results for a combined **100 MW FPV-100 MW** LFC power plant (15h TES)

CSP Power Plant with Flat-plate PV-modules (FPV)

Aperture area	1000 m^2	1728	1536	1344	1152	960	768
Q_{el} (gross)	GWh/a	857.6	824.4	786.6	740.4	683.4	612.2
Q_{el} (net)	GWh/a	795.4	766.9	733.9	692.7	641.2	575.8
Op. Hours	h	8047	7875	7686	7437	7110	6814
CF	%	91%	88%	84%	79%	73%	66%
CAPEX	€/kW	10143	9477	8812	8146	7480	6814
LEC	€/kWh	0.148	0.143	0.139	0.136	0.134	0.136

Results for a combined **150 MW FPV-100 MW LFC** power plant (15h TES)

CSP Power Plant with Concentrator PV (CPV)

Aperture area	1000 m^2	1536	1344	1152	960	768	576
Q_{el} (gross)	GWh/a	900.8	865.4	823.8	771.6	708.3	635.6
Q_{el} (net)	GWh/a	840.0	809.4	772.8	725.8	668.1	601.2
Op. Hours	h	7759	7566	7349	7066	6673	6082
CF	%	96%	92%	88%	83%	76%	69%
CAPEX	€/kW	10100	9434	8768	8102	7437	6771
LEC	€/kWh	0.129	0.126	0.122	0.120	0.120	0.121

Results for a combined 150 MW CPV-100 MW LFC power plant (15h TES)

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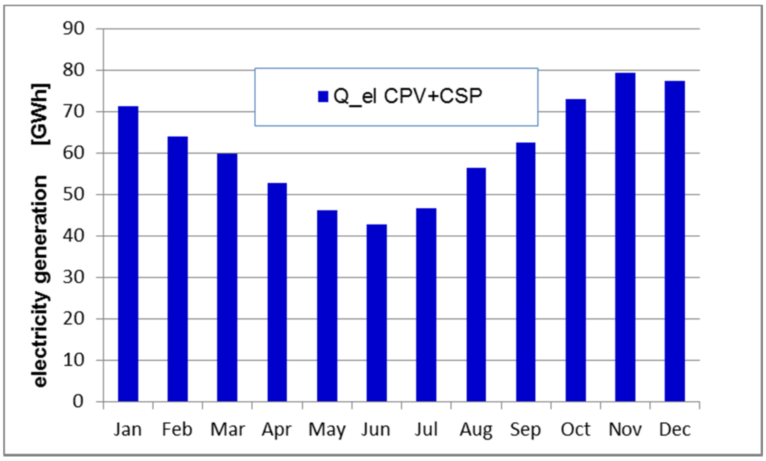
CSP Power Plant with Concentrator PV (CPV)

Monthly electricity production by combined CSP-CPV power plant 100 MW_e for Upington, South Africa; (150 MW CPV, 15h TES, Solar field SM 2.2)



- Net generation of 715 GWh/a is split up into generation by CPV of 412 GWh/a and by the storage CSP plant of 303 GWh/a

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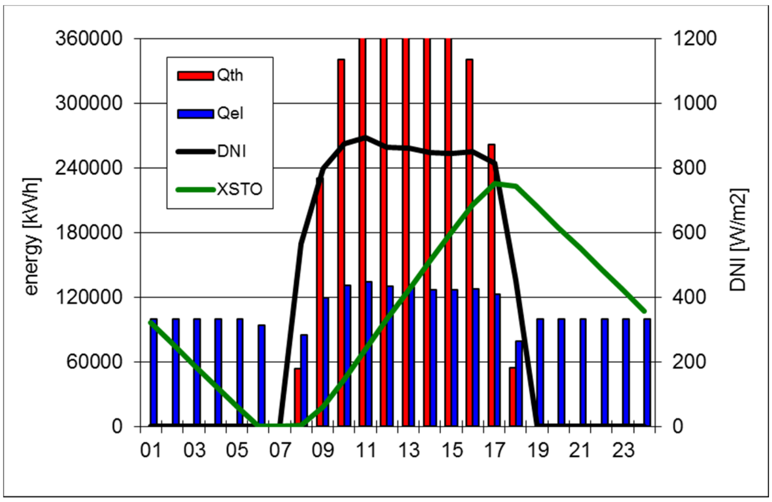
CSP Power Plant with Concentrator PV (CPV)

Hourly electricity production by combined CSP-CPV power plant 100 MW_e Upington, SM 2.2, 15h storage, 150 MWe CPV



21st March - XSTO: relative charge state (0=empty, 1000=full), Qth: thermal production of collector, Qel: gross electricity generation

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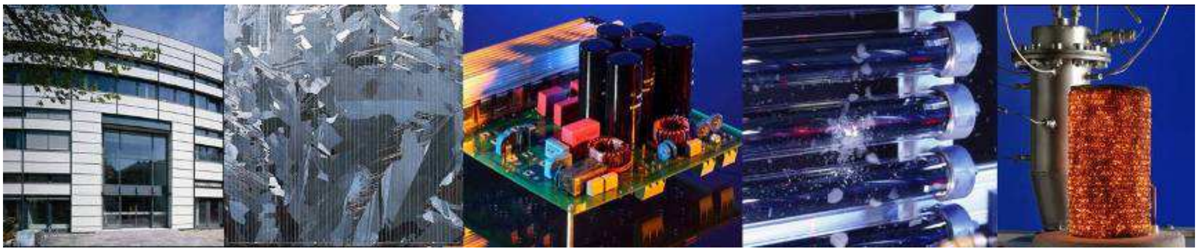
Summary and Conclusions

- Using the new concept of combining CSP and CPV a capacity factor of 80% can be reached
- Simultaneously the LEC is lower for a hybrid PV-CSP plant than for a CSP power plant without photovoltaics
- A molten salt Linear Fresnel collector with a large direct 2-tank storage is offering attractive cost options
- Storage capacities of about 15 h are needed

- Power plant design has to be optimized in details like storage size and reduction of excess generation above the nominal 100 MWe
- Operational details also need more investigation – influenced by demand and tariffs!

Thank you for listening!



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