Integration of solar thermal energy in a conventional power plant: The Colón solar project

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Abstract. This paper reports on the first phase of the Colón Solar Project, originally conceived as the hybrid repowering of an existing thermal power plant, with the addition of a gas turbine in a *topping* configuration integrating thermal energy (steam) produced by a solar system. However, the project developed in a changing economic environment, in which a new legal structure, still incomplete, as of January, 1998 has liberalized the electricity generation market. This forced the original configuration to be modified, resulting in an all-new combined cycle with solar energy integrated into a Heat Recovery Boiler. Basic plant engineering placed special emphasis on the most important solar components (heliostat and receiver), and an economic analysis showed that the plant is profitable under the assumptions of the analysis. Nevertheless, the relatively low IRR, as well as the uncertainty of realization of some of those assumptions, made the utility postpone its decision to build the plant.

1. INTRODUCTION

Since January 1, 1998, the Spanish power market has been liberalized. This means that from now on, its operation will be based on a system of supply and demand, under which the existing power demand at any given moment is covered by the production plants offering the cheapest kWh.

Thus those power production plants or units that can offer the cheapest kWh are the first to operate to supply the demand, and therefore, those that have the best possibility of surviving in the new competitive environment.

Within this new deregulated framework, however, a kWh credit is planned (not yet expressly enacted), for solar or other renewable energy-based production.

Such a credit for electricity produced from renewable resources would provide some very advantageous opportunities for solar thermal technology, which, when integrated into hybrid power plants, could be the key to their lowering conventional generation costs (because of the mutual synergies of the conventional and solar technologies) enabling them to compete on the new market.

If the satisfactory integration of solar thermal and conventional plants can be demonstrated, it will then be the market that demands the solar technology, and, accompanied by the advances now underway in R&D, will lead to its wide-scale utilization in the Mediterranean basin and elsewhere.

This demonstration is one of the main objectives of the Colon Solar Project, which is supported by the Thermie program of the European Commission. The recently completed first phase of this project involved 9 organizations (utilities, equipment manufacturers, engineering firms and research centers) from 4 different European countries, led by one of the utilities, Sevillana de Electricidad. This is one of the distinctive aspects of the project compared to other solar energy projects, since the leader is a final user of the technology, instead of an R&D institution.

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2. BACKGROUND

First conceived as hybrid repowering of an existing thermal power plant with a *topping* configuration based on the existing plant, an added gas turbine and an integrated solar field, the Colón Solar Project employs the SOLGAS concept [1], as developed in the APAS SOLGAS Project [2]. The SOLGAS concept postulates hybridization of high-efficiency power plants (combined Brayton-Rankine cycle, cogeneration cycles) and the use of Central Receiver Systems (CRS) as a realistic and viable path towards marketable solar thermal energy applications.

Hybridization has traditionally been considered a means to override the most significant drawbacks of solar energy, which is intermittent and random, for electricity production. This point of view conceives the *fossil part* of the hybrid power plant primarily as auxiliary support to adapt production to the demand when solar energy is unavailable or insufficient.

However, despite the considerable progress in solar technology in recent years, none of the proposals to build solar (hybrid or stand-alone) power plants has succeeded, with the remarkable exception of the SEGS plants in California. Solar thermal technology seems to be trapped in a *vicious circle* [2] impeding market access.

The concept of the *Optimized Power Plant*, which is the core of the SOLGAS proposal, is a realistic, innovative approach to hybridization, emphasizing viability in the real-world scenario, in which a large solar fraction of the hybrid plant is no longer relevant. In the present situation, any progress in marketing solar thermal technology makes sense. In the same regard, the SOLGAS concept advocates the use of proven, reliable components of the Central Receiver System (CRS) technology, in order to convince potential users (utilities) and financial institutions that the solar thermal (and more specifically, CRS) technology is not immature. This does not imply that other more ambitious schemes that take full advantage of solar radiation's potential for high exergy are forgotten or may not be feasible in the future.

