New Design of Heat Recovery Steam Generator (HRSG) for Solar Thermal Hybrid Power Plants ISCCS (Integrated Solar Combined Cycle System)

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Abstract

One of the cheapest renewable energy productions is the hybrid solar thermal power plant. This is a thermal solar power production linked with a combined cycle process (CCP). The advantages are:

- Very high efficiencies due to high superheat and reheat temperatures
- Extra energy extraction out of the flue gas, flue gas exit temperature drops
- Rather low invest cost because of use of standard gas turbine and standard steam turbine
- Very flexible operating modes, also in the night and with no sunshine

For high solar thermal power production linked into a combined cycle power plant a special HRSG design has to be taken in consideration to keep the invest and operation cost low. The optimisation has to be done with 3 mayor operation modes:

- Only gas turbine mode
- With maximum solar thermal power
- With maximum duct fire

For each case there would be an optimum size of superheaters, reheaters, evapoators and economizers, but there is only one size for all cases possible.

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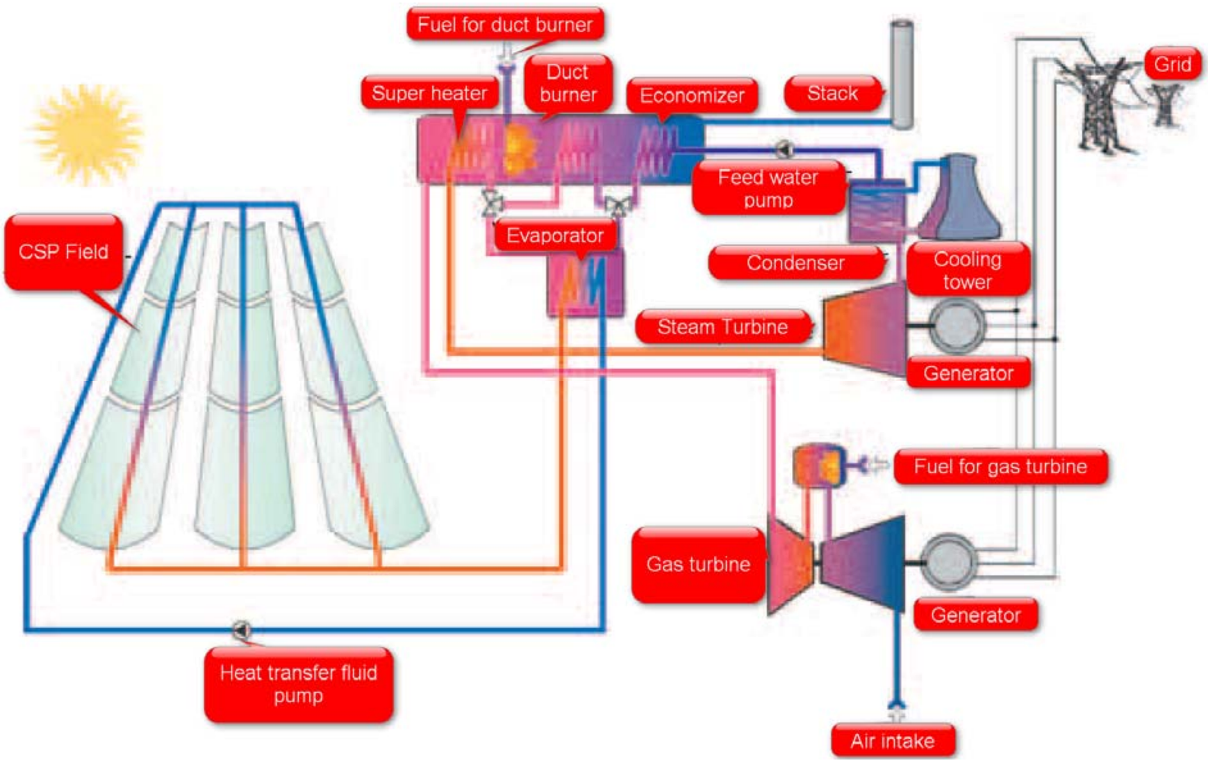
[1] KED (Kraftwerktechnik Entwicklung Dynamik) is a Germany based engineering and consulting company www.ked.de

