STUDY OF SOLAR GAS AND STEAM TURBINES PERFORMANCE

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An analysis of the performance of power production configurations, using solar heat source in combination with conventional fuels in gas or steam turbine power plants, with the possibility of continuous and fully controlled operation (solar hybrid configurations), is presented.

Provisions for using solar energy for hybridization of conventional gas turbines are analyzed. The solar radiation is concentrated by mirrors (heliostats) to a receiver that heats the air, which exits the compressor, prior its entrance into the combustion chamber. This heating reduces or even eliminates the amount of fuel required to produce the output power. The performances of two types of hybridized turbines, single shaft and twin-shaft, are compared. The analysis includes the effects of hybridization on performance parameters of each engine (operating point, power output, fuel consumption, etc.) on a yearly basis. The size of the heliostat field on the overall performance of the single-shaft engine and the effect of compressor variable guide vane system is also studied. The hybridized single shaft gas turbine is further assessed considering economic parameters.

The performance of a steam turbine cycle using solar energy is also analyzed, including a study of its behavior for a typical day.

Comparative advantages and disadvantages of different configurations are discussed.

- Scope of this work is the demonstration of the ability to model and simulate the performance of Solar Thermal Power Plants (STPPs) and to compute the effect of design and operation parameters. For this, the examples of solar steam turbine and hybrid gas turbines are studied. The effect of design and operation parameters is demonstrated trough the examples of the type of gas turbine, the heliostat field size and the operation of Inlet Guide Vanes (IGVs).
- STPPs are based on the hybridization, where the fossil fuel thermal power is partially or totally replaced by solar thermal power. (*slide 3*)
- The studied solar steam turbine cycle, uses troughs and oil as Heat Transfer Fluid (HTF). For off design performance, HTF flow is proportional to irradiation, the pressure of produced steam is kept constant, while the water flow is computed in order the evaporator to produce saturated steam. The percentage deviation of gross power production (P), water/steam and HTF flows (W) and Steam and HTF temperatures (T) in accordance to the irradiation deviation (DNI) is shown. (*slides 5-7*)
- Hybrid gas turbines are equipped with a tower solar receiver which preheats the air before its entrance into the combustion chamber. Two hybrid gas turbine types are studied, the single shaft and the twin shaft. The design characteristics are chosen in order to have high solar share, maximum fuel efficiency and solar-only operation at the design DNI. Limitations of receiver are taken into account. (*slides 9-10*)
- The performance of the two hybrid engines is simulated over the year using constant Turbine Inlet Temperature (TIT) and hourly ambient data. The annual overall performance is obtained through integration of the hourly results. The percentage difference between solar hybrid and fuel-only engines in annual

produced energy (E), consumed fuel (Fuel) and fuel efficiency (eff_f) as well as the solar share is shown. (*slide 11*)

- The difference of Levelized Cost of Electricity (LEC) between the single shaft hybrid engine and the fuel-only one is depicted for various fuel and emission cost values. Also, it is depicted the same quantity if the acquisition and maintenance costs of the solar part components were reduced to 75%, 50% and 25% of the current values. (*slide 13*)
- The percentage difference between single shaft solar hybrid and fuel-only engines in annual performance, in accordance with the number of mirrors is shown. (*slide 15*)
- For standard day ambient conditions and for solar radiation at the half of the design one, is simulated the performance of the hybrid single shaft engine for various angles of the IGVs. The difference of produced power and specific fuel consumption between the variable angle operation and the fully open IGVs operation is depicted considering hybrid operation with constant TIT and solar-only operation. (*slides 17-18*)

