Assessment of the integration of a MED-TVC plant into a solar tower with Brayton cycle

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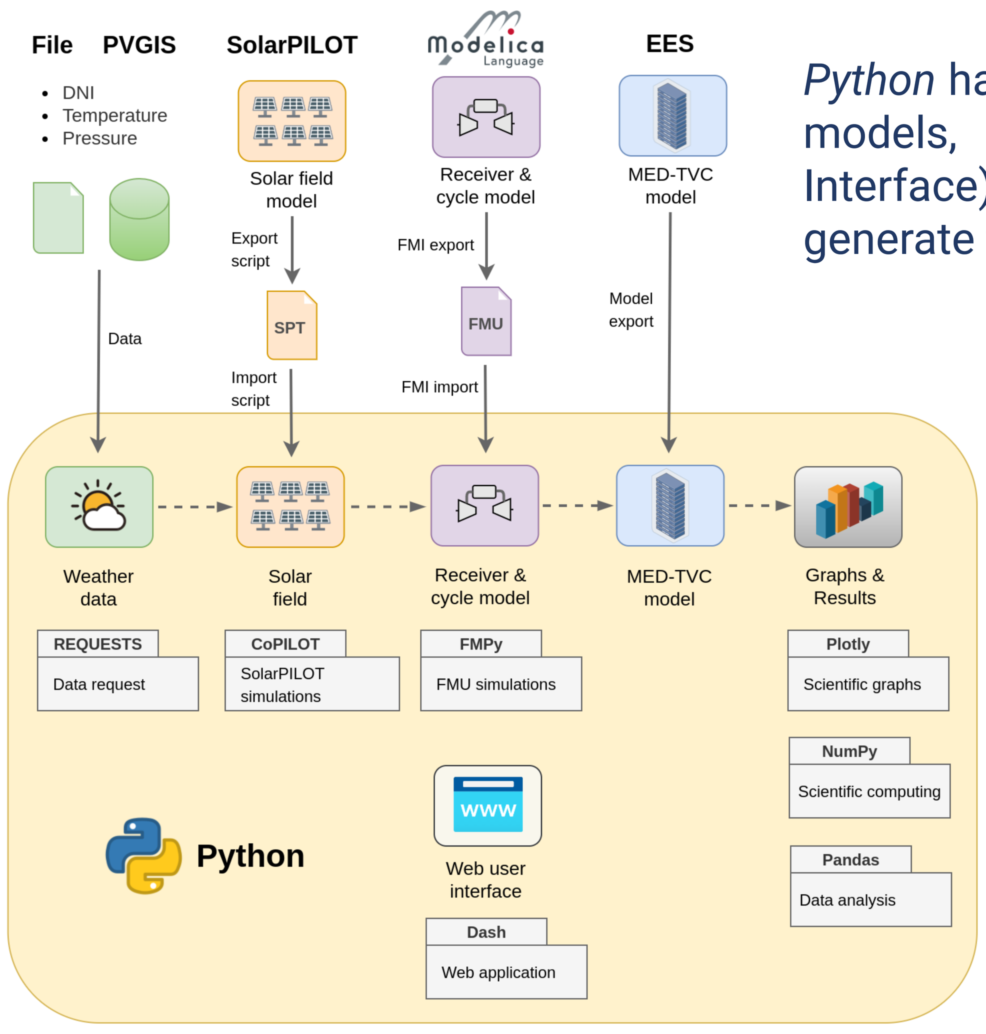
Introduction

This work presents the assessment on the integration of a thermal seawater desalination system, based on Multi-Effect Distillation technology with Thermal Vapor Compression (MED-TVC), into a high-temperature power cycle (air Brayton cycle) and high-temperature Concentrating Solar Power (CSP) technology, Central Receiver Solar (CRS) tower system. For such integration, the exhaust gases from the gas turbine are addressed to a recovery boiler where steam is generated to drive the MED-TVC unit.

The system is based on the AORA solar plant located at Plataforma Solar de Almería (PSA).

Simulation Structure

- **Input weather data:** weather data files or online *PVGIS* data can be used.
- **Solar field model:** the heliostat field model was developed using *SolarPILOT* (Solar Power Tower Integrated Layout and Optimization Tool) from *NREL*.
- **Receiver & Brayton cycle models:** these models have been developed in *Modelica*.
- **MED-TVC model**: a model that evaluates its thermodynamic performance has been implemented in *EES* (Engineering Equation Solver).