[2] Bertsch is an Austria based OEM boiler manufactory www.bertsch.at

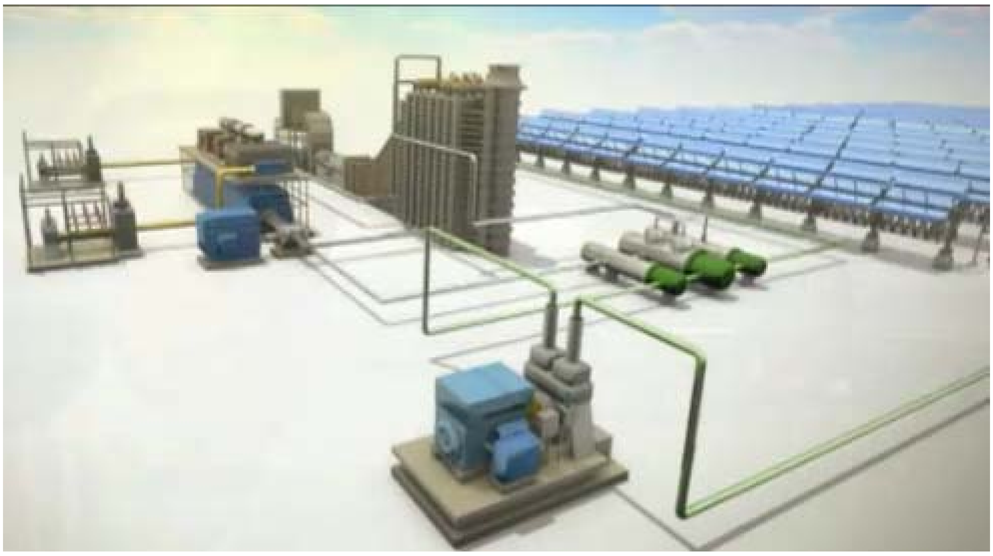
This paper shows how to find an optimal solution and show the basic techniques are used to solve this problem. Each of the techniques is proven many times but rarely have all the techniques been used combined in a HRSG for a ISCCS. The design of the HRSG and the thermal power steam generator must been proven as reliable in all operation modes and be able to operate in a fast transient mode.

What is a Solar Thermal Hybrid Power Plant?

At a thermal hybrid solar power plant (is the same as a ISCCS (Integrated Solar Combined Cycle System)) a concentrated solar power (CSP) field is integrated in a combined cycle power plant (CCP). The heat recovery steam generator (HRSG) is so modified, that the additional steam from the solar field is superheated in the HRSG and the feed water is preheated in the HRSG.



Pic [1] see also Ref [1]


Pic [2] Florida Power & Light ISCCS

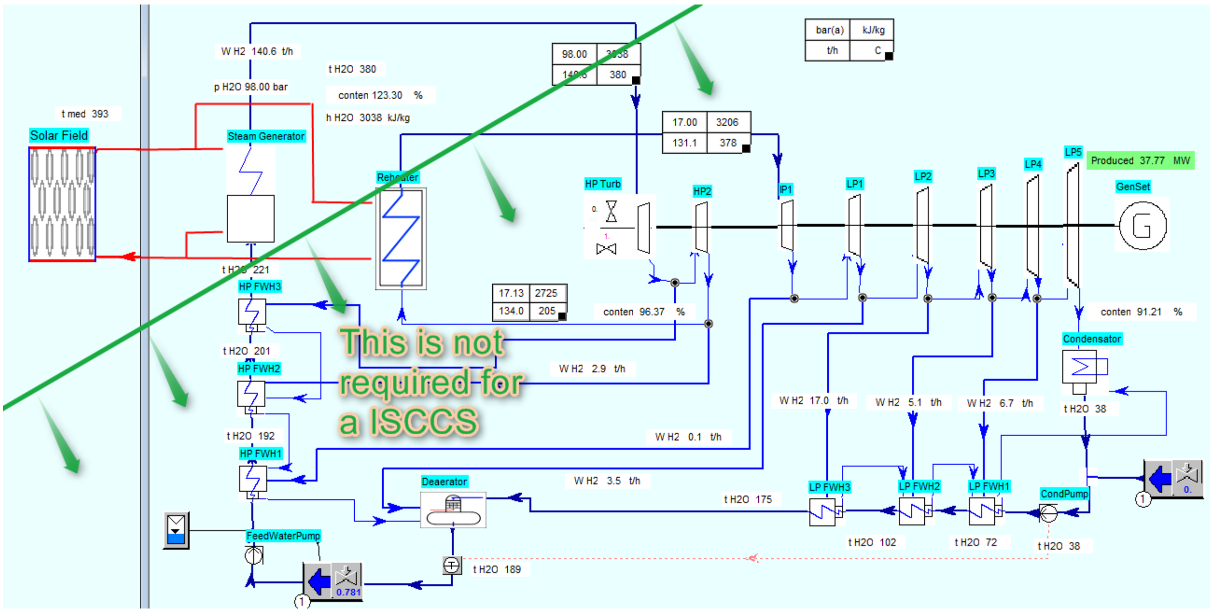
The advantages and disadvantages of a ISCCS are:

Advantages

- Very high efficiencies due to high superheat and reheat temperatures
- Extra energy extraction out of the flue gas, flue gas exit temperature drops
- Rather low invest cost because of use of standard gas turbine and standard steam turbine
- Very flexible operating modes, also in the night and with no sunshine
- Not so many start ups and shut downs
- No feed water preheat system required
- No thermal solar steam superheater and economizer required

Disadvantages

- Need of fossil fuel
- Modified HRSG



Pic [3] Typical CSP power plant; the parts below the green line is not needed with ISCCS

Design of a ISCCS HRSG

Design criteria for HRSGs are:

- Pinch point
- Approach point
- Pressure drop flue gas side
- Pressure drop water / steam side
- Velocities Water – Evaporator – Saturated steam- Superheated steam
- Steaming in Economizer
- Spray cooling
- Material / Max material temperatures
- Fin Temperatures
- Natural circulation system
- Cold end temperature
- Etc.

9FA Simple-Cycle Performance Ratings

	50 Hz
Output	256 MW
Heat Rate	9,250 Btu/kWh 9,757 kJ/kWh
Pressure Ratio	17.0:1
Mass Flow	1,413 lb/sec 641 kg/sec
Turbine Speed	3,000 rpm
Exhaust Temperature	1,116°F 602°C

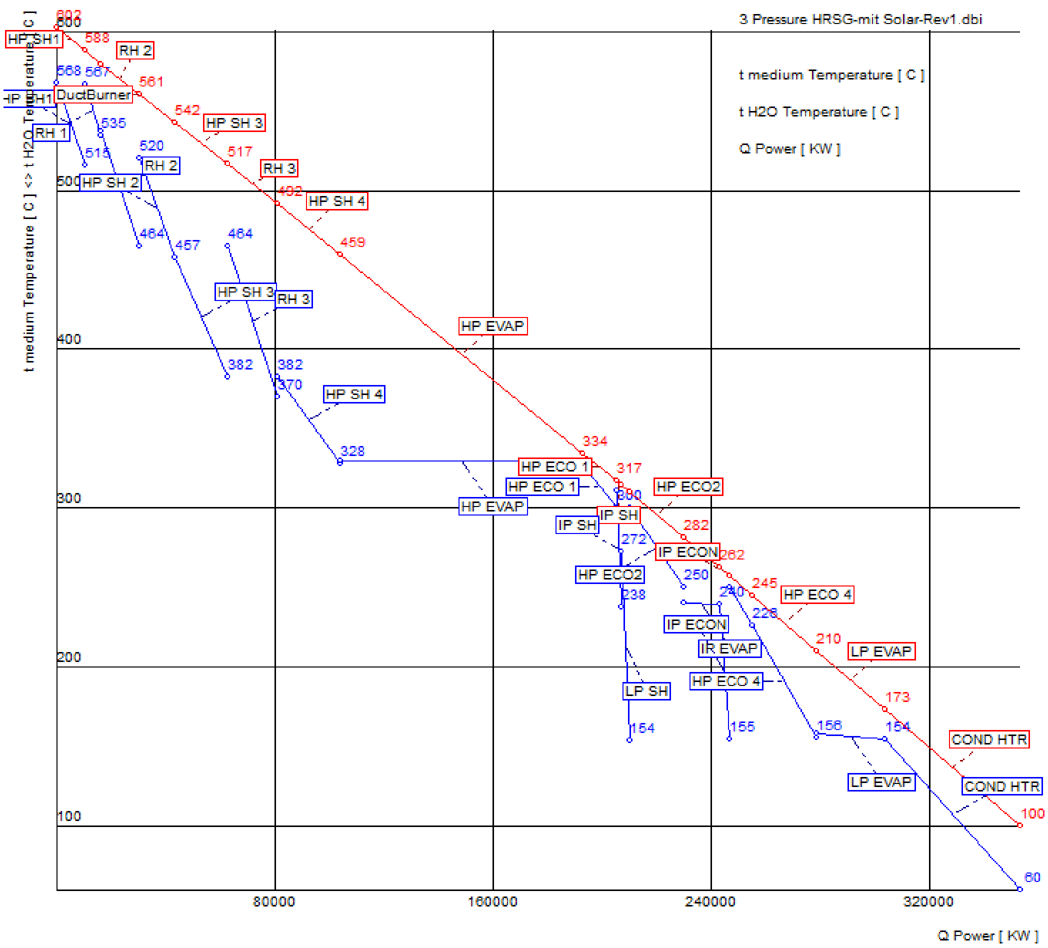
Pic [4]
Gas turbine data Ref [2]