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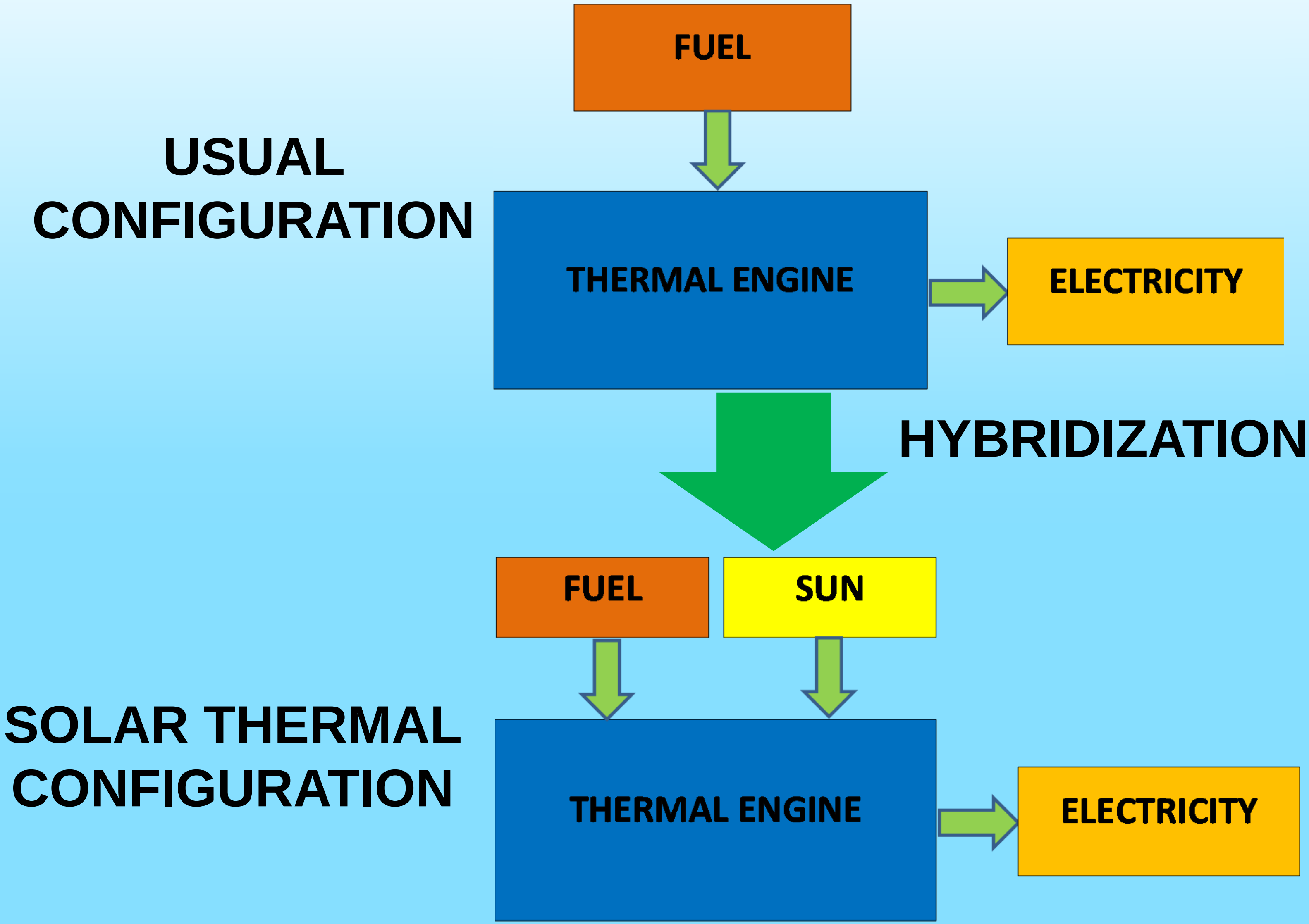
- **Hybridization**
- **Solar Steam Turbine**
- **Solar Hybrid Gas Turbines**
  - **Performance Simulation – Annual Performance**
  - **Cost of Electricity Production**
  - **Effect of Design Parameters**
  - **Effect of Operational Parameters**


USUAL CONFIGURATION
FUEL
THERMAL ENGINE
ELECTRICITY
HYBRIDIZATION
SOLAR THERMAL CONFIGURATION
FUEL
SUN
THERMAL ENGINE
ELECTRICITY

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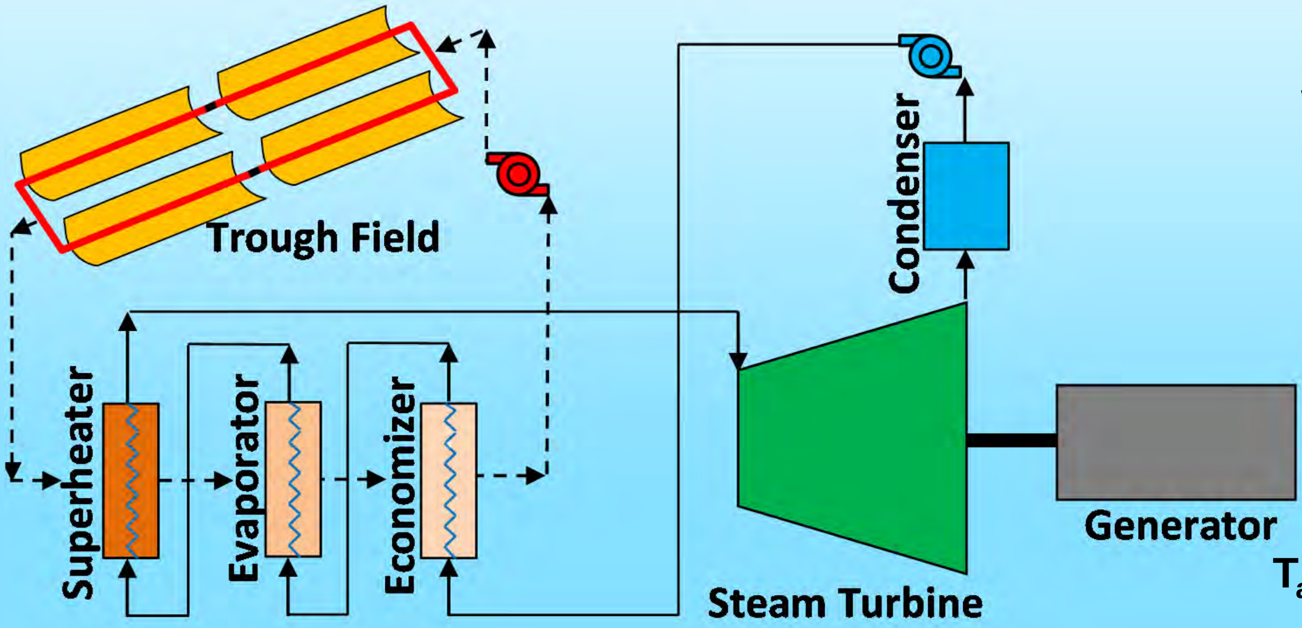
Solar Steam Turbine