Python has been used to integrate all the models, add a GUI (Graphical User Interface), perform the simulations and generate the results.

More details at
http://soltermin.es

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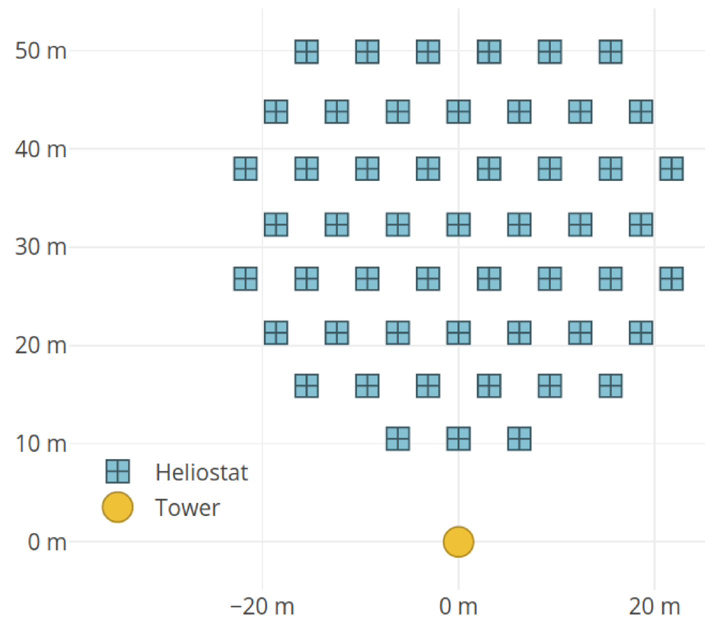
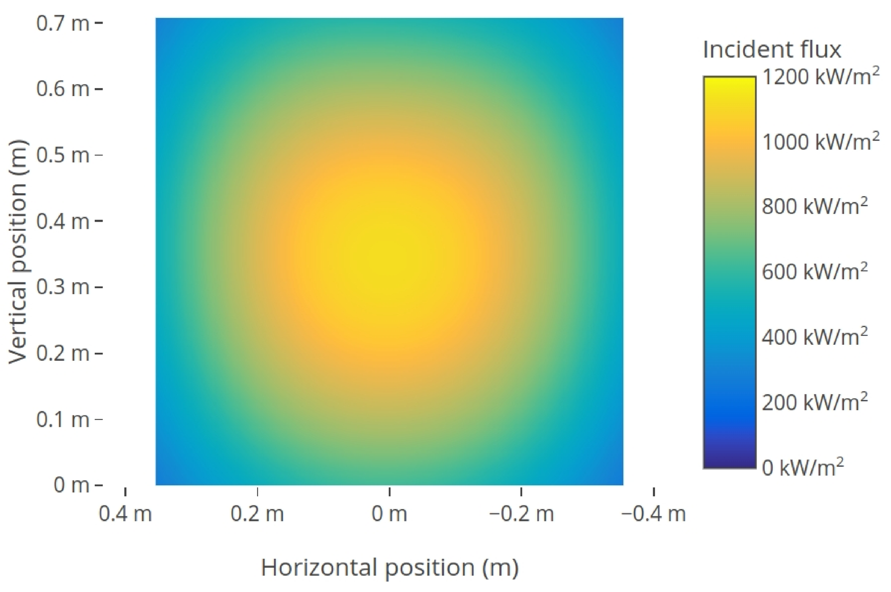
Heliostat Field Model

