INTEGRATION OF CCGT PLANT & EXISTING LNG TERMINAL AT BARCELONA PORT

This paper presents the work undertaken by Gas Natural and Foster Wheeler Iberia to estimate the economic value of the integration of Barcelona LNG receiving terminal and the 800 MW combined cycle gas turbine (CCGT) power plant under development adjacent to the regasification facility.

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Power market deregulation began a few years ago in Spain. One of the new players in this new scenario is the largest gas company in Spain, Gas Natural sdg S.A. With a history going back more than 150 years, the company has become one of the most active investors in new power generation plants. Gas Natural will reach approximate 5,000 MW based on CCGT by the end of 2007. This power will represent over 35 per cent of the total new CCGT plants to be installed in Spain in this period.

Natural gas consumption in Spain will double within next the 10 years, mainly due to its utilization for power generation. The new CCGT plants will supply the power to cover the growth in electricity demand (it is estimated that demand will have grown by 50 per cent by the end of 2010, versus 2000), but also CCGT-generated power will replace the energy from other old power generation facilities that will be closed under environmental restrictions.

The limited indigenous gas production and geographical location of Spain (supply of piped gas is limited) means that liquefied natural gas (LNG) imports will be critical to meet the future gas demand. Barcelona LNG terminal, owned by Enagas, is currently developing a large expansion program. The regasification capacity will reach 1,650,000 Nm^3/hr in 2005.

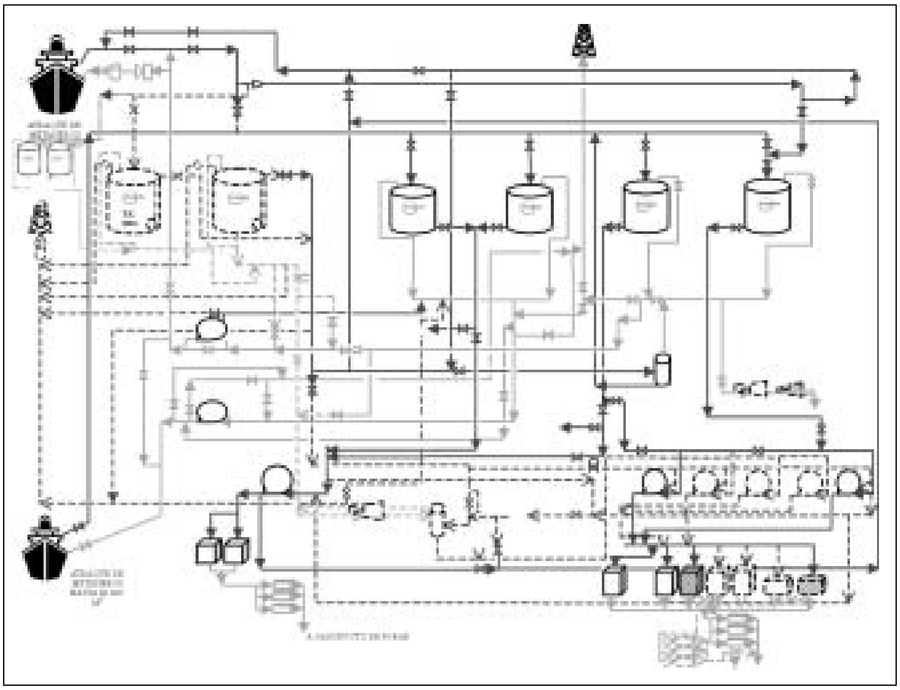
Barcelona CCGT will be located adjacent to the existing LNG terminal. The interfaces between the power plant and the terminal are limited to the supply of gas from the terminal and the utilization of the seawater (5-10 per cent) discharged from the terminal to the sea as make-up of the CCGT cooling towers. Cooling tower blow-down is mixed with the main seawater flow and discharged by the LNG terminal outfall, reducing the thermal impact of the cold water flow.

This paper includes the preliminary engineering work to evaluate the economics of a larger integration of the facilities. The proposed integration scheme is based on the utilization of cold from LNG vaporization to increase the electrical energy production of the CCGT plant.

