Optimization of a Decoupled Combined Cycle Gas Turbine Integrated in a Modular Multi-Tower Solar Power Plant

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1 The Multi-Tower Decoupled Solar Combined Cycle concept

With the Multi-Tower Decoupled Solar Combined Cycle concept developed in the CAPTure project funded by the European Union, a small solar-driven gas turbine is located atop each modular tower. An innovative volumetric air receiver uses a primary loop of atmospheric air as heat transfer fluid. The primary air heats the gas turbine's working air by means of a fixed-bed regenerative system. The waste heat from the exhaust of all gas turbines is recovered through one or two heat transfer fluids (in order to cover the whole temperature range) that are also used as media of a centralized thermal storage system. The heat extracted from this direct storage system is then converted into dispatchable power through a mutualized, industrial-scale steam turbine.

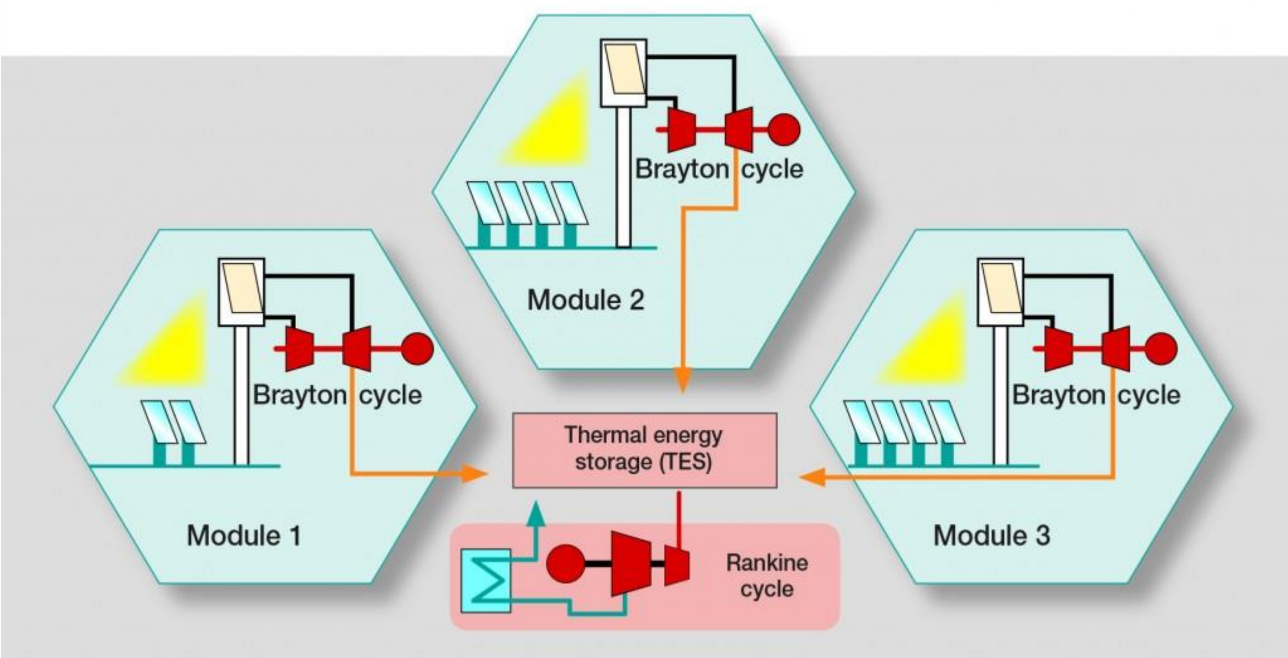


Figure 1 - The CAPTure plant configuration is based on a multi-tower decoupled advanced solar combined cycle approach