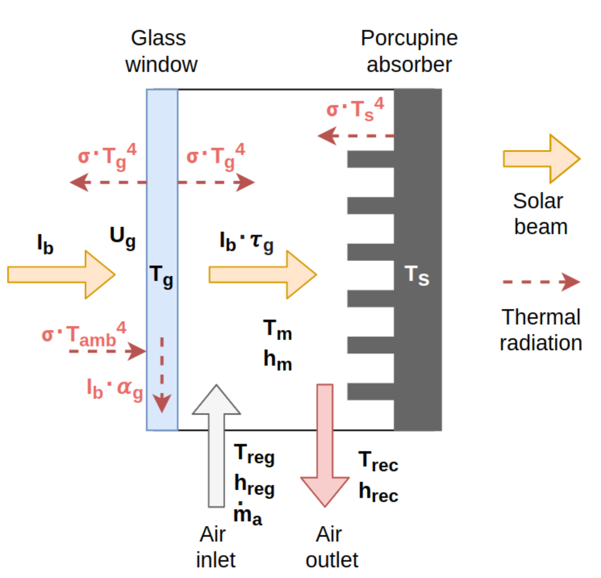
The *SolarPILOT* tool was used to model the heliostat field and the hourly distribution of concentrated solar irradiance onto the receiver.





Receiver Model

Solar Receiver



Model Diagram

Glass Window

$$I_b \cdot \alpha_g + \sigma \cdot (T_{amb}^4 + T_s^4 - 2 \cdot T_g^4) = U_g \cdot (T_g - T_{reg})$$

Absorber

$$G = \frac{I_b \cdot \tau_g + \sigma(T_g^4 - T_s^4)}{h_{rec} - h_m}$$

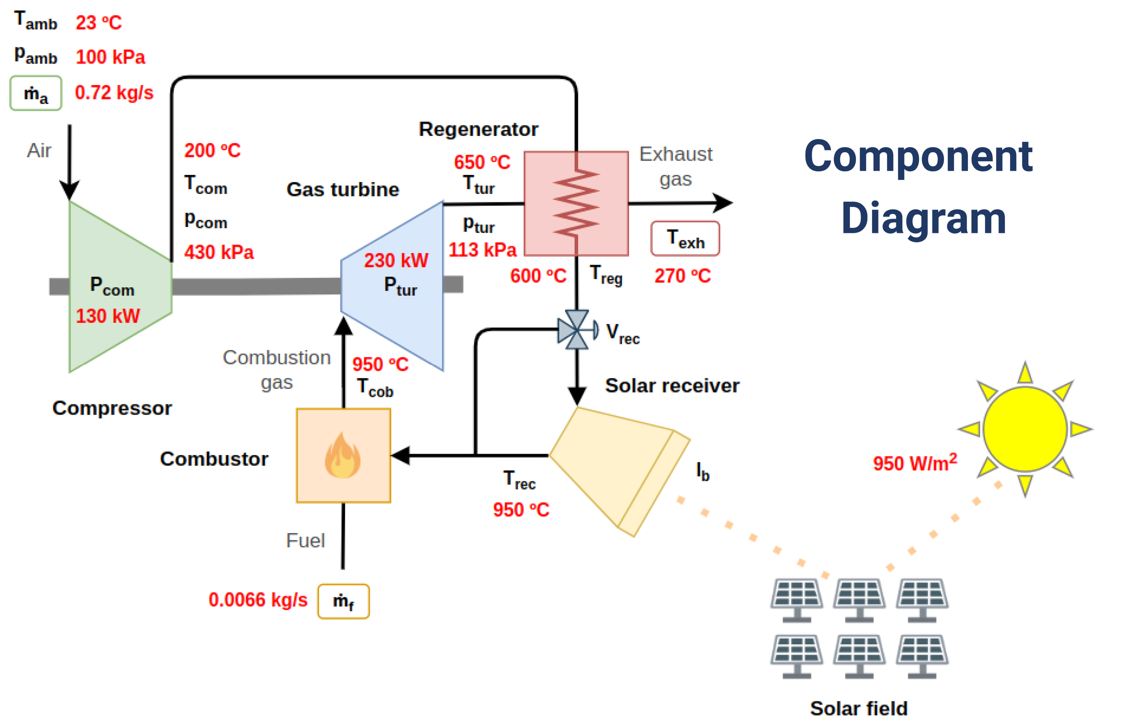
$$G = \frac{\dot{m}_a}{A_s} \qquad T_s = \frac{T_{reg} + T_m}{2}$$