See also HRSG Heat Recovery Steam Generators Design and Operation Ref [3]

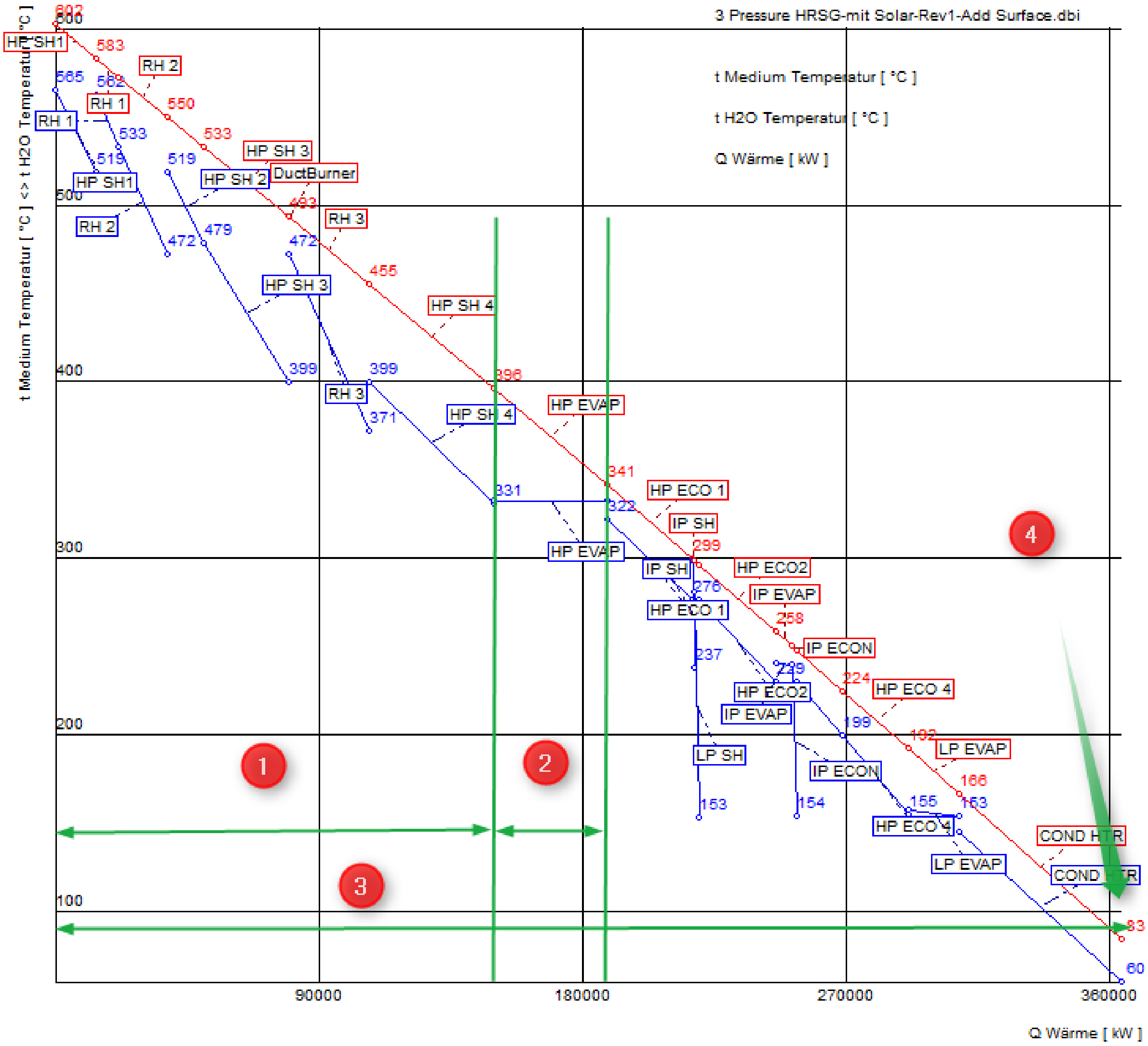
For a HRSG integrated in a hybrid solar thermal power plant there are the same design criteria valid as for HRSGs in typical CCPs.