CCGT plant

The plant will be located at the Barcelona Port. The proposed area, which covers approximately 75,000 square meters, has been reclaimed by the Port Authority who owns the land. The area will be leased under a long-term contract by Gas Natural.

The soil survey conducted by Gas



Process flow diagram showing LNG terminal

Natural concluded that the bearing capacity will not be sufficient for most of plant equipment. Therefore, the foundation design will be based on piling. Other solutions, like the replacement of filling material by better quality materials and compaction, have been rejected due to cost and time implications.

The CCGT plant will have two single train power blocks (400 MWe net, each) using forced draft cooling towers as the cold source. The condenser cooling system will use seawater as the cooling medium.

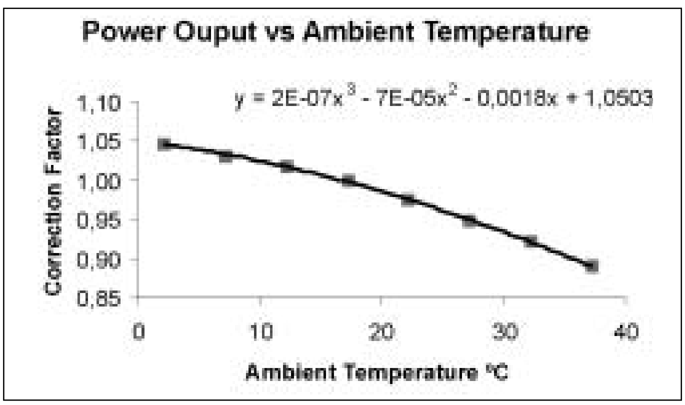
The proposed CCGT plant consists of three advanced single shaft units. Each single shaft power train consists of:

- One heavy-duty industrial gas turbine equipped with dry low NOx combustion system.
- One triple pressure reheats water/steam cycle with a heat recovery steam generator (HRSG).
- One axial flow exhaust, triple pressure reheat steam turbine (ST).
- One (1) H_2 cooled generator, common to GT and ST.

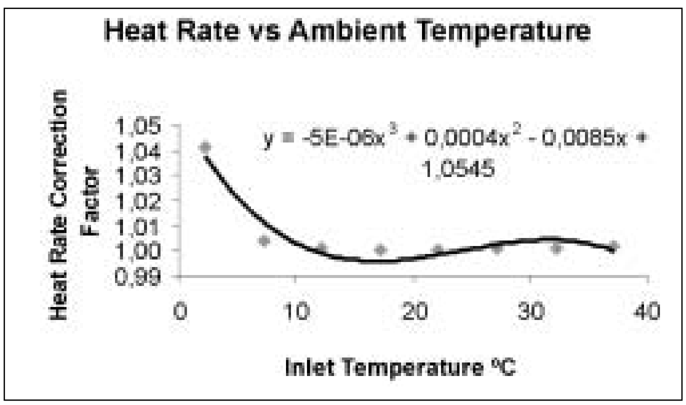
The gas turbine will be designed for natural gas and fuel oil. For natural gas operation, due to the dry low NOx burner, there is no water or steam injection to control the emission levels. The water/steam cycle is a state-of-the-art triple pressure reheats cycle with a natural circulation HRSG that allows optimum utilisation of the gas turbine exhaust gas energy. The main cooling water system provides cooling water to the steam turbine condenser and the water/water cooler of the closed cooling water system by means of two 50 per cent cooling water pumps installed adjacent to the cooling tower basin. The warm water is returned to a multi-cell induced draft cooling tower where it is cooled and then collected in the cooling tower basin. The cooling tower will be of concrete construction with top-mounted exhaust fans and film-type filling.

The cooling tower will be hybrid type. It is anticipated that the tower will operate for 70 per cent of the time without plume (as a wet tower); the remaining 30 per cent of the time, the cooling tower will operate in the hybrid mode.