The solar system, which starts up at slightly under the saturation point, is used to boil water, with the following advantages:

a) For the heat exchanger (the "heat recovery" unit):
- It lessens the temperature drop between the hot gases leaving the turbine and the coolant in the Rankine cycle.
- It all but eliminates the heat-exchanger pinch.
- It does not waste high-temperature gas in the energy-guzzling evaporative process.

b) For the solar system:
- It alleviates operating conditions by eliminating high temperatures and instabilities associated with superheating.
- It increases the thermal efficiency of collection by taking advantage of two-phase heat transfer throughout most of or the entire receiver.
- It eliminates the need for storage.
- It significantly reduces plant startup time.

c) For the overall system:
- It enables all of the collected solar energy to be used as a substitute for the fossil fuel.
- The solar contribution justifies a modest amount of combustion in the Rankine cycle, to maintain boiling during cloudy periods or early and late in the day

3. PROJECT ORGANIZATION

The first phase of the project involved 10 organizations led by one of the utilities, Sevillana de Electricidad. This is one of the distinctive aspects of the project compared to other solar energy projects, since the leader is a final user of the technology, instead of an R&D institution. The participants were:

- Utilities: Sevillana de Electricidad, ENDESA (Spain), EDP (Portugal)
- Manufacturers / Engineering firms: ABB Stall (Sweden), INABENSA, BWE (Spain), PROET (Portugal)
- Research institutions: CIEMAT, AICIA (Spain), DLR (Germany).

The three groups were coordinated by Sevillana.

4. RESULTS

As a consequence of the changes in the legal framework since the project was first proposed (June, 1996), the initial scheme (topping) proved economically unfeasible in the new electricity generation scenario. The plant configuration evolved during project development into a hybrid power plant in which the power block is a completely new combined cycle (Figure 1) for which only some auxiliary systems of the existing power plant are reused.

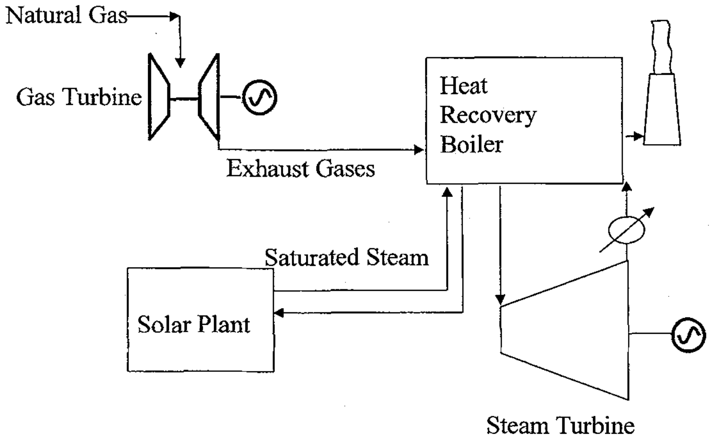

Figure 1. Colon Solar plant final configuration

The ABB GTX-100, 43-MW nominal power gas turbine works at full load under normal operating conditions. The dual pressure Heat Recovery Boiler, has two additional burners to control the flow of steam to the steam turbine in different operating modes and in the event of sudden changes in solar radiation. Steam Turbine design power is 30-MW, with a steam flow of 78.8 t/h at 510°C in the high-pressure (99.8 bar) section and 15.5 t/h at 181°C in the low-pressure (2.76 bar) section.

Table shows the main performance parameters of the Colon Solar Plant.

Table 1. Main performance parameters of the Colon Solar Plant

	Unit	Without Sun	With Sun
Steam Turbine Power	MW	20,0	28,4
Gas Turbine Power	MW	42,7	42,7
Total Gross Power	MW	62,7	71,1
Total Net Power	MW	60,0	70,4
Fuel Consumption	MWt s/LHP	114,8	114,8
Net Efficiency	% s/LHP	54,0	61,3

The Colón Solar power plant is located in Huelva (Southern Spain) where annual irradiance is 2063 kWh/m^2. The solar part is a Central Receiver System with a collector subsystem of 489 heliostats (each with a 70-m^2 reflective surface) and a 21.8 MW_{th} steam cavity receiver (power to fluid under design conditions), on a tower at a height of 109 m. The land allotted for the project is approximately triangular, but non-symmetrical, crossed by power lines and supply ducts. Because of these characteristics, the heliostat field (Figure 2) and the flux on the absorber are not symmetrical and the tower is taller than usual. However, the solar system performance parameters are not very different from those of a symmetrical field and receiver behavior is unaffected.

