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Power and Energy Systems Technologies & Economics

Case Study Integrated Techno-Economic Model for Parabolic Trough Solar Power Plants

Notes:

1. Cells with black characters include inputs
2. Cells with red characters include formulas
4. Download of Add-Ins (Macros) from website required
5. Description of Case Study in Section 5.5.3 in the book

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The Examples are solely and exclusively indented to provide support and assistance to the readers for practicing and better understanding of the theoretical part of this book.

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Proposals for improvements of the contents are welcome and will be considered in upcoming updates!

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Summary

Item	Unit	100 MW		
		TES 0 h	TES 8 h	TES 12 h
Power balance				
Power output, solar field operation	MW	100		
Power output, TES operation	MW	85		
Number of collectors	-	655	1,400	1,773
Solar field heat production	MJ / s	271	579	734
Thermal Storage	hours	-	8	12
Solar multiple	-	1.0	2.1	2.7
Energy balance				
Annual irradiation DNI	kWh / (m ² a)	2,400		
Solar heat to power block	GWh _t / a	591	1,263	1,599
Net electricity production	GWh _e /a	213	456	578
Financial parameters				
Discount rate, in real terms (WACC)	-	4.6%		
Project lifetime	years	25		
Capital expenditures, US\$2014, ± 20%	mIn US\$	402	766	937
Electricity generation costs, in real terms, 2014				
Annual generation cost	mIn US\$ / a	39.2	71.0	87.1
of which capital cost		70%	73%	73%
Levelized electricity cost	US\$ / MWh	214	181	175

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Input Solar Field

Item	Unit	100 MW		
		TES 0 h	TES 8 h	TES 12 h
Site parameters				
Latitude	degrees	28		
Irradiance, solar noon equinox	W/m ²	900		
Annual irradiation	kWh /m ² a	2,400		
Collector net aperture area	m ²	817		
Thermal storage				
Capacity per unit	MWh	925		
Number of units	-	-	2	3
Charge time	h	-	6	6
Discharge hours	h	-	8	12

*) Cycle calculation with KPRO[®] see also heat flow diagram and table in text part

For LEC calculations with escalation rates ? Insert yes	➔	yes	!!!!
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Input Power Block

Item	Unit	Solar field direct	Thermal storage
Power output	MW	100	85
Solar heat input	MJ / s	271	234
Electrical efficiency	-	36.9%	36.3%
Live steam	bar / °C	103 / 377	88.6 / 359
Reheat stem	bar / °C	22 / 377	19 / 359

Note: Cycle calculation with KPRO[®] Fichtner

Solar_Fied_thermal_capacity

Item	Unit	100 MW		
		TES 0 h	TES 8 h	TES 12 h
Thermal storage				
Solar heat for power plant, solar field operation	MJ / s	271		
Solar heat for power plant, storage operation		234		
Storage capacity, total	MWh	0	1,850	2,775
Charging time	h	0	6	6
Discharge time, storage operation	h	0.0	7.9	11.9
Solar field heat production, required	MJ / s	271	579	734
Solar multiple		1.0	2.1	2.7
Sola field				
Latitude	digress	28		
Irradiance DNI, solar noon, summer solstice	W / m ²	900		
Incident angle modifier IAM	-	0.88		
Effective DNI	W / m ²	795		
Collector thermal efficiency	80% nominal	0.64		
Collector net aperture area	m ²	817		
Collector heat capacity	KJ / s	414		
Number of collectors	-	655	1,400	1,773
Total aperture area solar field	1000 m ²	535	1,144	1,448
Total heat production of solar field	MJ / s	271	579	734

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Solar Field Size

Item	Unit	100 MW			
		TES 0 h	TES 8 h	TES 12 h	
Size of solar field					
Direction of center line of collector	-	N-S	N-S	N-S	
Net aperture area, Solar field	1000 m ²	535	1,144	1,448	
North South dimension of Solar Field	m	1,315	2,585	3,220	
East West dimension of Solar Field	m	1,641	1,739	1,759	
Land area of Solar Field	1000 m ²	2,159	4,495	5,663	
Factor Land area / Collector area	-	4.03	3.93	3.91	
Number of Collector and loops					
Number of subfields (N-S)	-	4	8	10	
Number of collectors	-	655	1,400	1,773	
Number of Collectors for each loop	-	4	4	4	
Number of loops	-	164	350	443	
Collector size					
Length of one collector	m	148.50	148.50	148.50	
Width of one collector	m	5.77	5.77	5.77	
Width for Header Piping in center of Solar field	m	10	10	10	
Center line distance between adjacent collectors	m	17.3	17.3	17.3	
Longitudinal distance between adjacent collectors	m	3	3	3	
Width of roads (around solar field)	m	35	35	35	

CAPEX

Item	Unit	100 MW		
		TES 0 h	TES 8 h	TES 12 h
Exchange rate	Euro/US\$	1.4		
Nominal plant size				
Rated electric power, gross	MW _e	100	100	100
Number of collectors	-	655	1,400	1,773
Aperture area of solar field	1000 m ²	535	1,144	1,448
Thermal storage units	-	-	2	3
Thermal storage	MWh	-	1,850	2,775
EPC Contract Costs	mIn US\$	325.9	638.1	794.0
Solar Field	mIn US\$	156.6	295.2	366.0
HTF System	mIn US\$	33.0	61.8	77.9
Thermal Energy Storage	mIn US\$	-	126.0	189.0
Power Block	mIn US\$	107.8	107.8	107.8
Balance of Plant	mIn US\$	28.5	47.3	53.3
Engineering	mIn US\$	18.7	31.9	35.7
Contingencies	mIn US\$	39.1	63.8	71.5
Owners Costs	mIn US\$	17.9	31.9	35.7
Grand Total, 2014, ± 20%	mIn US\$	401.7	765.7	937.0
Specific CAPEX	US\$ / kW	4,017	7,657	9,370

