CSP-gas hybrid plants: Cost effective and fully dispatchable integration of CSP into the electricity mix

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0. Abstract:

Today, Concentrated Solar Power (CSP) Plants are being implemented in several countries around the world where corresponding incentive schemes for renewable energies are in place. While some CSP technologies like parabolic trough can already be considered proven and bankable, large scale introduction of CSP technology into the electricity generation mix is yet limited mainly due to the relatively high costs of electricity.

CSP Hybrid solutions can help bridging the gap from a mainly fossil to a fully renewable power generation scenario. Although today’s incentive schemes do mostly disregard the value of dispatchability and limit the share of allowable fossil fuel co-firing for CSP plants, technology providers and developers are already working to advance technology and project configurations to help improve project economics and thus the speed of penetration of CSP into the electricity market.

Solar-gas hybrid power plants and integrated solar combined cycle power plants (ISCC) are among the best configuration choices that can enable a much quicker fielding of solar energy into today’s energy mix, as they represent a good combination of the advantages of both combined cycles and CSP plants. Hybrid and ISCC plants offer the following advantages:

- reduced costs compared with separate combined cycle and CSP plants
- higher efficiencies achieved for the solar part
- full operational flexibility and grid dispatchability

As such, hybrid power plants are a better solution compared to stand alone builds of independent combined cycle and CSP power plants.

1. Introduction to CSP Hybrid Power Plants

In general, the word “Hybrid Power Plant” can refer to any plant configuration that is based on more than one fuel or technology. As such, any Concentrated Solar Power plant (CSP) that uses an additional fuel (e.g. gas, coal, biomass, etc.) can be called a “Hybrid Power Plant”. For the sake of simplicity, this paper is only based on CSP/gas hybrid plants, using parabolic trough technology. Other combinations of CSP with coal, oil or biomass are also possible, as are the use of other CSP technologies like Parabolic Trough with molten salt, Tower and Linear Fresnel technologies. The conclusions shown in this paper apply for these combinations as well.

Concentrated Solar Power (CSP) Plants are being built in many countries with an ever increasing development status since the first large projects were built in the 1980’s in the USA. Concentrated Solar Power Plants use the direct irradiation of the sun by means of concentrating them by the use of mirrors which is used to heat up a thermal medium which itself is being used to generate electricity by means of a thermodynamical cycle. It is the only renewable energy technology (apart from hydro
and biomass) that can offer a reasonable amount of dispatchability by means of molten salt storage systems. The facts that CSP is still a rather new and innovative technology, coupled with high costs (compared with conventional fossil fuelled power plants) have so far limited its application potential.

In order to increase the share of renewable and solar energy into the electricity mix, intelligent solutions are required that offer more cost effective solutions while fulfilling the requirements for operational flexibility and dispatchability required by the grid without having to resort to back up solutions. Hybrid CSP/gas solar power plants are the ideal solution for this problem.

The rationale for CSP/gas hybrid power plants is that these plants offer the lowest costs of solar electricity at an unprecedented level of operational flexibility and dispatchability and are therefore a better solution compared with separate installations of Combined Cycle Power Plants (CCPP) and CSP or PV plants. This is mainly because:

- Synergies in plant design allow for much lower costs of construction compared with separate plants (one bottoming steam cycle vs. two, synergies in Balance of Plant equipment)
- The use of a larger steam cycle at higher steam conditions increases the efficiency of the solar fraction compared with a stand alone CSP plant
- High flexibility and dispatchability offered by hybrid plants enable full grid code compliance even if no storage solutions are adopted. They also allow for a flexible dispatching approach depending on the prevailing market conditions for gas and electricity, thus increasing flexibility for the operator to adapt operation in changing market environments.