Cavity

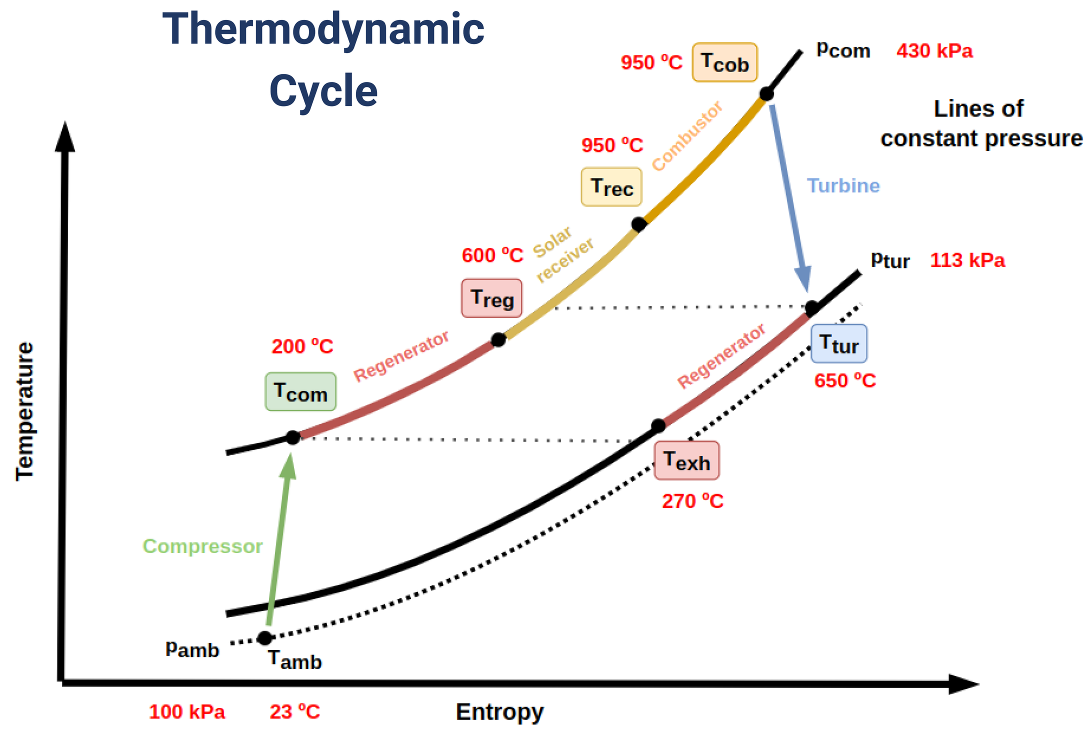
$$h_m - h_{reg} = \frac{U_g \cdot (T_g - T_{reg})}{G}$$

Model

Brayton Cycle Model



Component Diagram



Thermodynamic Cycle

Compressor

$$\gamma_{com} = \frac{c_{p,com}}{c_{v,com}}$$

$$x_{com} = \left(PR_{com} \cdot \frac{\dot{m}_a}{\dot{m}_{a,n}}\right)^{\frac{\gamma_{com}-1}{\gamma_{com}}}$$

$$T_{com} = T_{amb} \cdot \left(1 + \frac{x_{com} - 1}{\eta_{com}}\right)$$

$$p_{com} = p_{amb} \cdot PR_{com}$$

$$P_{com} = \dot{m}_a \cdot c_{p,com} \cdot (T_{com} - T_{amb})$$

Regenerator

$$T_{reg} = T_{com} \cdot \frac{c_{p,com}}{c_{p,reg}} + \frac{\eta_{reg}}{c_{p,reg}} \cdot (T_{tur} \cdot c_{p,tur} - T_{com} \cdot c_{p,com})$$

$$T_{exh} = T_{tur} \cdot \frac{c_{p,tur}}{c_{p,exh}} - \frac{\eta_{reg}}{c_{p,exh}} \cdot (T_{tur} \cdot c_{p,tur} - T_{com} \cdot c_{p,com})$$

Combustor

$$T_{cob} = T_{rec} + \frac{\eta_{cob} \cdot LHV}{c_{p,cob}} \cdot \frac{\dot{m}_f}{\dot{m}_a + \dot{m}_f}$$

Gas Turbine

$$\gamma_{tur} = \frac{c_{p,tur}}{c_{v,tur}} \qquad p_{tur} = \frac{p_{com}}{PR_{tur}}$$