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OPEX

Item	Unit	100 MW			
		TES 0 h	TES 8 h	TES 12 h	
Technical-financial constraints					
Exchange rate	EURO / US\$	1.40	1.40	1.40	
Aperture area	1000 m ²	535	1,144	1,448	
Land area of solar plant	1000 m ²	2,159	4,495	5,663	
Power generation, gross	GWh / a	213.4	456.2	577.6	
EPC Price					
	mIn US\$	325.9	638.1	794.0	
Solar Field	mIn US\$	156.6	295.2	366.0	
Thermal Storage + HTF System	mIn US\$	33.0	187.8	266.9	
Power block + BoB	mIn US\$	136.3	155.1	161.1	
Consumables					
Lease cost	US\$ / m ²	1.0	1.0	1.0	
Number of operating staff	-	45	55	65	
Manpower cost (average)	1000 US\$ / a	65.0	65.0	65.0	
Price diesel fuel	US\$ / liter	0.8	0.8	0.8	
Fuel consumption	1000 Liter / a	120	120	120	
Raw water	US\$ / m ³	1.00	1.00	1.00	
Annual raw water consumption	1000 m ³ / a	73.9	157.9	199.9	
HTF Consumption	t / a	60.8	54.3	64.1	
HTF price	US\$ / t	3,000	3,000	3,000	
Annual OPEX					
Fixed O&M Costs:		1000 US\$/a	9,972	17,641	21,798
Solar field & storage system	1000 US\$/a	1,896	4,830	6,329	
Power block	1000 US\$/a	1,363	1,551	1,611	
Personnel	1000 US\$/a	2,925	3,575	4,225	
Lease	1000 US\$/a	2,159	4,495	5,663	
Insurance	1000 US\$/a	1,629	3,190	3,970	
Variable O&M Costs:		1000 US\$/a	672	1,101	1,355
Fuel	1000 US\$/a	96	96	96	
Water	1000 US\$/a	74	158	200	
HTF refill	1000 US\$/a	182	163	192	
Other consumables & residues *)	1000 US\$/a	320	684	866	
Total OPEX		1000 US\$/a	10,644	18,742	23,153

*) Electricity import, nitrogen, chemicals

Item			Equity	Debt
Asset shares	%		20	80.0
Risk free rate of return	% /a		5.0%	5.0%
Risk and venture premium	% /a		5.0%	0.0%
Subtotal after corporate tax	% /a		10.0%	5.0%
Corporate tax rate 25%	% /a		3.3%	0.0%
Cost of capital, before inflation	% /a		13.3%	5.0%
Weighted average cost of capital	% /a		6.67%	
./ Inflation	% /a		2.00%	
WACC inflation adjusted	% /a		4.58%	

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LEC_Calc

Item	Unit	100 MW				
		TES 0 h	TES 8 h	TES 12 h		
Solar Field						
Aperture area, total	1000 m ²	535	1,144	1,448		
Solar field heat output	MJ/s	271	579	734		
Heat supply to power block, solar field direct	MJ / s	271	271	271		
Heat supply to power block, TES operation	MJ / s	234	234	234		
Solar Multiple	-	1.0	2.1	2.7		
Thermal Storage						
	MWh	0	1,850	2,775		
Charging time	h	-	6.0	6.0		
Discharging time	h	-	7.9	11.9		
Technical Parameter, Power Plant						
Rated power output, field operation	MW	100	100	100		
Power output, gross, TES operation	MW	85	85	85		
Electrical efficiency, gross	%	36.9%	36.9%	36.9%		
Condenser	-	Air cooled				
Annual Production						
Annual irradiation DNI	kWh / m ² a	2,400.0	2,400.0	2,400.0		
Solar heat to power block	46.0% GWh _t / a	590.8	1,263.0	1,599.1		
Electricity production	-0.20%/a 0.98 GWh _e / a	213.4	456.2	577.6		
of which in TES operation	GWh _e / a	0.0	242.8	364.2		
Auxiliary consumption	14.0% GWh _e / a	29.9	63.9	80.9		
Net electricity production	GWh _e / a	183.5	392.3	496.7		
Capacity factor	-	24.4%	52.1%	65.9%		
Full load hours, ref. field rated output	h / a	2,134	4,562	5,776		
Techno-Economic Parameters						
Basic year	-	2014	2014	2014		
Project life time	a	25	25	25		
Discount rate, in real terms	%	4.6%	4.6%	4.6%		
Capital Expenditures (CAPEX), US\$2014; ±20%		mIn US\$	401.7	765.7	937.0	
specific		US\$ / kW	4,017	7,657	9,370	
Levelized annual costs, in real terms						
Annualized Capex		1000 US\$ / a	27,298	52,037	63,677	
OPEX, fixed *)	1.00%/a	1.115 1000 US\$ / a	11,122	17,641	21,798	
OPEX, variable *)	1.50%/a	1.180 1001 US\$ / a	793	1,299	1,598	
Total		1000 US\$ / a	39,213	70,977	87,072	
Levelized electricity cost		US\$ / MWh	213.66	180.91	175.29	

*) Escalation rates 1.00%/a 1.5%/a

Electricity to solar heat (DNI)	14.3%	14.3%	14.3%
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CAPEX breakdown Option 100 MW, 8 h TES

