Experiences with Direct Steam Generation at the Kanchanaburi Solar Thermal Power Plant

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Abstract

In 2011 the parabolic trough power plant TSE1 has started operation in Thailand. As a novelty it uses the direct steam generation (DSG) process, evaporating and super heating water and steam directly in the solar field. During the commissioning phase and first months of operation the start-up procedure has been optimised for the solar field and turbine system resulting in a reduced start-up time. The DSG process can be controlled well in the evaporator and super heater section securing a safe operation of the solar field and keeping live steam parameters in an acceptable range for the turbine even at fluctuating DNI. Apart from pressure control also control of the plant's electrical power output is possible, depending on DNI and electricity demand.

Keywords: Direct Steam Generation, DSG, Parabolic Trough, Recirculation, Super heating

1. Introduction

In Kanchanaburi, Thailand the solar thermal power plant TSE1 has been erected based on direct steam generation in parabolic trough collectors. Since August 2011 the solar field is functional; after flushing and steam blow-down during commissioning it has been operating normally. Up to today (August 2012) the direct steam generation in the solar field, including evaporation and superheating, runs smoothly. The utility Thai Solar Energy (TSE) is running the full plant by itself, after assistance from Solarlite for the first months.

This paper describes experiences gained from running the solar field with direct steam generation.

2. Direct Steam Generation

The plant (Fig. 1) is located in the region Kanchanaburi, to the north-west of Bangkok, Thailand. Its layout has been described in [1]. This solar field is the first to commercially apply the direct steam generation (DSG) concept with solar superheating in parabolic troughs.

Fig. 1. TSE1 Solar Thermal Power Plant from north-east

The field is divided into a larger section of 12 loops for evaporation (west side) and a smaller section with 7 super heater loops (east side) for super heating. Power block and steam drum are on the north-east corner. At a live steam pressure of 30 bar and a temperature of 330°C the turbine can reach up to its nominal 5 MWel.

The first steps to run the solar field were conducted with semi-automatic control sequences. These have been developed by Solarlite during the commissioning into a fully automatic operation mode.

The evaporation section operating in recirculation mode can be controlled without difficulties. Instabilities due to parallel evaporator loops, a former concern in DSG research, do not occur. The automatic control of the mass flow at each evaporator loop secures minimum mass flows, such that dry-outs in the evaporators (EV) can be avoided. Significant variation of mass flows between loops, which would occur without control, has not been detected.

A defocus strategy in the EV loops is being applied

1.) to prevent dry out and superheating in EV receivers

2.) to control steam production & steam drum pressure either when the DNI (Direct Normal Irradiance) is higher than the design value or when the plant has to be operated in continuous power output mode.

Also, operating the super-heaters (SH) can be controlled well. A minimum steam mass flow must be ensured in each loop before focussing the collectors. No receivers have been damaged during operation, especially not due to stratification during normal operation.

3. Start-up

The start-up procedure of a solar power plant is a sensitive phase, as it should be tackled as quickly as possible to start producing electricity soon and on the other hand thresholds for heating transients must be respected. For direct steam generation special attention to the super heater loops and the turbine live steam temperature and pressure is required.

A typical start-up is described here for the 1st of May 2012 (Fig. 2).