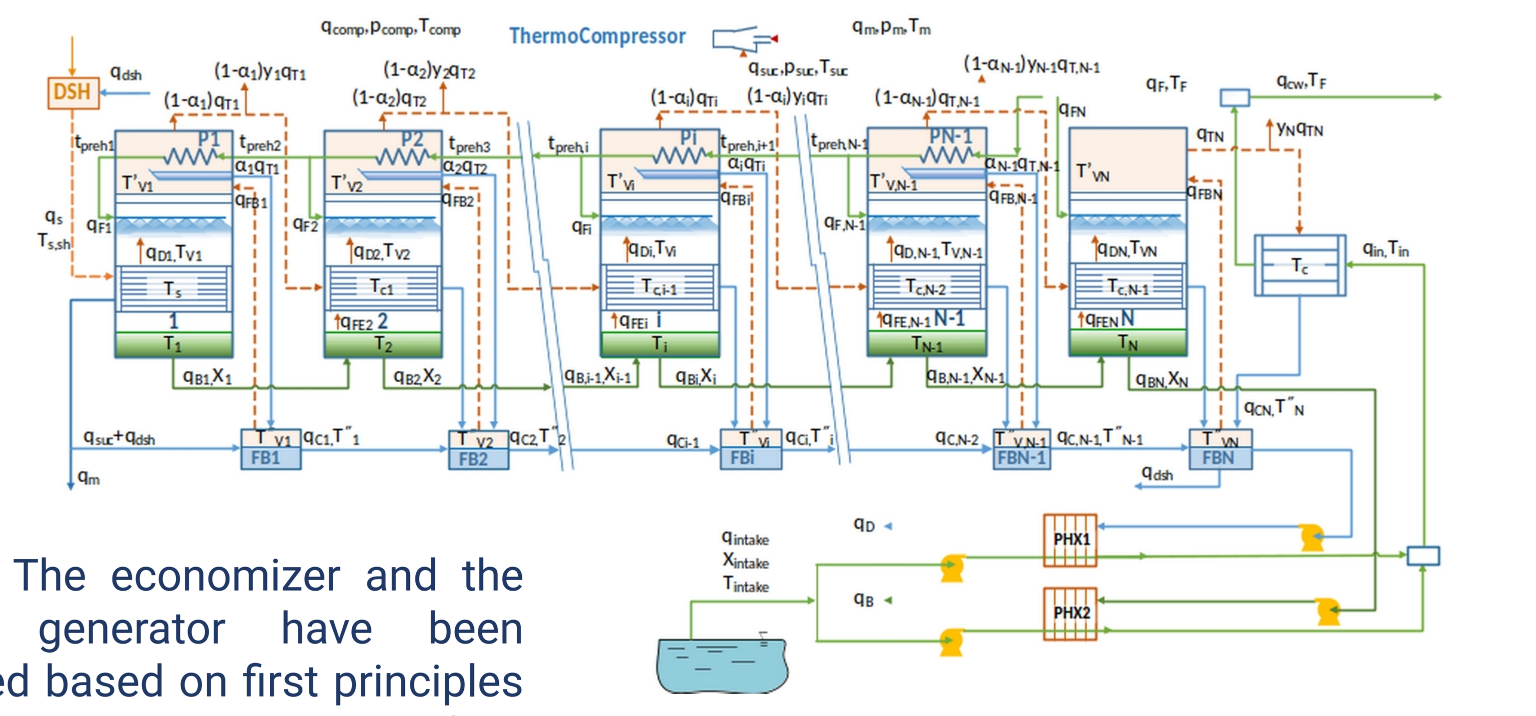
$$x_{tur} = \left(PR_{tur} \cdot \frac{\dot{m}_f + \dot{m}_a}{\dot{m}_{f,n} + \dot{m}_{a,n}}\right)^{\frac{\gamma_{tur}-1}{\gamma_{tur}}}$$

$$T_{tur} = T_{cob} \cdot \left(1 - \eta_{tur} \cdot \left(1 - \frac{1}{x_{tur}}\right)\right)$$