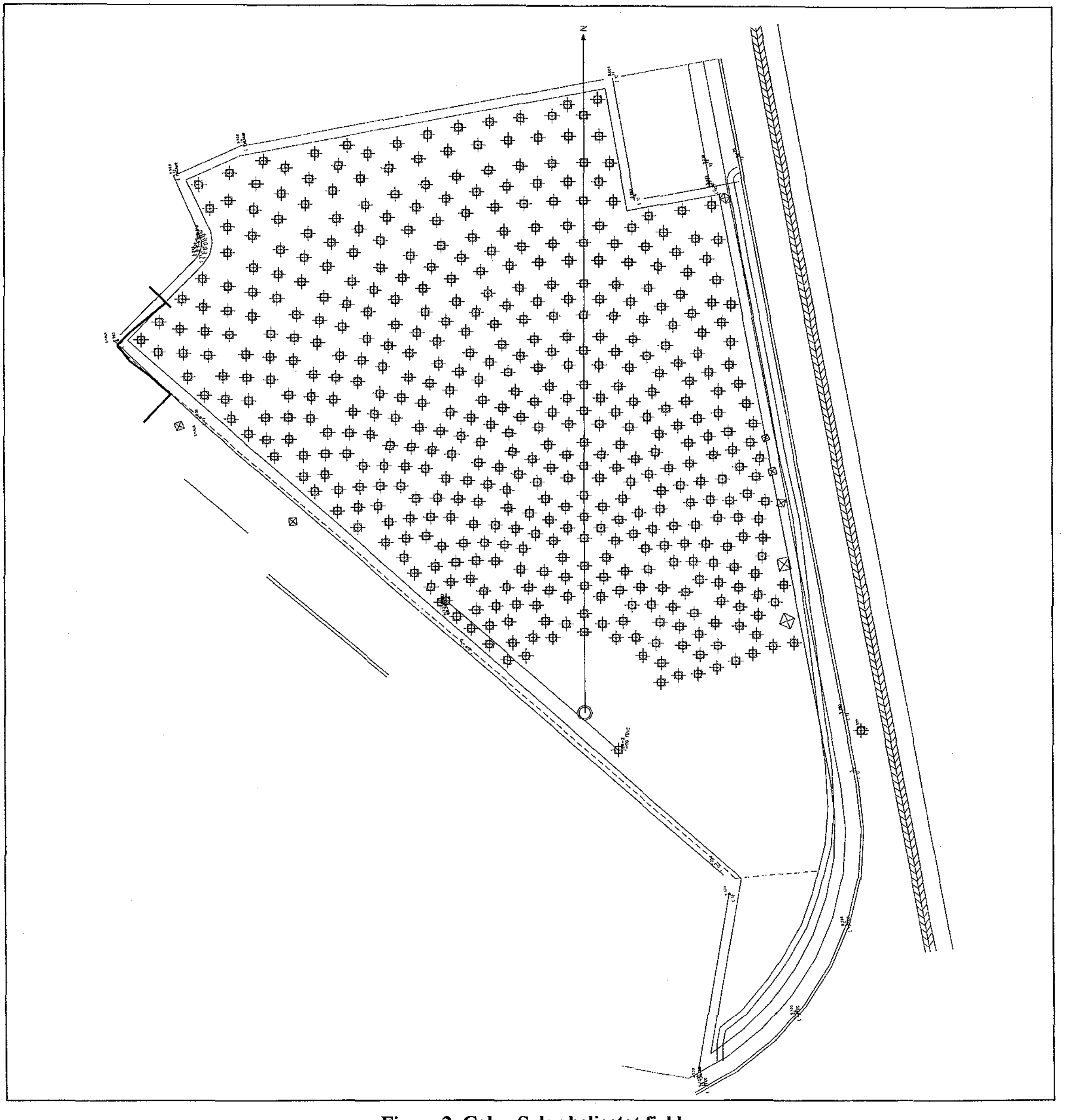

Figure 2. Colon Solar heliostat field

The main characteristics and performance parameters of the solar system are presented in Table 2.

Table 2. Main characteristics and performance parameters of the solar system

Design point	Spring equinox, solar noon
Design irradiance (DNI)	859 W/m^2
No. of heliostats	489
Heliostat reflective surface	69.3 m^2/heliostat
Design reflectivity	0.94
Average reflectivity (estimated)	0.90
Receiver type and fluid	Cavity, tubular type, Water/steam
Aperture dimensions	7.1 m (horizontal) x 6.6 m (vertical)
Aperture height	109 m
Aperture tilt angle (to vertical)	30°
Maximum flux on absorber (design point)	690 kW/m^2
Tower height	120 m
Power to fluid (design point)	21.8 MW
Heliostat field efficiency (design point)	0.805
Receiver efficiency (design point)	0.935
Solar system efficiency (solar to thermal, design point)	0.753
Energy collected by fluid (excluding operational losses, yearly)	43.5 GWh
Heliostat field efficiency (yearly)	0.747
Solar system effciency (yearly)	0.619

The most significant components of the solar plant, heliostats and receiver engineering have been worked out in great detail.

The non-symmetrical shape of the land available (Figure 2) and the restrictions on its use made necessary a new heliostat design that would make the best possible use of the land.