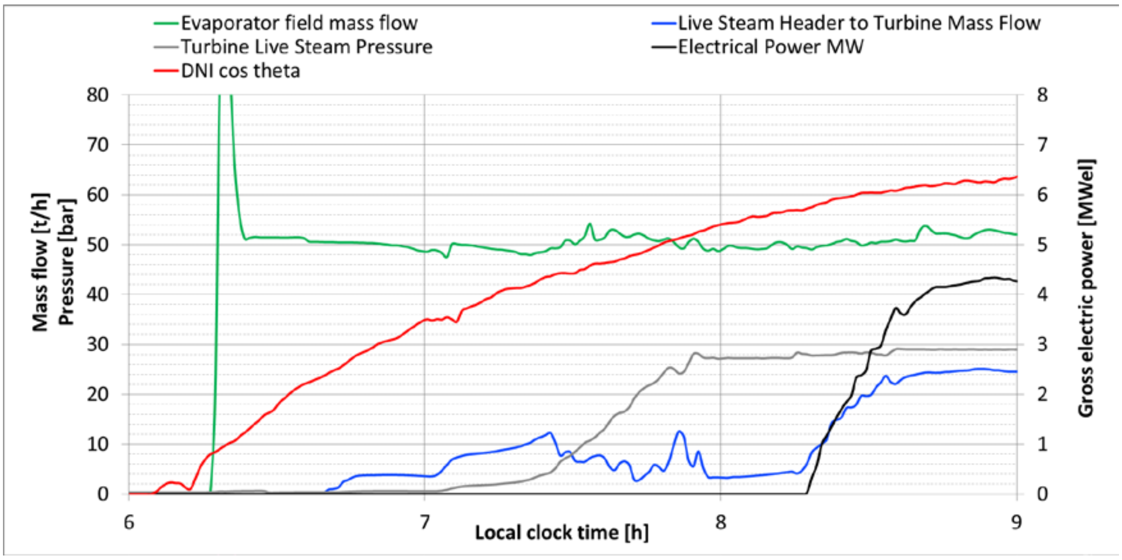

Fig. 2. Start-up of TSE1

06.06 The first activity in the plant is to move all collectors to defocus position (a few degrees from focussing), which takes up to 10 minutes. Pumps for cooling water are started.

06.17 The recirculation pump is started to supply the evaporator loops. Shortly after this the collectors of the evaporator field are focused except for two loops under maintenance.

06.40 Steam from the steam drum is being sent to the super heater collectors for pre-heating

07.05 Evaporation in the evaporator loops begins

07.06 Six of the seven super heater loops are being focussed, (one loop was under maintenance). Super-heated steam starts to leave the SH

07.42 Condenser evacuation starts

07.50 Warming turbine inlet body started

07.52 Turbine bypass started

07.54 After reaching the set point temperatures the turbine is started. As it cannot take the full mass flow of the solar field, the by-pass valve controls the flow and the major steam share flows to the condenser.

08.00 Turbine live steam pressure at about 28 bar

08.18 Turbine synchronised to the grid, electricity generation starts

An important measure for a quick start-up is not only to start the evaporator field, but also to start super heating steam early and to heat the steam turbine sooner. If the water in the steam drum is still hot enough it can be evaporated and the super heater can be flooded with steam immediately in the morning.

The advantage of heating steam instead of water is the higher outlet temperature at the super heaters, heating the super heater header and the turbine earlier.

After reaching the threshold temperature and pressure the start-up sequence of the turbine is started. Along rising temperatures and pressures various steps are taken such as lube oil system on, gland steam system on etc. The solar field needs to supply the steam as early as possible, but the speed of tackling the steps of the turbine start-up is limited. Accordingly the live steam parameters must best be provided in parallel by the solar field. However, although the SF has to "wait" for the turbine to warm up, during this time the steam drum pressure is continuously increasing, which allows a better pressure buffer between steam drum and turbine at synchronisation. It depends on the operators to harmonise start-up of turbine and solar field.