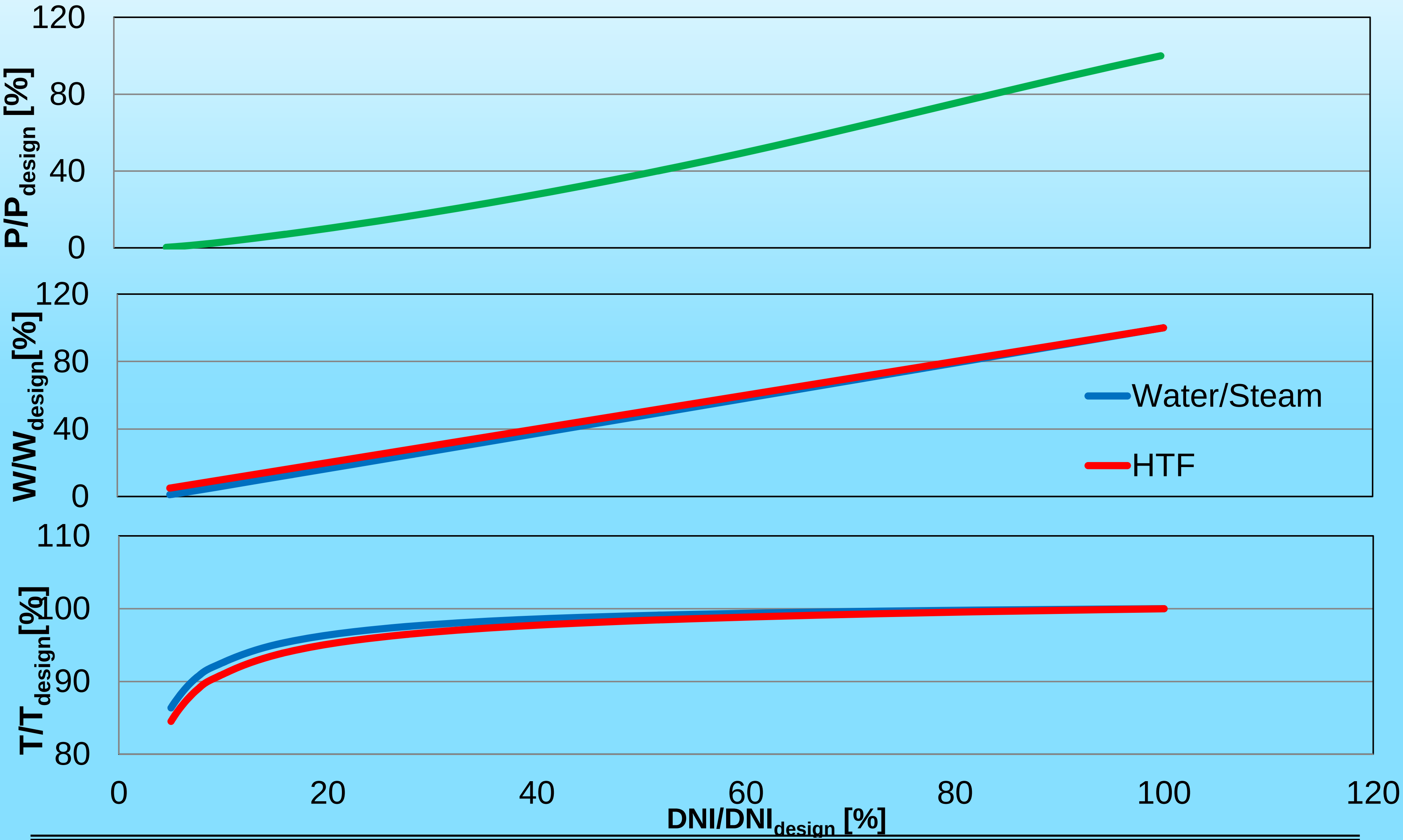
P	= 45.7	MW
W_{steam}	= 53.5	kg/s
T_{steam}	= 385	ºC
P_{steam}	= 48.5	bar
W_{HTF}	= 346.5	kg/s
T_{HTF}	= 400	ºC
T_{pinch}	= 7	ºC
$T_{approach}$	= 3	ºC
DNI	= 600	W/m^2