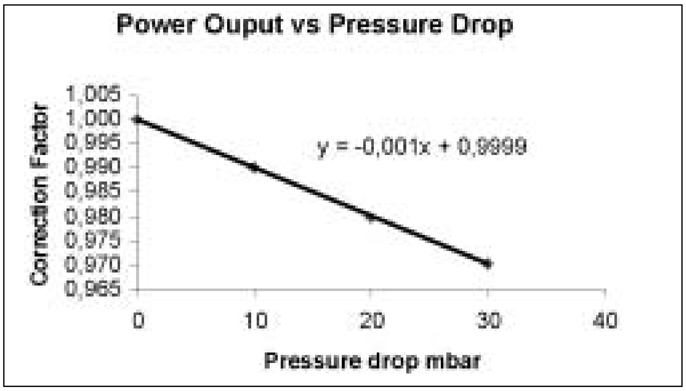
The make-up water is taken from the Enagasseawater discharge system and fed into the cooling tower basin by the inlet pumps. These pumps are required as the discharge from Enagas flows by gravity to the sea. The inlet pumps also provide



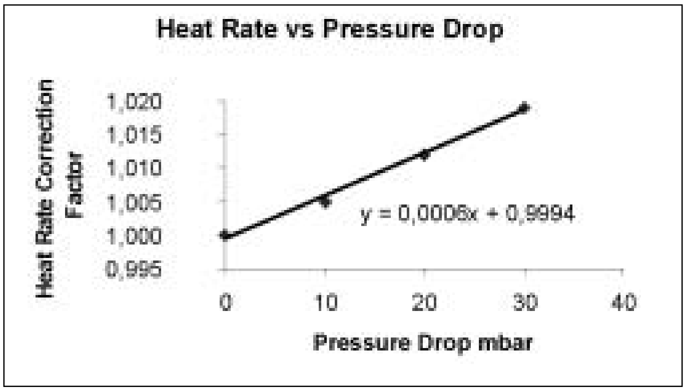
Impact of inlet temperature on the power output of the combined cycle gas turbine



Impact of inlet temperature on the heat rate of the combined cycle gas turbine



Impact of inlet air system pressure drop (which corresponds to ambient conditions) on the power output of the combined cycle gas turbine



Impact of inlet air system pressure drop (which corresponds to ambient conditions) on the heat rate of the combined cycle gas turbine

seawater to the desalination plant. In order to maintain the required water quality, the cooling system blow down is extracted from the cooling tower basin and returned to Enagas discharge line. The mixing of the cold and warm streams will contribute to improved environmental performance.

LNG terminal

Barcelona LNG terminal uses a conventional LNG regasification process, using two types of vaporizers; open rack seawater and submerged combustion vaporizers as back-up.

LNG vaporization is an energy intensive process. Typically, vaporizing 50,000 Nm^3 requires approximately 8.000 kWh (6.9 MM Kcal) of heat duty. This can be supplied either through the combustion of 725 Nm^3 of natural gas or with the heat obtained by reducing the temperature of 1,000 m^3 of seawater by 7°C. The amount of seawater required is directly adjusted by the possible delta T.

Barcelona LNG terminal uses seawater as the heating medium for baseload and normal operations. The terminal is being expanded; storage capacity will be over 540,000 m^3 and vaporization capacity increased to 1,650,000 Nm^3/hr. The vaporizers will comprise seven 150.000 Nm^3/hr open rack type (72 bar g), four 150.000 Nm^3/hr open rack type (45 bar g) and two 150.000 Nm^3/h submerged combustion type.

Integration scheme

Barcelona LNG terminal has a conventional configuration, but the new LNG regasification process integrates the vaporization process with power generation to maximize overall efficiency.