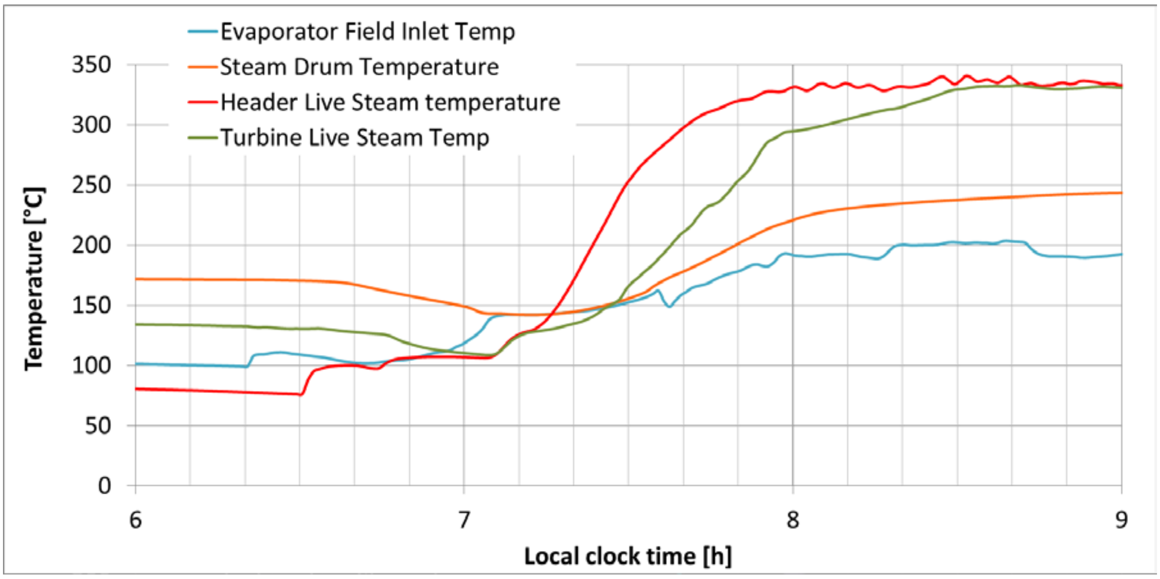

Fig. 3. Temperatures of header and turbine live steam

During start-up the temperature of the turbine live steam is 15–30 minutes behind the temperature of the header of the superheaters, mainly due to heat capacities in the piping. The temperature curves of "Header Live Steam" and "Turbine Live Steam" are shown in Fig. 3.

After implementing the main control strategies to run the full plant, the solar field control has been optimised in conjunction with the turbine for a faster start-up and higher output. The turbine manufacturer MAN and Solarlite have worked together to implement a range of turbine parameter adjustments which together result in a reduction of approx. 40 minutes in start-up time. With several more measures the start-up time has been shortened by about 1 hour during the first months of operation.

To optimise the start-up time for the plant a shorter piping section between super heater outlet and turbine is helpful. Furthermore a greater collector aperture width while maintaining absorber diameter would improve the relation of incoming power and thermal capacities and therewith further shorten start-up time of the solar field. The effect of a quicker solar field start-up is limited though, as the turbine launching procedure takes its time. The steam parameters at the turbine inlet can only be slowly raised, compared to the solar field, which can increase the steam parameters quicker.

Operation after start-up

After the start-up phase, the live steam pressure and temperature can well be controlled in a quite acceptable range for the turbine even at fluctuating DNI (Fig. 4 and 5). At steady state conditions with only small fluctuations of DNI between 10:00 and 15:00, the live steam pressure is kept in a range of +/- 0.2 bars and the live steam temperature in a range of +/- 5 °C. On other days the temperatures were even regulated in a span of +/- 2°C for several hours with a different control strategy.