W_{HTF} ~ DNI

P_{steam} = constant

W_{steam} → Sat. Steam @Evaporator

Solar Steam Turbine Performance



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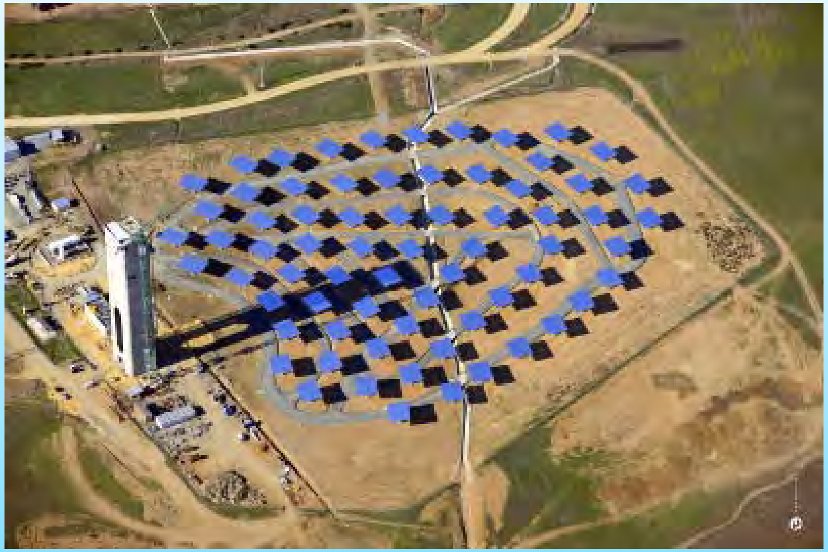
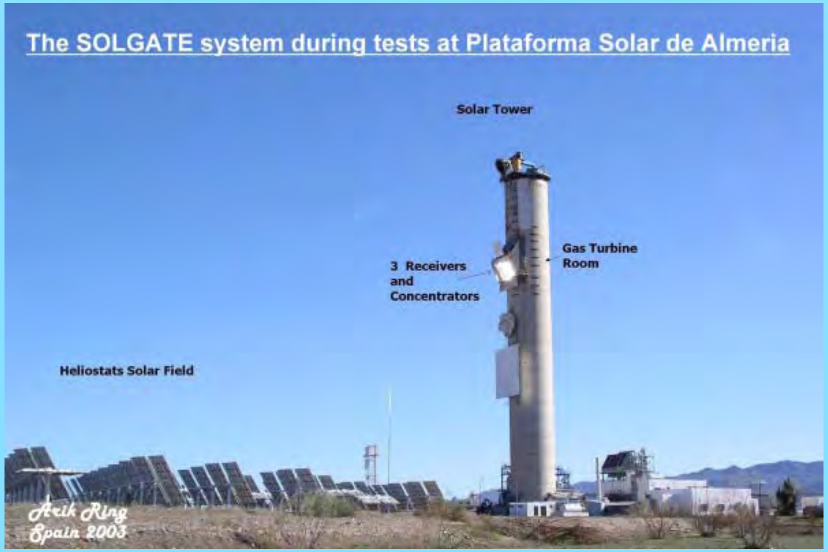
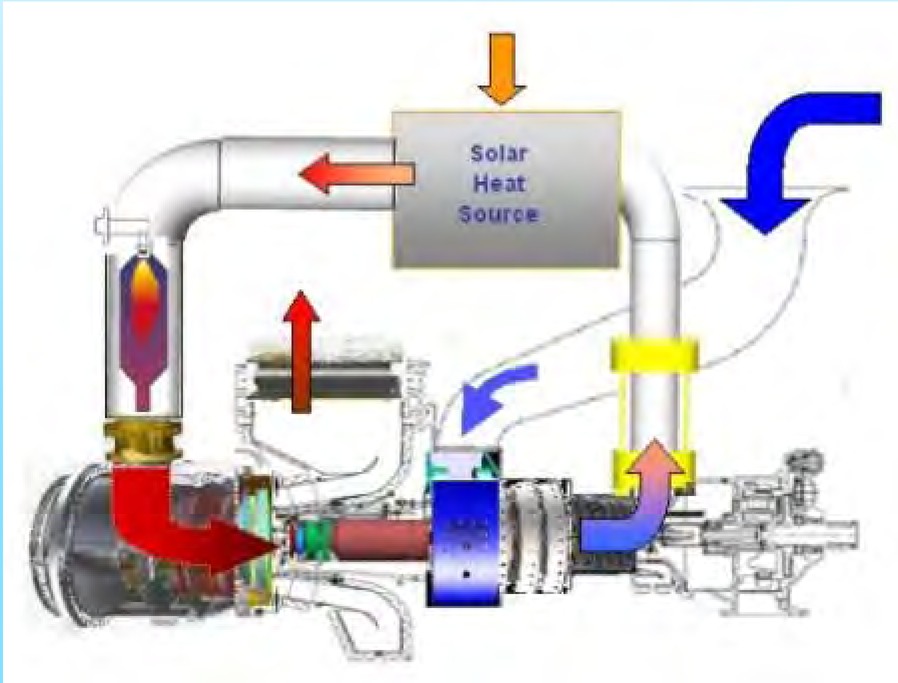
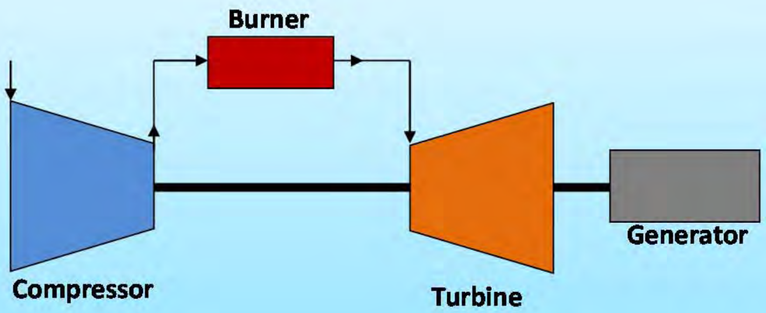
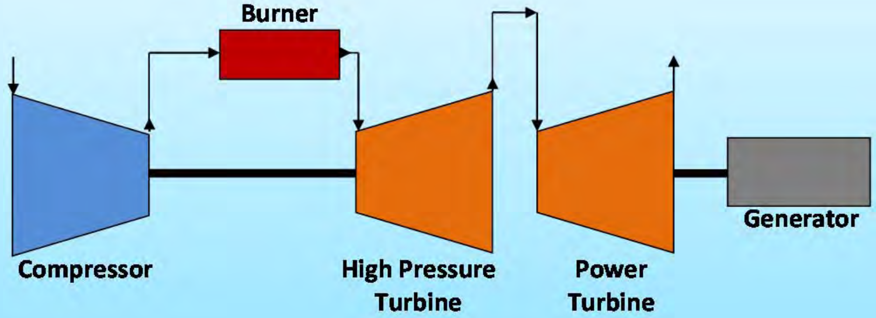



The SOLGATE system during tests at Plataforma Solar de Almeria
Solar Tower
Gas Turbine Room
3 Receivers and Concentrators
Heliostats Solar Field
Arik Ring Spain 2003