A heliostat prototype with 21 3-x-1.1-m facets, 70-m^2 reflective surface and no central gap has been designed and built and tested at the Plataforma solar de Almería. Test results show that the heliostat meets the specifications (total error ≤ 2.9 mrad) with low power consumption.

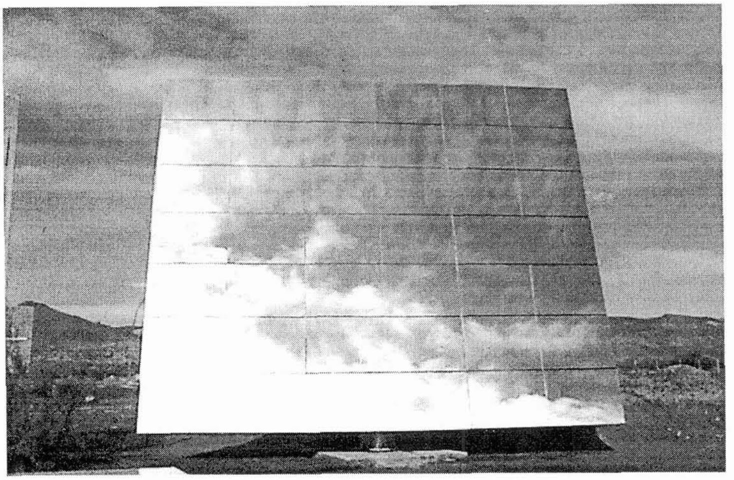

Figure 3. Front view of the Colon Solar heliostat

The saturated steam receiver has been designed for maximum reliability and performance. Thermal and stress analyses show that these objectives have been achieved with a simple, durable design. The receiver demonstrates excellent efficiency (above or close to 90% in an operating range up to 20% part load) and due to two-phase fluid conditions during most of its transit through the receiver tubes, limited temperature gradients.

5. ECONOMIC AND PROFITABILITY ANALYSIS

The project budget was based on offers from qualified suppliers. According to these offers, the total Colón Solar Plant investment will be 7933 Mptas., 36% of which corresponds to the solar part.

Among other hypotheses, the profitability analysis assumes that subsidies from the EU and other will be 2417 Mptas and credit (price support) for the electricity of solar origin will be 15 ptas/kWh. Electricity sales and operating costs for a 15-year period under the new regulations were estimated using a model of that generation scenario. According to this model, the plant is profitable, with IRR of 8.36% and NPV of 1085 Mptas, assuming a 12%.discount rate.

However, because of the uncertainty regarding the above mentioned assumptions (enactment of the law regulating subsidies for renewable electricity is still in process) and the fact that the IRR is lower than that required by the utility for new investments led to the utility's decision to postpone the decision to build the plant.

6. CONCLUSIONS

The new deregulated legal framework of the power generation market substantially modified some of the premises that led to the original Colón Solar proposal, requiring additional effort to adapt to this changing environment, while maintaining the quality of the project and keeping, in so far as possible, on schedule. The most relevant conclusions of this phase of the project are the following:

- The original plant configuration (repowering the Cristóbal Colón Thermal Power Plant Unit I with a topping scheme), was discarted in favor of a configuration based on a **new combined cycle, in which solar generated steam is integrated into the Heat Recovery Boiler)**. This new configuration meets the technical and economic criteria for viability in the competitive environment.
- Economic analysis of the new configuration showed that the **Colón Solar project is viable in the new competitive environment,** provided that the hypotheses used in the analysis (credit for solar power production, subsidies from the UE and other financing bodies, prices of natural gas and electricity) are realized, in which case, Colón Solar plant income would be greater than its operating costs.

  However, project returns (IRR = 8.36%) are still less than required by the utility for new investments. This, in view of the uncertainty regarding some of the hypotheses of the economic analysis, led the utilities to **postpone their decision to build the plant until the uncertainties are resolved.**
- When designing the main plant systems, special emphasis was placed on the non-conventional equipment, that is, solar receiver, heliostats and heat recovery boiler received.
- Commercial quotations for system components received from experienced manufacturing and engineering firms are not only a reliable basis for a plant construction budget, but also show that there is a sound technological base in the industry, which affirms the maturity of the Central Receiver System technology.

Bibliography

[1] M. Blanco and V. Ruiz. The Solgas Project. Proceeding of the European Conference and Contractors Meeting. Venice, Italy. November, 1995.

[2] M. Blanco (coordinador) et alt. SOLGAS Project,: Hybrid Combined Cycle Cogeneration Plant Based on Central Receiver Technology. Final Report. Contratc APAS RENA-CT94-0043. Sevilla, 1996.