The approach for designing a HRSG is in short words:

- Specify the gas turbine flue gas data (see pic. [4])
- Take some HRSG and calculate with some computer program a heating power vs. temperature diagram (Q- T diagram).
- Adjust the heating surface so that the pinch point (temperature difference flue gas and evaporation temperature) and approach point (temperature difference evaporation temperature and economizer outlet temperature) have a specific value e.g. 10K for approach point and 5K for pinch point.
- Adjust the heating surfaces so that the final super heater steam and final reheater steam have the desired temperature and pressure.
- Check all other design criteria from some HRSG OEM design handbook



Pic [5] A typical conventional HRSG configuration in Q- T diagram



Pic [6] HRSG for ISCCS

1. More superheating energy is transferred
2. Less high pressure (HP) evaporating energy is transferred
3. More energy all together is transferred
4. Lower flue gas exit temperature = higher efficiency

To adapt a typical HRSG to a HRSG integrated in a ISCCS there must be this modifications:

- Increase the HP super heaters heating surfaces
- Increase the reheaters heating surfaces
- Decrease the HP evaporator heating surfaces
- Increase the HP economizer heating surfaces
- Increase the condensate heater heating surfaces

This has to be done because the additional steam generated by the solar power steam generator is fed in the HP superheaters of the HRSG so a higher HP superheater heat exchanger surface is required. After the HP steam turbine the additional steam has to be reheated, so the reheater has to be increased. The solar power steam generator is fed by hot feed water from the HRSG, so the HP economizer and the condensate heater have to be increased due to the additional water flow to the solar power steam generator.
The heat input with the gas turbine remain the same, so in the case solar power steam is fed in the HRSG and this additional steam is taken some additional superheating energy compared with the pure gas turbine case, the HP evaporator can recover less energy, so the HP evaporator heating surface can be smaller. See also pic [6].
Decreasing the HP evaporator heating surface saves not only costs in investing in heating surfaces but also smaller heating surfaces means less flue gas pressure drop.
A too big HRSG has a too high flue gas side pressure drop. For example each additional HP evaporator row of the HRSG costs ca. €400 000 in 20 years operation due to the flue gas pressure drop.
Because of the bigger superheaters compared with a typical HRSG in the “gas turbine only” mode and especially in the duct burner mode a lot of spray cooling water have to be used to control the final superheating temperatures. To cover these modes with high thermal HRSG efficiency “hot spray cooling” is strictly recommended. I.e. the spray water is taken out at the end of the last economizer. This has two benefits:

1. More heat is recovered in the economizers
2. Less steaming in the economizers

To reduce the steaming in the economizers and to increase the pressure difference for spray cooling it is also recommended to insert an orifice after spray water extraction and steam drum.
Also the place of the duct burner between the bundles has to be optimised to have a minimum reheater spray water flow (see Pic [7])

Comparing typical HRSG design vs. Hybrid Design in m² (Tab [1])

	Typical Desing	Hybrid Design	Difference
High pressure superheater	22308	41190	84.64%
Reheater	23861	44311	85.70%
High pressure Evap	47701	28621	-40.00%
High pressure Economizer	84178	92596	10.00%
Other heating surface	88699	99923	12.65%
Total	266747	306641	14.96%