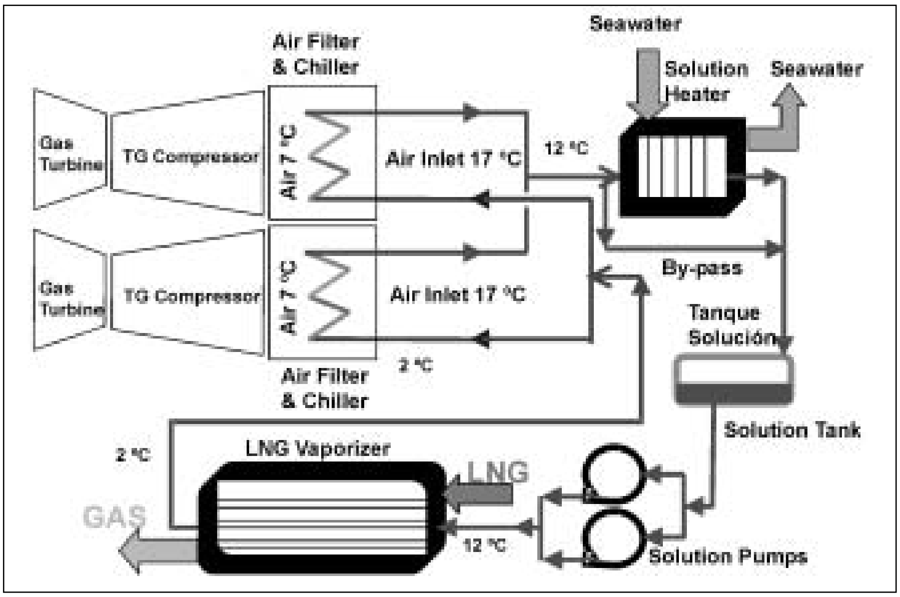
The advance schemes are:

- Power generation with LNG used as working fluid.
- Integration with a power plant to improve efficiency.

The first option is investigated further as, currently, only pilot units are in operation. The second option is evaluated in this paper. The technical basis of the scheme is the utilization of the LNG as a cold source to improve the power generation of the CCGT.

Power output of standard CCGT plants is reduced when ambient temperature rises. Typically, this occurs when the power demand is higher and consequently the power can be sold at higher prices.

The proposed integration scheme shows that the LNG derives the heat for the vaporization from a 60 per cent wt water / 40 per cent wt ethylene-glycol solution in a shell and tube heat exchanger. As a consequence, a chilled water/ethylene-glycol solution stream can be circulated to the power plant.



Process flow diagram

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Power output with chiller	830,4	830,2	830,7	829,6	826,8	813,5	809,6	811,0	814,5	821,6	828,6	831,3
Power output without chiller	816,1	813,0	809,8	805,9	800,4	781,2	775,8	777,7	782,3	792,1	804,2	812,6
Increase in MW	14,2	17,2	21,0	23,6	26,4	32,3	33,8	33,3	32,2	29,4	24,4	18,8

Increase of power output (both units) due to the cooling effect

This chilled water/ethylene-glycol solution is used in a heat exchanger located at the GT compressor inlet to cool down the inlet air. The cooler air temperature allows higher mass flow through the compressor, which is downstream, expanded in the gas turbine providing higher output.

The tables show the impact of the inlet temperature and inlet air system pressure drop (which corresponds to ambient conditions) on the power output and heat rate of the CCGT. This graphics have been developed using average values from different suppliers. As yet, the gas turbine supplier for the combined cycle plant has not been selected, but the specific data from each supplier is close to the average values.

The significant change in heat rate versus ambient temperature at values close to 0°C is due to the start-up of anti-icing system, which prevents operation of the air inlet filter close to 0°C.

To avoid the effect on the heat rate, the following calculations will assume that the minimum inlet temperature is limited to 5°C. Therefore, it can be considered that the inlet temperature has no significant effect on the heat rate. This value changes for each GT supplier; 5°C is a conservative approach.

Other ambient conditions like humidity, etc., have also some influence, but the impact on the economics in not significant.

Therefore, the effects to be evaluated due to the installation of the chiller upstream of the GT inlet are:

- Reduction of Inlet Temperature:
  - Increase in power output
  - Heat rate variations will not be analysed
- Increase of inlet air system pressure drop:
  - Reduction of power output
  - Increase of heat rate.