2. Types of CSP/gas Hybrid Power Plants

CSP/gas hybrid plants can be catalogized into three different groups depending on their solar/gas fraction, each allowing a multitude of different detail configurations, depending on the equipment and thermodynamic design chosen:

- Large Integrated Solar Combined Cycle Plants (ISCC): These projects can be described as a conventional combined cycle plants that have a rather small CSP field attached to. The ratio solar/gas is usually less than 20/80% (measured by capacity). A typical configuration is e.g. an ISCC based on one SGT5-4000F gas turbine with 450MW total power output for a low DNI site at local ambient conditions, of which 51MW would be the contribution from the Solar Field. While the pure CC gas efficiency would amount to 58.7%, total plant efficiency would increase to 66.1%, if the additional solar energy is factored in. Main rationales behind this configuration are:
  - dispatch profile and costs like a conventional CCPP plant
  - possibility to sell solar electricity at premium peak load prices
  - resell some gas on spot market not required to meet full load at midday
  - compensation of CCPP output drop at high ambient temperatures
  - easy inroads into CSP technology for conventional generating companies
  - green messaging to public
- Balanced Hybrids and ISCCs: Here the power output from the CSP field and from gas are of similar size, with the solar/gas fraction ranging from 30/70% to 70/30%. A typical configuration would be a hybrid plant with one SGT-800 gas turbine package with a total power output of 101MW, of which 40MW would be solar fraction. Total plant efficiency would increase to 87%. Main rationales behind this configuration are:
  - fully dispatchable plant (qualifies for capacity payments)
  - maximum “green” share with utility-like reliability
  - highest flexibility of all hybrid plants (plant can operate in “gas only”, “CSP only” and “full hybrid” modes)
  - possibility to sell solar electricity at premium peak load prices
  - resell gas on spot market during hot sunny days if more cost effective than selling gas based electricity
  - easy inroads into CSP technology for conventional generating companies
  - green messaging to public

- Gas augmented CSP plants: These are conventional CSP plants with a gas turbine booster to burn the allowable fossil fired fuel fraction more efficiently. The ratio solar/gas is usually higher than 80/20%. Typical configurations are CSP plants between 100 and 250MW of power output boosted by a SGT-400 or SGT-800 turbine. Main rationales behind this configuration are:
  - more efficient use of allowable gas fraction
  - gas burned effectively in a much more efficient cogeneration/CHP mode
  - sell additional gas based peaking load at combined cycle efficiencies
  - use the allowable gas fraction to sell electricity at premium peak load prices
  - offers some degree of dispatchability without the need for storage solutions
  - additional revenue from the provision of peak load capacity to the grid
  - black start capability of plant and savings associated with requirements for aux. boilers and emergency power supply.

All of these configurations can be based on any CSP solar technology (parabolic trough, tower, fresnel) and may or may not include a storage system. Several thermodynamic variations are possible within each group depending on the GT equipment and total size chosen, the required degree of operational flexibility, operational regime and the required level of maximization/optimization of gas firing efficiency.

In general, the optimized configuration will always be a tailorized solution based on:
- expected operational regime
- costs of fuel and electricity prices/market characteristics
- DNI and local ambient conditions
- load regimes and electricity demand in the country
- CO₂ taxation and incentive schemes for CSP
i.e. there is no “universal hybrid solution”, rather it is important to factor all these parameters into the design and involve an experienced EPC contractor to optimize the configuration.

Important attention needs to be placed on managing the higher complexity of such plants in order to keep safe and stable operation under all normal, transient and disuptional conditions in order to achieve high plant reliability and availability. Siemens, having an extensive experience in power plant design, integration and commisioning of
all sorts of power plants, and having all key technologies in house (e.g. gas and steam turbines, solar field, Benson boiler, DCS system, etc.) is in a privileged position to make this happen.

3. Operational and dispatching considerations:

Hybrid power plants can be designed in general for two different operational strategies:

- **Solar Booster**: The combined cycle part runs in baseload operation mode, and additional CSP steam from the solar field during sunlight hours increases the total power output of the plant. This additional power output during the day compensates for the loss of output of the CCPP during the warm midday hours and produces additional power output at times of higher demand during the day, mirroring a combination of a baseload and a daily cycling plant. A small storage solution can shift the solar peak to the late afternoon hours if so required. The efficiency loss during “gas only” operation mode (due to the bottoming cycle running in part load) is rather small, as the GT will still run full load and the ST will be able to run at a lower condenser backpressure, compensating for some of the efficiency losses.