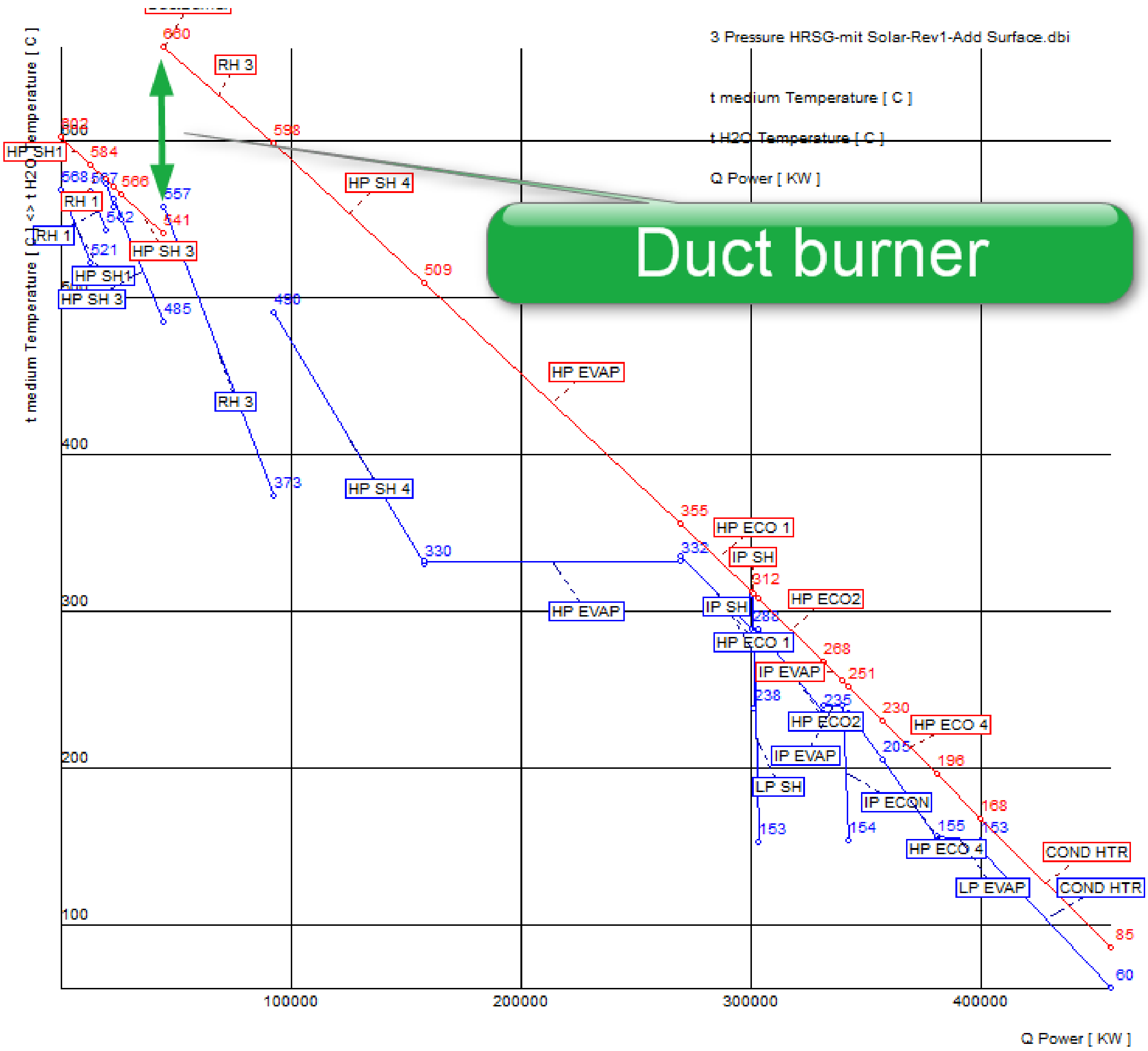
Comparing typical HRSG design vs. Hybrid Design in kg (Tab [2])

Model	MassSt Typical Design Kg	MassSt Hybrid Design Kg	Difference -
COND HTR	299629	366213	22.22%
LP EVAP	133168	133168	0.00%
LP SH	11678	11678	0.00%
RH 3	58314	77752	33.33%
RH 2	52833	140887	166.66%
RH 1	50072	66762	33.33%
IP ECON	14262	14262	0.00%
IP EVAP	57048	57048	0.00%
IP SH	13320	13320	0.00%
HP ECO 4	99876	99876	0.00%
HP ECO 3	99876	99876	0.00%
HP ECO2	149814	149814	0.00%
HP ECO 1	149814	199753	33.33%
HP EVAP	282983	169790	-40.00%
HP SH 4	29609	59219	100.00%
HP SH 3	30926	92777	200.00%
HP SH 2	42075	56100	33.33%
HP SH1	41646	55528	33.33%
Total weight	1616943	1863823	15.27%