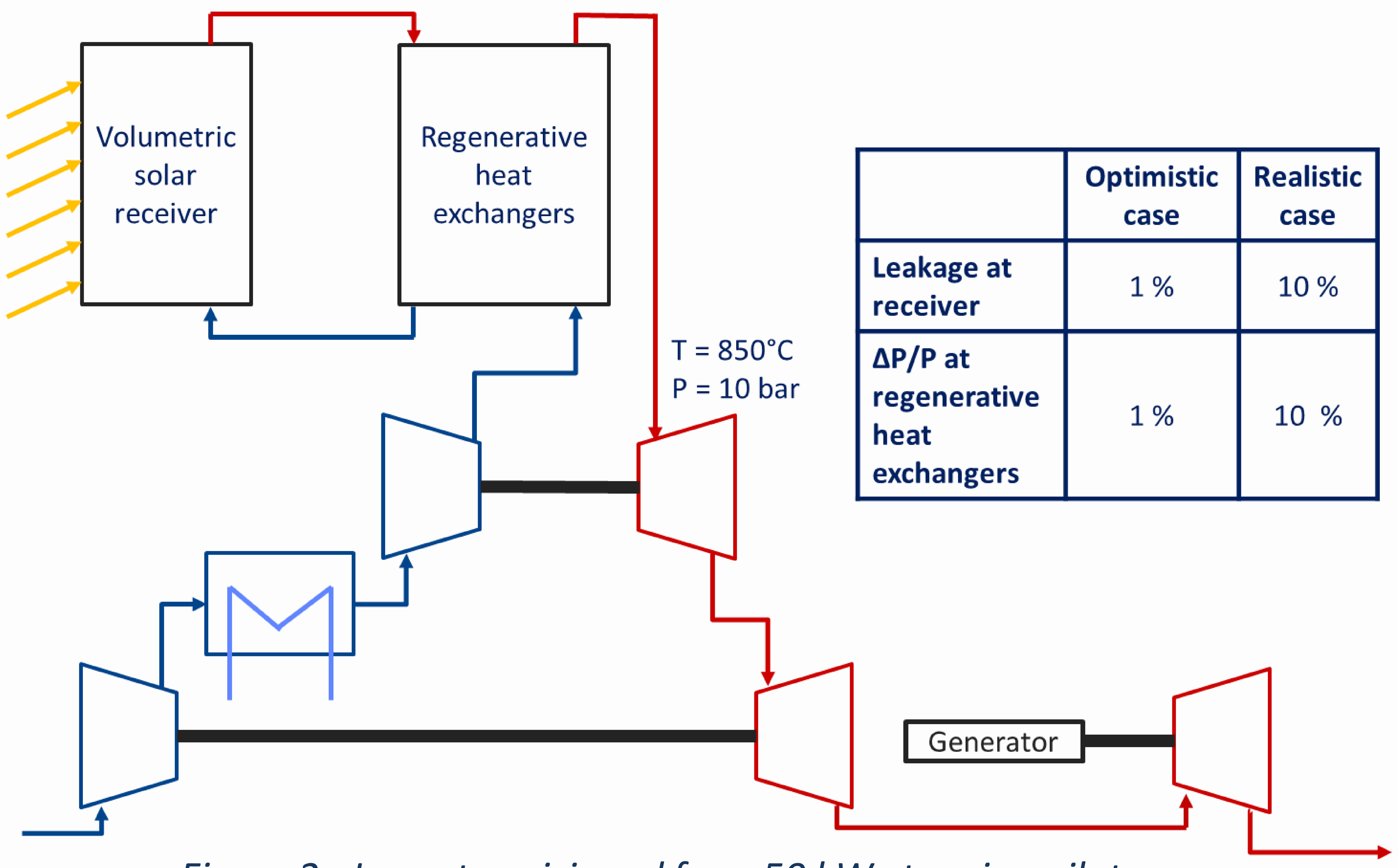
As part of the project, various validation-scale prototypes of the key elements as well as a complete unit including a solar receiver and a gas turbine will be developed and tested.

2 Objectives

The objective of this study is to assess various design options regarding the design of the power cycle of a utility-scale plant based on the modular multi-tower decoupled solar combined cycle concept developed in the CAPTure project. The performances of each system were evaluated in a steady-state Thermoflex model.

3 Validation of the topping cycle

Thermoflex models were built in order to match the thermal performances of a 50 kWe topping pilot gas turbine and to be able to discuss the underlying hypotheses. A multi-shaft turbine layout was considered, with an intercooling between LP and HP compressors. Realistic hypotheses were made regarding the compressor and expansion polytropic efficiencies. The regenerative system was simulated as a heat exchanger.



	Optimistic case	Realistic case
Leakage at receiver	1 %	10 %
ΔP/P at regenerative heat exchangers	1 %	10 %

Figure 2 - Layout envisioned for a 50 kWe topping pilot gas turbine and hypotheses tested

The relative pressure loss of the regenerator on both sides (primary air and working air) is by far the most critical parameter regarding the performances of the topping cycle. Conversely, the impact of the leakage rate affecting the primary air loop is rather low.

Table 1 - Gross and net efficiencies and auxiliary consumption of the topping cycle depending on the leakage rate and the relative pressure loss of the regenerative system on the primary air side

	1 % leakage and ΔP/P	10 % leakage and ΔP/P
Gross efficiency	16,8 %	16,5 %
Net efficiency	16,3 %	12,9 %
Auxiliary consumption	3,5 % of gas turbine electric output	22,8 % of gas turbine electric output

4 Combined cycle including direct storage system inserted between topping cycle and HRSG

Three options were considered for the bottoming cycle of a utility-scale combined cycle, with different levels of heat recovery, complexity and affordability.