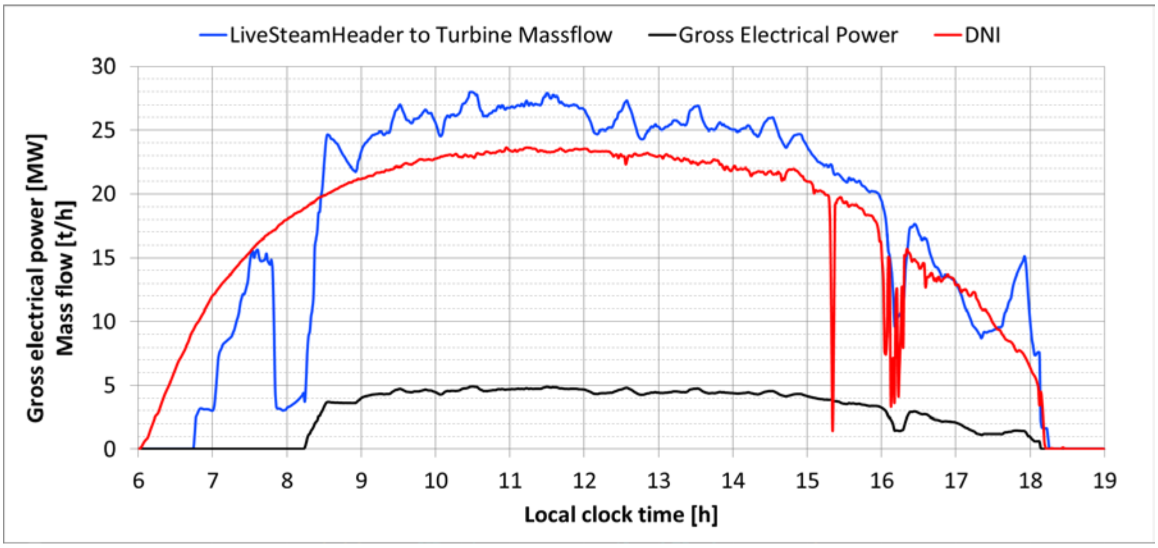

Fig. 4. Electrical output during the day on 11th of May 2012

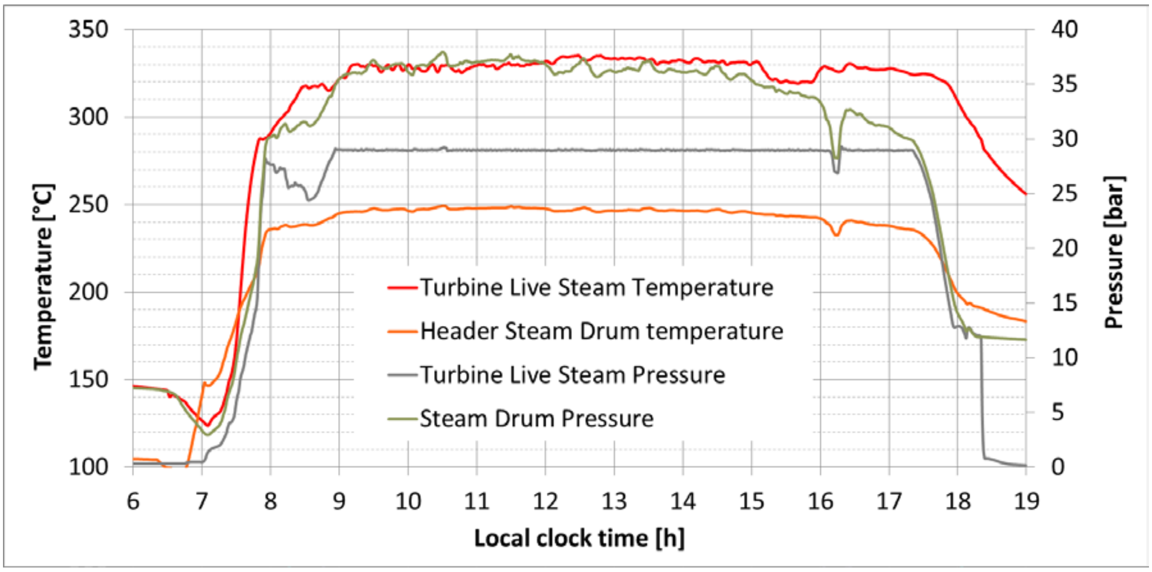

Fig. 5. Pressures and temperatures in solar field and at turbine on 11th of May 2012

The thermal capacities in the superheaters plus the piping between superheater and turbine do not only even out small fluctuations in temperature from the solar field, but also super-heat saturated steam after decrease of irradiation for a significant duration. During a drop of DNI as around 16:00 transients occur in the live steam mass flow resulting in a reduced electrical power output (Fig. 4).

Effects of a longer lasting reduction in DNI are visualised in Figures 6 and 7. At a strong drop of DNI live steam mass flow is reduced quickly to a level at which the turbine can still be operated. Even during 90 minutes of very low DNI on this day the turbine can stay in operation, then accelerating quickly with rising DNI.

During this period the turbine can still be supplied with high temperature steam. The pressure remains above the parameters allowed for the turbine.