After finishing the design it can be checked with the balance of plant:
Tab [3]

		Typical HRSG	ISCCS HRSG	Duct Burner Mode	Typical HRSG	CSP Solar Power Plant
Power Plant Efficiency (Gross; LHV; Fuel input)	%	55.49	62.31	54.36		
Power Plant Efficiency (Gross; LHV; Fuel+100 MW Solar)	%		54.46		53.95	
Efficiency solar power	%		47.33		43.36	37.77
Gas turbine	MW	256	256	256	256	
Steam turbine	MW	129	176.33	172.02	172.36	37.77

The model of the balance of plant (BoP) and the HRSG was generated with the Power Plant Simulator & Designer (PPSD) software, which includes a library of component models for solar applications.

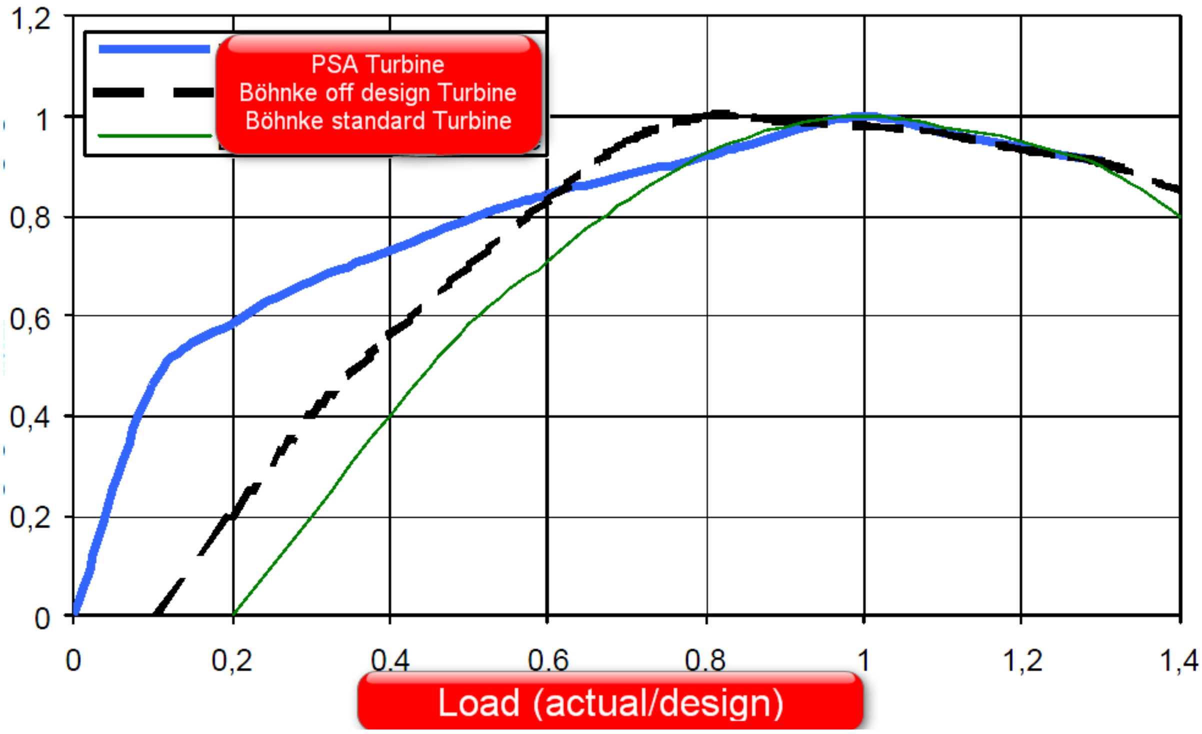


Pic [7] Q-T diagram duct burner mode

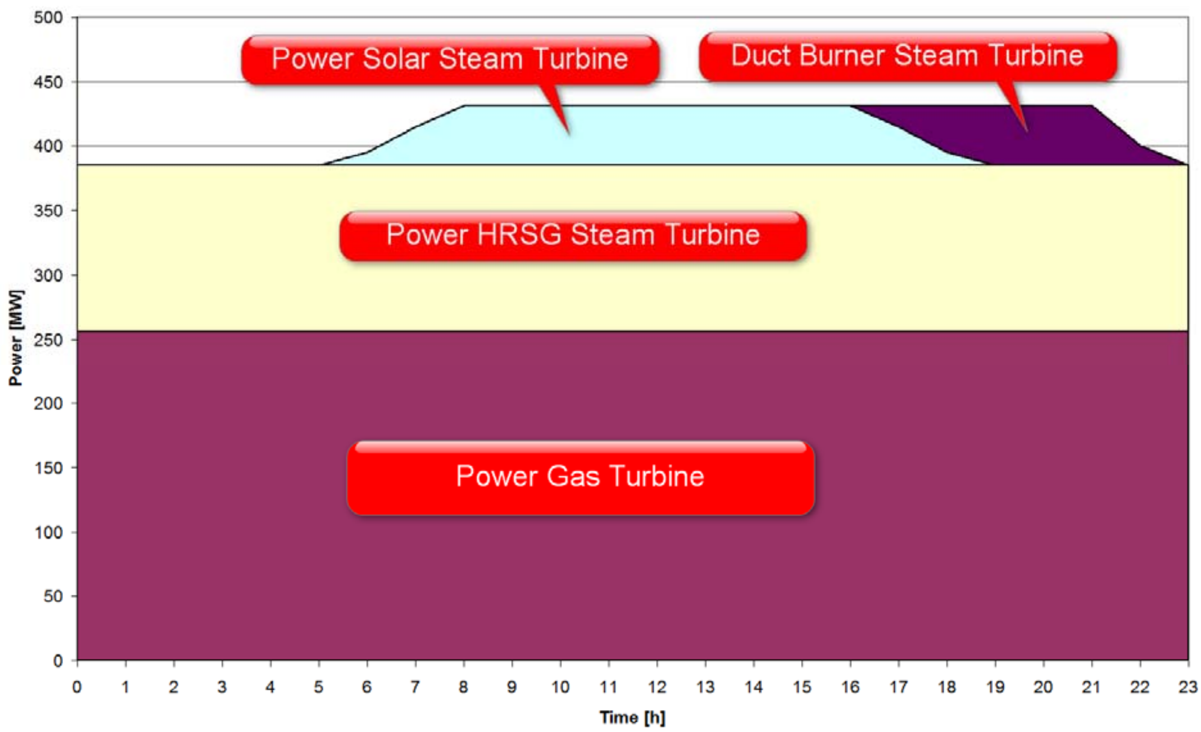
Mild hybrid

Mild hybrid means that the solar power heat input is much lower then the heat input from fossil fuel and the power plant can’t operate only with solar power.

So the steam turbine operates only from ca. 70% to 100% load and the steam turbine efficiency is in nearly all operating modes near by the design point.



Pic [8] Steam turbine load vs. relative efficiency to design point efficiency



Pic [9] Time vs. power of ISCCS plant

Real Example

Florida Power & Light Martin Plant 75 MW solar power (hurricane prove)

Lat/Long Location: 27°3′ 13.0″ North, 80°33′ 46.0″ West

Pic [10] Florida Power & Light Martin Plant