Solar Heat Source

Solar Hybrid Gas Turbines



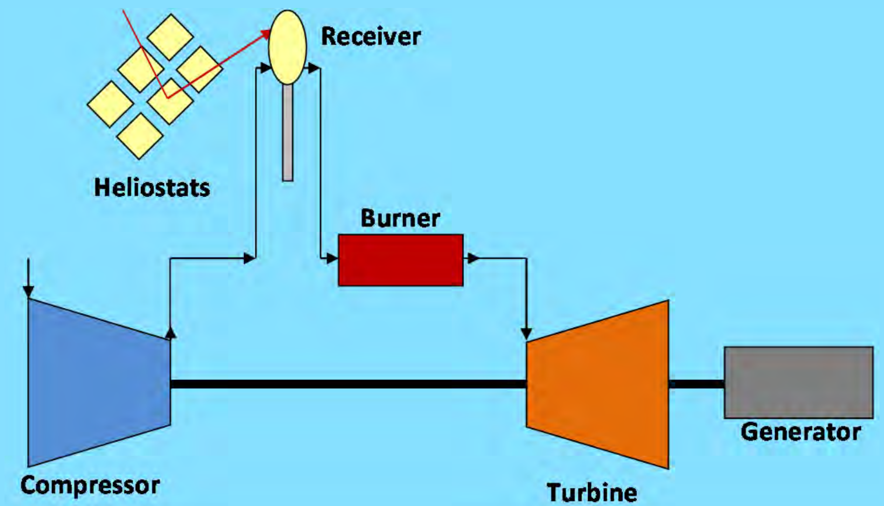


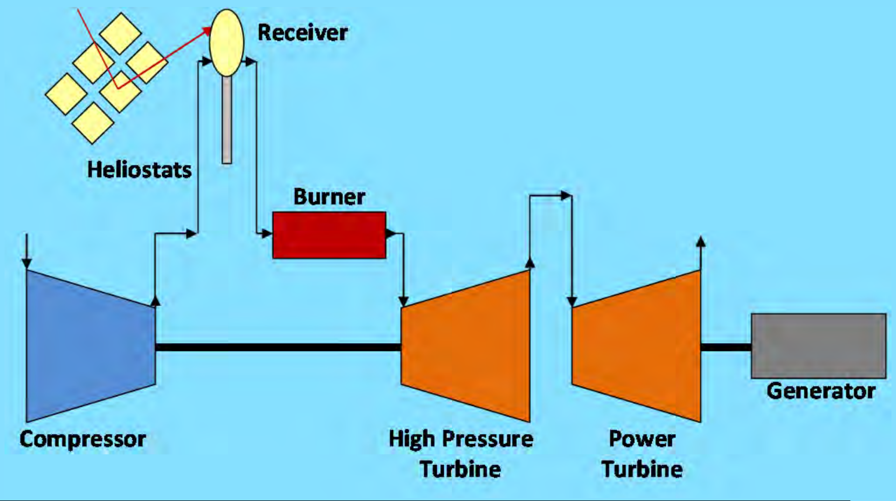
Wf=0 @600W/m²

P = 5 MW

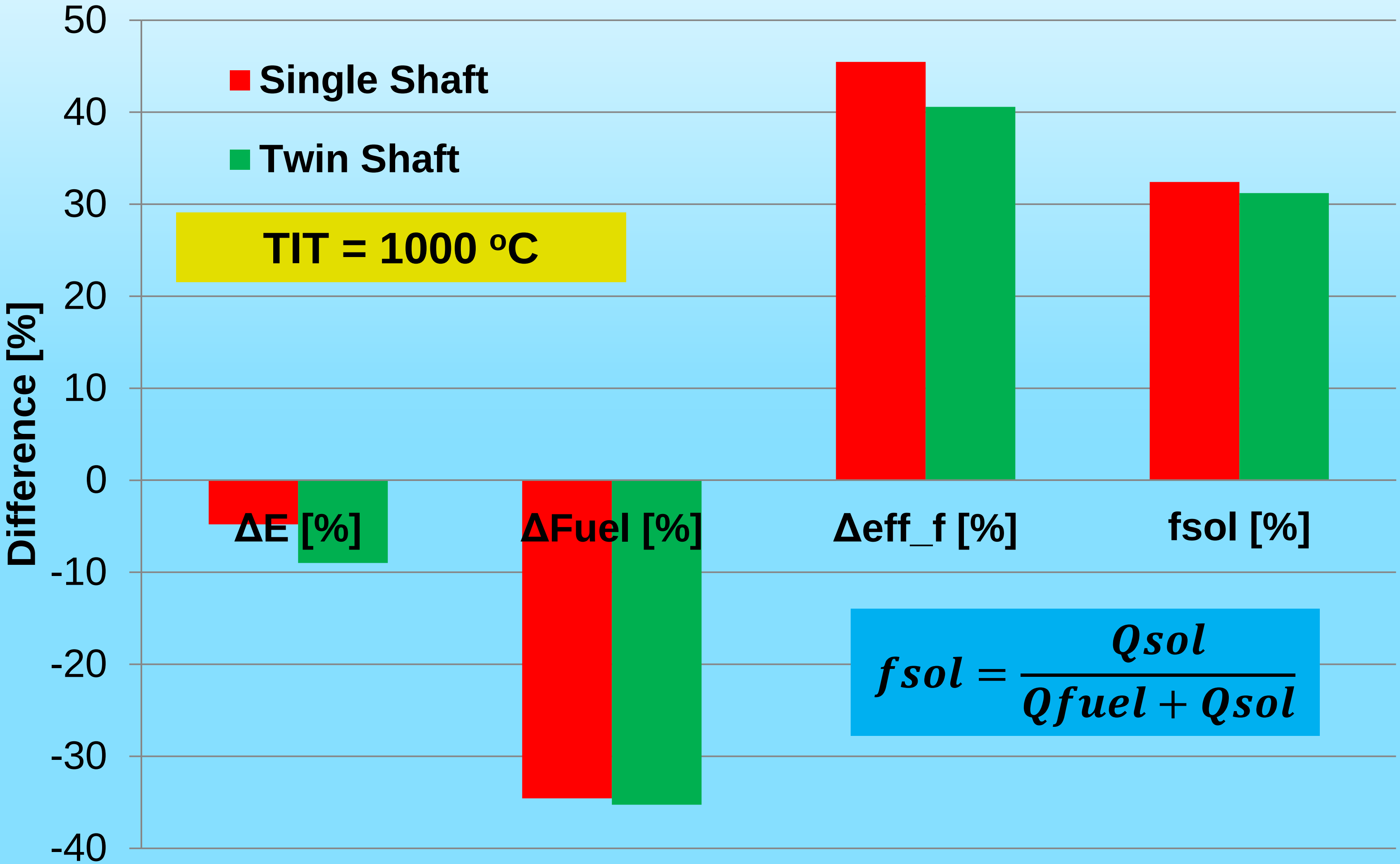
π_C = 10

TIT = 1000 °C