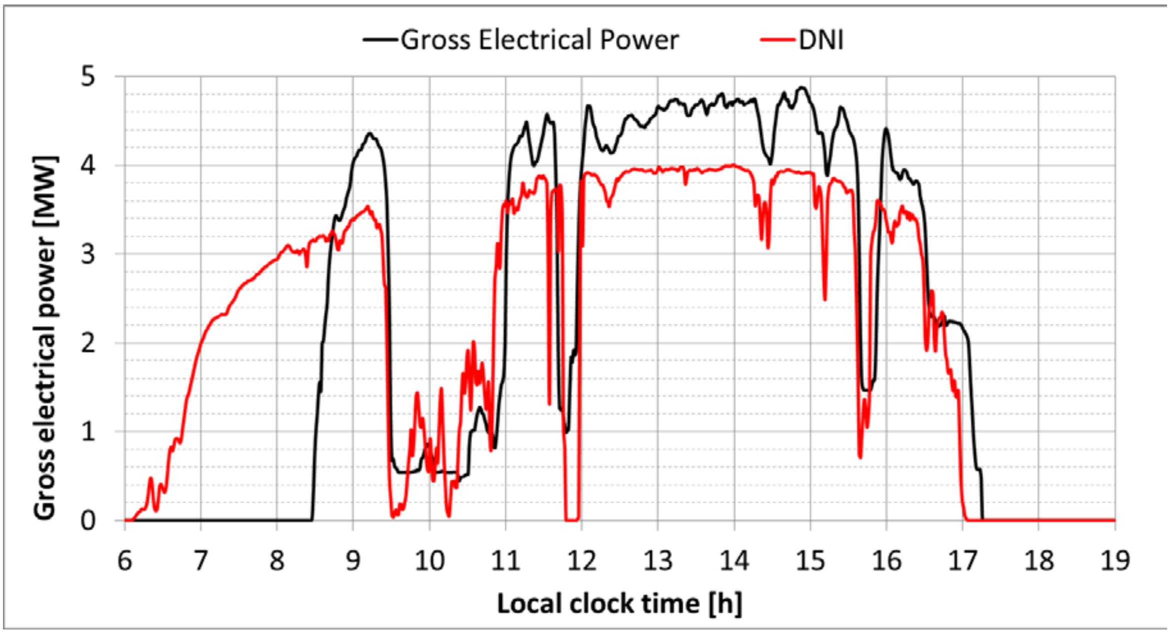

Fig. 6. Long drop in DNI and its effect on electrical power output

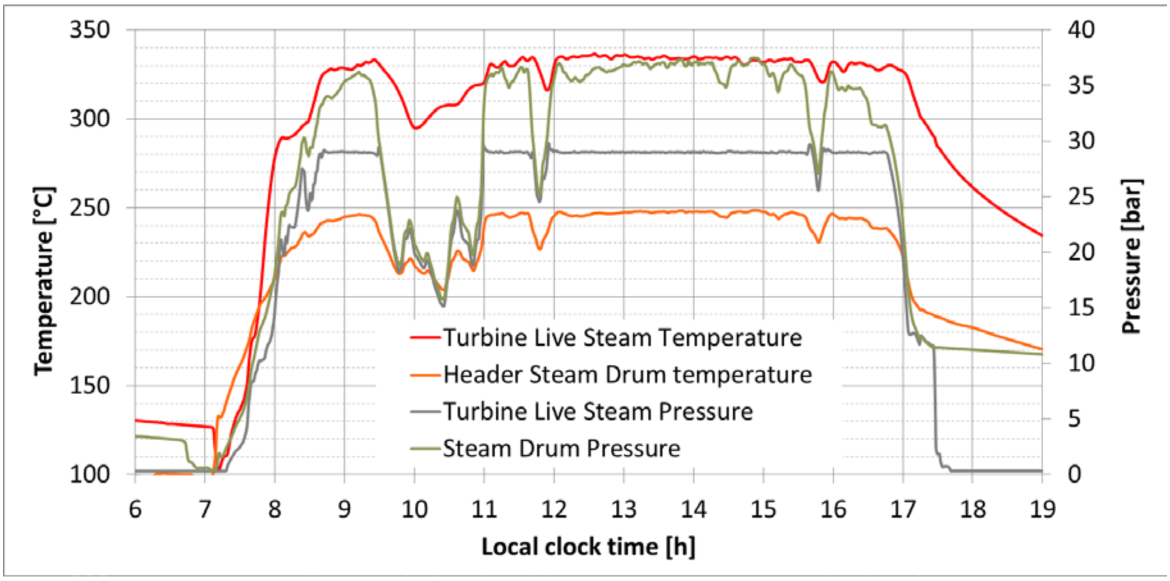

Fig. 7. Long drop in DNI and its effect on pressure and temperature

Apart from pressure control also power control is possible, depending on the DNI and electricity demand. During the commissioning of the turbine on 9th of January (Fig. 8) the electrical output is kept constant at 3 MWel as desired for the commissioning phase. This example shows the reliability of the process and is of significance for the grid stability.

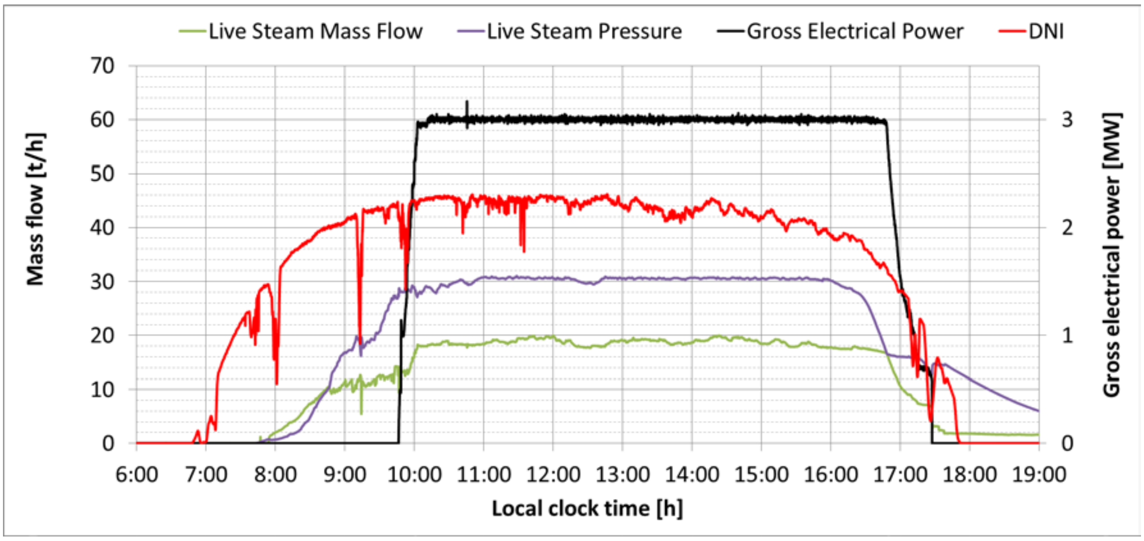

Fig. 8. Keeping electrical output constant

3. Summary

Direct steam generation (DSG) in recirculation mode has been demonstrated as a good and technically well viable solution in a solar thermal power plant. Mass flows and temperatures can be controlled well to avoid any damage to the receivers.

Live steam pressure and temperature can well be controlled in a safe range for steam turbines. Even during transients the live steam temperature can be held very stable and power output can be controlled well.

While during the start-up phase initially the turbine first needs to “wait” for the solar field to provide steam at the desired parameters, it is later the turbine taking time for launching while the solar field could already provide steam at higher parameters.

References

[1] Krüger, Dirk; Krüger, Joachim; Pandian, Yuvaraj; Feldhoff, Jan Fabian; Eck, Markus; Eickhoff, Martin; Hennecke, Klaus: Kanjanaburi Solar Thermal Power Plant with Direct Steam Generation – Layout. 16th SolarPACES Conference, Perpignan, France, 21. - 24.9.2010