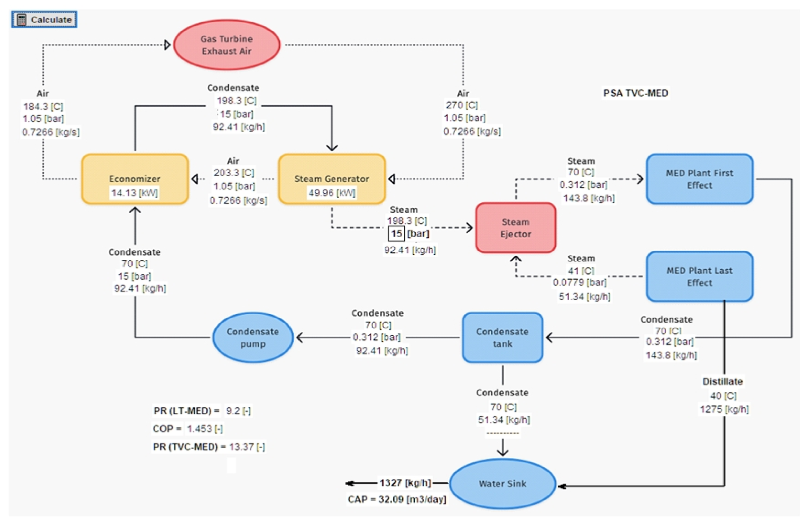
$$P_{tur} = (\dot{m}_a + \dot{m}_f) \cdot c_{p,tur} \cdot (T_{cob} - T_{tur})$$

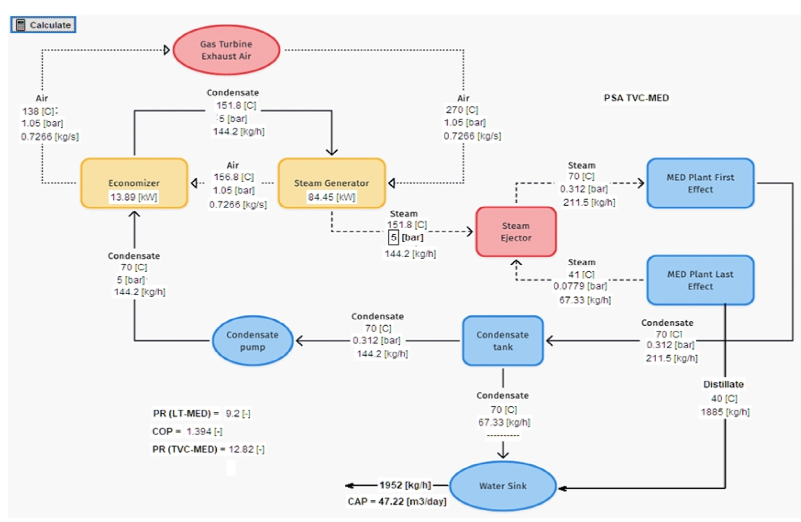
$$P_{net} = P_{tur} - P_{com}$$

MED-TVC Model



- **HRSG:** The economizer and the steam generator have been modeled based on first principles accounting the exhaust air flow rate leaving the gas turbine at nominal conditions. The aim is to evaluate the thermal power entering the steam ejector of the MED-TVC.
- **Steam ejector:** The empirical model from Hassan & Darwish has been used (A.S. Hassan, M.A. Darwish, Desalination 335 (2014) 41–46).
- **Sensitivity analysis:** Different motive steam pressures (5-15 bar) have been considered at the inlet of the steam ejector in order to evaluate the best motive steam pressure regards the distillate production and the use oif exhaust gases.





Conclusions and Future Work

- Hourly Brayton Cycle results for the Typical Meteorological Year (TMT) at Plataforma Solar de Almería includes: power distribution over the receiver, temperatures, pressures, power and performance summary.
- A motive steam pressure of 5 bar has been considered at the inlet of the MED-TVC at nominal conditions (higher distillate production and better use of exhaust gases). The distillate production obtained at nominal conditions has been 47.22 m³/day.

Performance summary

	Min	Max	Avg	Sum
Net power	37.16 kWh	110.15 kWh	68.25 kWh	597.90 MW
Solar %	0.00 %	87.83 %	27.66 %	
Fuel %	12.17 %	100.00 %	72.34 %	
CO_2 emissions	4.37 kg/h	31.08 kg/h	15.07 kg/h	132.03 ton
Fuel usage	19.11 l/h	59.40 l/h	52.50 l/h	459.86 kl

Future work: Obtain polynomial equations by simulating the MED-TVC simulation model developed in EES and integrate these equations into the CSP model to perform anual simulations.