ISCCS Al Kuraymat

The Kuraymat project has an overall capacity of 140 MW (120 MW combined cycle, 20 MW solar input).

Solar-Field Aperture Area: 131,000 m²

Lat/Long Location: 29°16′ North, 31°15′ East

Pic [11] ISCCS Al Kuraymat

Summary

Hybrid thermal solar power is one of the cheapest renewable electrical power productions because of:

- Only investing in solar power field and solar steam generator, there is no need for all other installations (steam turbine, feed water heaters, superheaters, economizers etc.)
- Much higher efficiency then a stand alone CSP power plant
- No backup need for night time and no sunshine periods
- Very simple modification of the CCP

With an improved HRSG for hybrid solar thermal power plants the steam turbine produces more ca. 9.1% more electrical power from thermal solar heat input.
The super heating temperature is higher so the steam quality at the last stages of steam turbine is much better.
The improved HRSG has just 16% more weight with an additional cost of ca. Mio 1.1 € compared with a typical HRSG, return on invest is less then 3 yeas (0.04€/kWh)

References

Lit [1] Volker Quaschning Hybride Solarkraftwerke; DLR 2002
Lit [2] GE Energy Heavy Duty Gas Turbine Products 2009, General Electric Company
Lit [3] Ch. Daublebsky von Eichhain, HRSG Heat Recovery Steam Generators Design and Operation, Publico Publications 2007