- **Fuel Saver**: The plant operates at full load 100% of the time, with the solar fraction used to reduce the gas consumption of the plant through GT operation in part load or by switching off a gas turbine in case of a 2+1 multishaft configuration arrangement.

Operational and market requirements will determine which one of the design philosophies is most suitable for a specific project and location. Additional variations of these configurations may arise out of:

- inclusion of a storage facility
- the type and number of turbines selected
- supplementary firing in the HRSG
- potential of retrofitting existing plants (CCPP plants, GT peakers, etc.)
- etc.

4. Market potential and regulatory issues:

Potential market areas for CSP/gas hybrid power plants are all those countries with medium to high Direct Normal Irradiation (DNI) levels that have plans to build both CSP power plants as well as gas fired combined cycle power plants. In these cases, it is economically much more reasonable to build this additional planned capacity in joint hybrid plants rather than in separate CCPP and CSP installations.

Therefore, most of the target areas foreseen for CSP plants are as well target areas for CSP/gas hybrid plant, such as the Middle East, North Africa/Maghreb, USA and China.
CSP/coal hybrid power plants would mainly be envisaged for countries like South Africa, India or Australia with significant indigenous coal reserves and where there is no gas supply in areas of high DNI.

In order to ensure a market success for hybrid power plants, it is required that suitable regulatory framework are put in place. Currently most CSP regulatory environments do not consider hybrid plants, thus leaving this technology in an unclear status about how they fit in or match into existing CSP incentive schemes.

In order to provide a suitable but fair incentive scheme, it is necessary to provide a regulatory environment which allows CSP/solar energy incentives to be made available for the solar fraction of hybrid plants without incentivising the fossil fired portion. Conventional Feed-In-Tariffs do not work in the framework of a hybrid power plant and will need to be adjusted to apply for the solar fraction only. This can be done by recalculating the FIT for a hybrid plant based on the expected mix of gas/solar fraction (maybe coupled with a not-to-exceed gas consumption) or by applying the CSP FIT to just the solar fraction of the electricity produced. Although it is not possible to discern the origin of a produced kWh, it is easily possible to calculate thermodynamically how much of the energy produced was originated by the fossil fuel and how much from the sun.

Regulatory frameworks that are based more on upfront incentives (like tax grants or construction subsidies), leaving the marketing of the produced electricity to market forces, will make it easier for hybrid power plants to play out their operational advantages in the electricity market and make more efficient use of the characteristics and flexibility of hybrid plants, thus contributing to reduced costs of electricity.

5. Economic analysis:

To check whether hybrid power plants have an economic benefit over separate installations, Siemens has calculated the Levelized Costs of Electricity (LCOE) and Net Present Value (NPV) for a multitude of hybrid configurations in several potential markets. An example is shown in the graph, where the hybrid plant is being compared with two separate CSP and CCPP plants of comparable size and same operational and market conditions. The result of these economic analyses have showed that:

- Hybrid plants offer lower costs and a better NPV than separate CCPP and CSP power plants
- When additional capacity payments, time-of-day prices and economic benefits of operational flexibility of hybrid plants (which were all not included in the analysis) are factored in, the economic advantage of hybrids becomes even greater
- The results are highly influenced by multiple parameters, and the most optimum configuration will always depend on project specific parameters
- Project specific tailorization is a must and will maximize the economic benefit of the plant
- The incremental costs of the CSP fraction is comparable to that of PV installations but as dispatchable energy and at a much higher rate of operational flexibility
6. Summary and conclusion:

Summarizing, Siemens’ view on the CSP/gas hybrid technology are:

- Hybrid plants offer better economics than separate CSP and CCPP plants
- Hybridization offers the most cost effective and efficient feed-in of CSP power into the grid, while maximizing operational flexibility and dispatchability
- There are many possible configurations that allow for any potential fraction between solar and gas as required by the business case
- The best configuration will always depend on a variety of factors and will need to be optimized for the specific conditions of the project, the fuel and electricity markets, the location and the business strategy of the operator.
- Project design, optimization and integration is best done by an experienced EPC contractor.