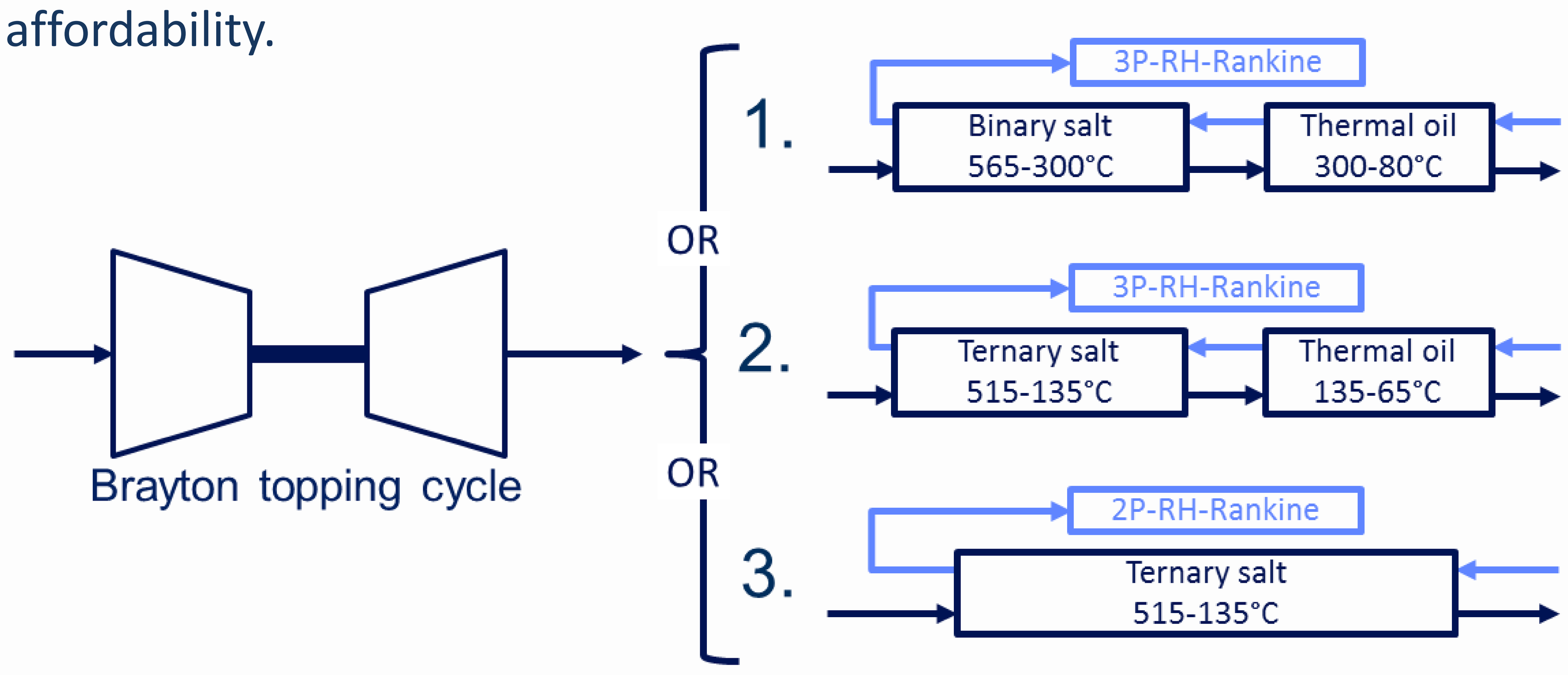


Figure 3 – The three intermediate storage and bottoming cycle layouts evaluated for a utility-scale combined cycle.

The same hypotheses as for the topping cycle were made concerning the leakage rate and pressure drop in the primary air loop. Optimal HRSG layouts were designed with GT PRO, then imported into Thermoflex in order to model the complete combined cycle.

Table 2 – Performances of the utility-scale combined cycle depending on the intermediate storage and bottoming cycle layout and the performances of the regenerative heat exchanger.

Bottoming cycle layout	Share of dispatchable power	1 % leakage and ΔP/P		10 % leakage and ΔP/P	
		Gross efficiency	Net efficiency	Gross efficiency	Net efficiency
1.	57,7 %	43,1 %	40,5 %	42,6 %	37,2 %
2.	50,0 %	41,9 %	39,8 %	41,2 %	35,9 %
3.	46,4 %	40,7 %	38,8 %	40,1 %	35,3 %

Layout 1, however the most expensive and hazardous, provides the highest fraction of dispatchable power (i.e. output of the bottoming cycle) and the best overall net efficiency (about 40%). Layout 2 uses a largely reduced volume of cheaper oil; considering optimistic hypotheses, its heat rate is 1.8% higher than that of layout 1. Layout 3 is the cheapest and its heat rate is 4.4% higher than that of layout 1.

5 Conclusion and perspectives

The main conclusions of this study are as follows:

- The performances of the regenerative system have a critical impact on the performances of the plant;
- With TIT~850°C, the efficiency is not higher than that of current Rankine steam cycles (~42%). Other studies showed that a reheat on the topping cycle increases the cycle efficiency by about 3 percentage points. However, the need for a second regenerator would greatly increase the plant complexity.

6 Acknowledgements

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