Hybrid Gas Turbines Annual Performance Comparisson



$$fsol = \frac{Qsol}{Qfuel + Qsol}$$

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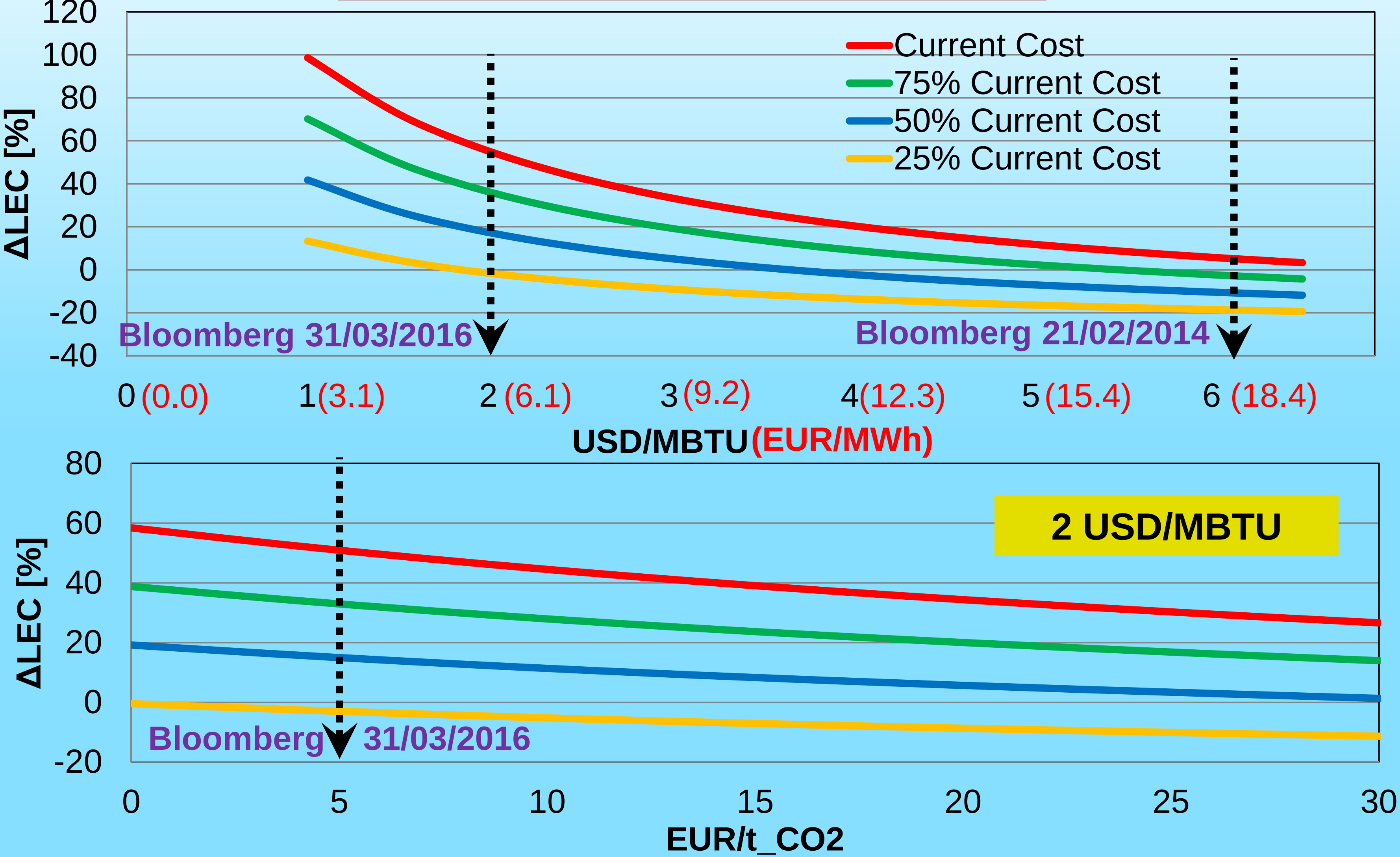
Cost of Electricity Production



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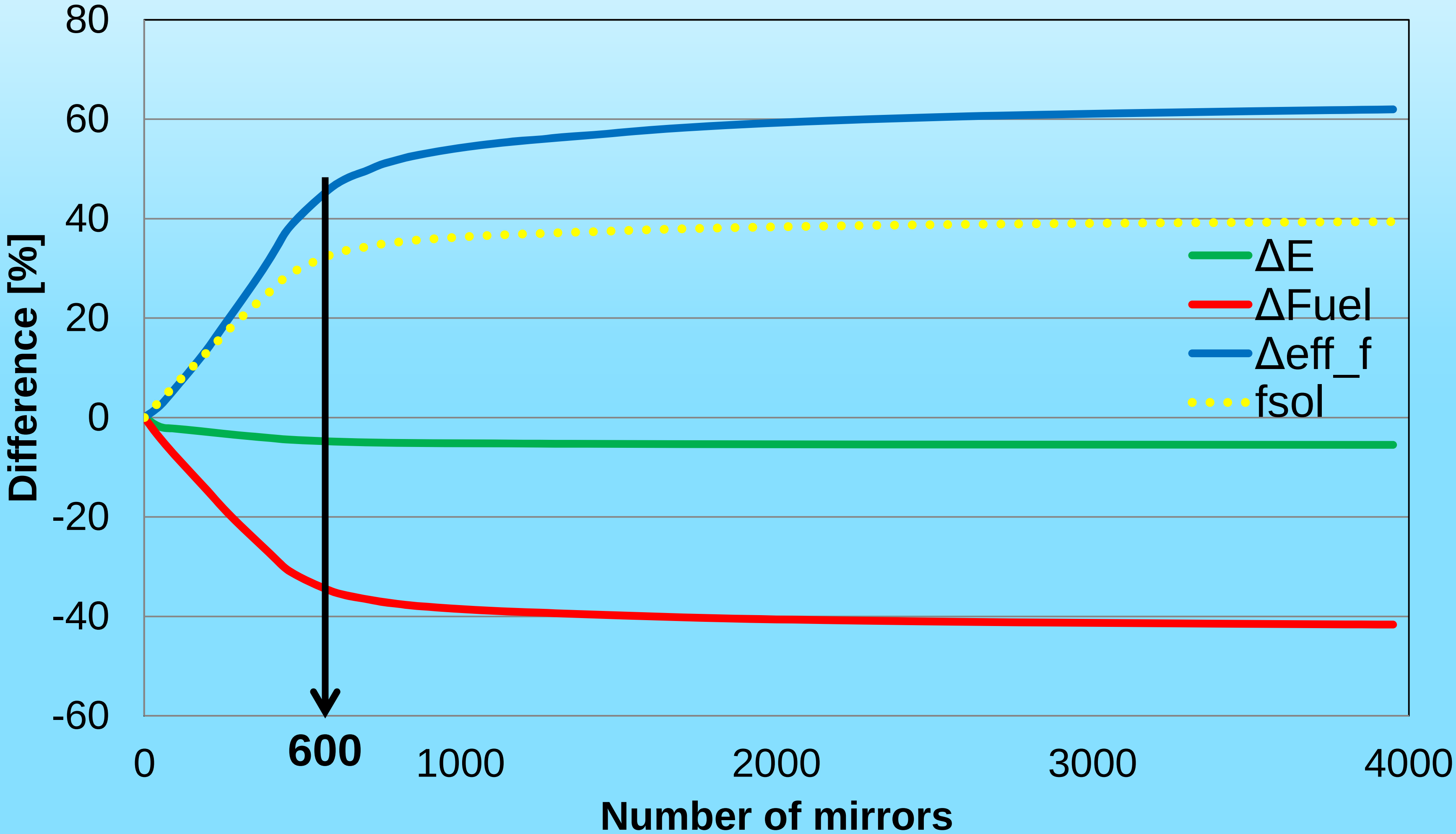
Number of Mirrors Effect on Annual Performance of Hybrid Single Shaft Gas Turbine



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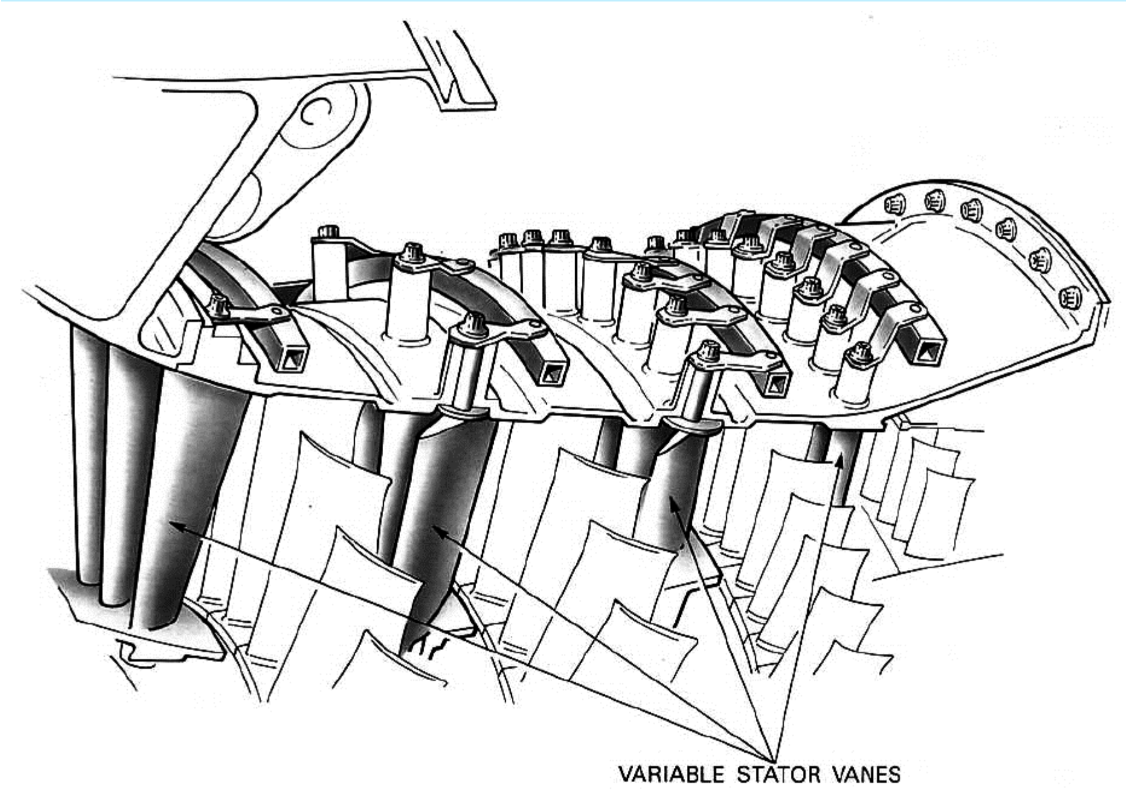
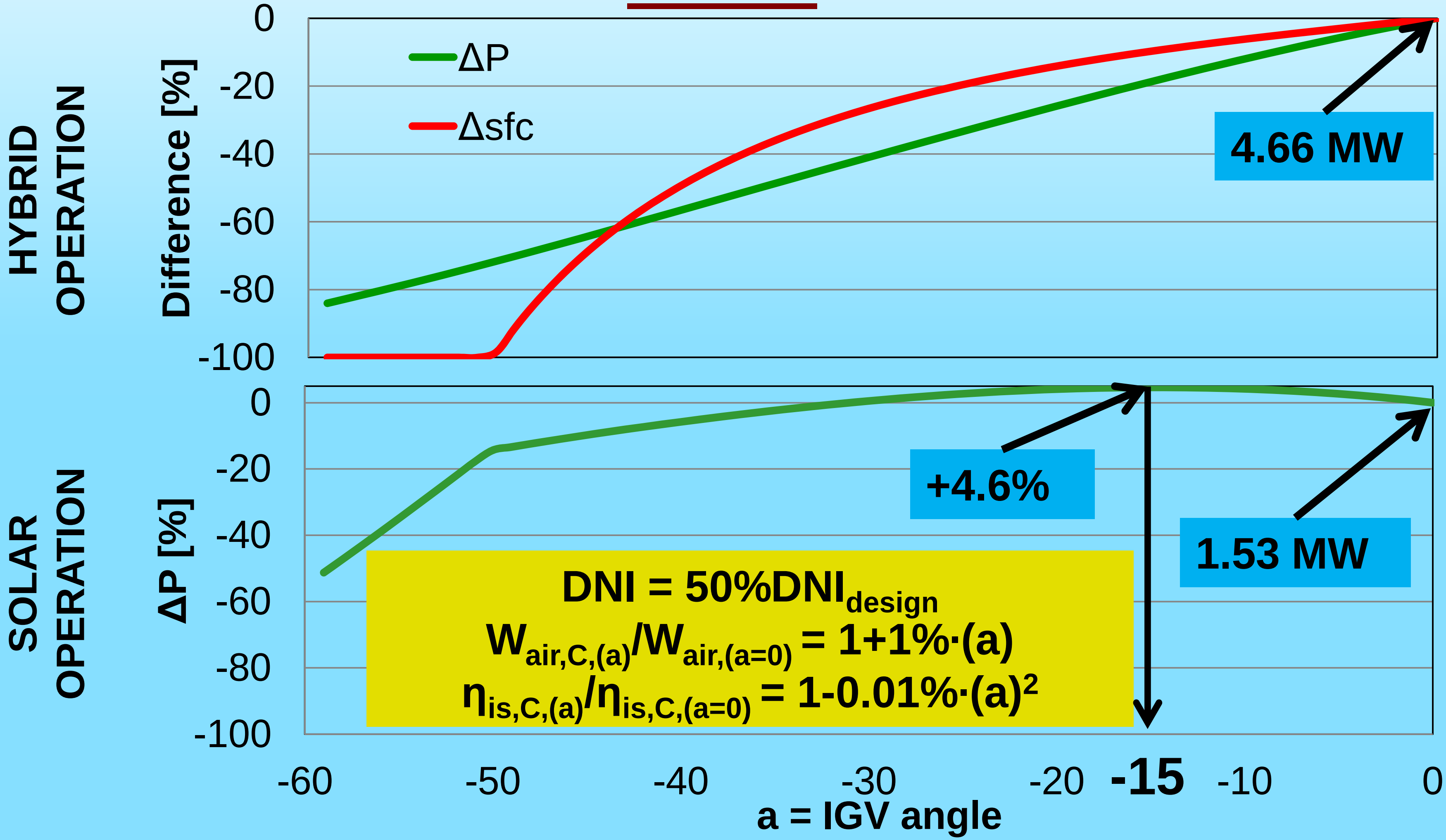
Compressor Inlet Guide Vanes (IGVs) for Operation Control



Effect of IGVs on Performance of Hybrid Single Shaft Gas Turbine



Summary – Conclusions

- **Solar Thermal configurations of steam and gas turbines have been demonstrated and studied**
- **Ability of modelling and performance simulation**
- **Effect of design parameters**
  - **Single shaft gas turbine shows better performance**
  - **Number of mirrors above which the performance is not affected**
- **Effect of operation parameters**
  - **Depending on the type of operation, inlet guide vanes: ↓ sfc or ↑ P**

THANK YOU

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