It has been assumed that the pressure drop caused by the chiller is 50 mmwc.

Required equipment

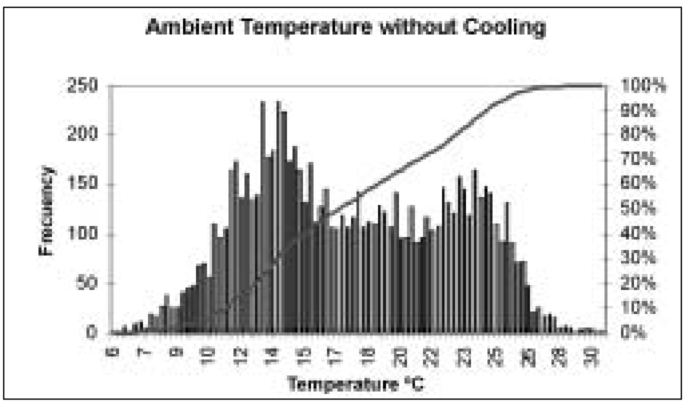
The objective is to avoid any disturbance in the operations of the LNG terminal. Therefore, the integration scheme is developed to provide a continuous flow of the heating medium (60 per cent wt water / 40 per cent wt ethylene-glycol solution) at a constant temperature.

Most of the time, this solution will be heated by the inlet air inlet to the gas turbine, but sometimes, the cool ambient conditions will not permit this operation. A sea water heat exchanger will be used on these occasions to provide the required heat to the solution.

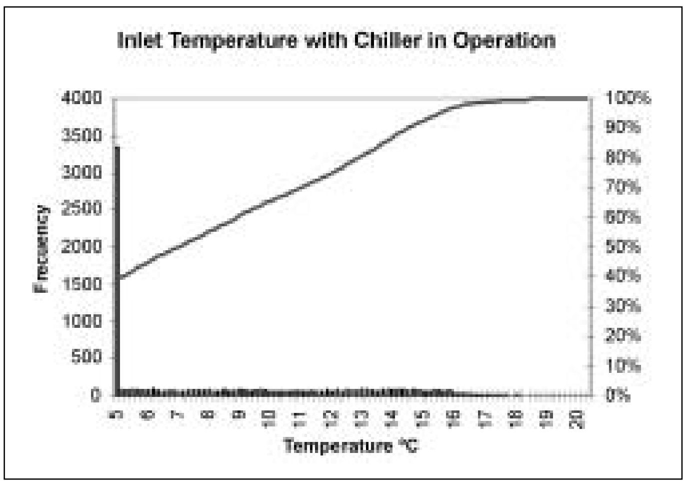
Changes of the LNG vaporizer loads will only mean that the heating medium will be returned to the CCGT plant at a higher temperature. Nevertheless, it is assumed for the economics calculations that the LNG vaporizers will operate as baseload, providing the required cooling continuously.

The equipment required for the integration is the following:

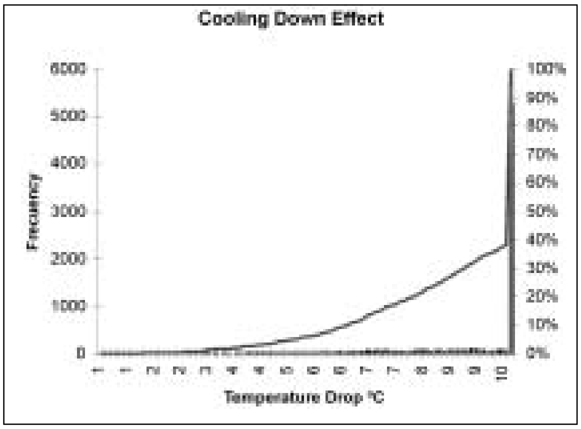
- LNG vaporizer (1x 100 per cent)
- Water/ethylene glycol solution pumping system (2 x 100 per cent) including expansion vessel
- GT inlet chiller (s) 1 x 100 per cent per unit
- Water/ethylene glycol solution seawater



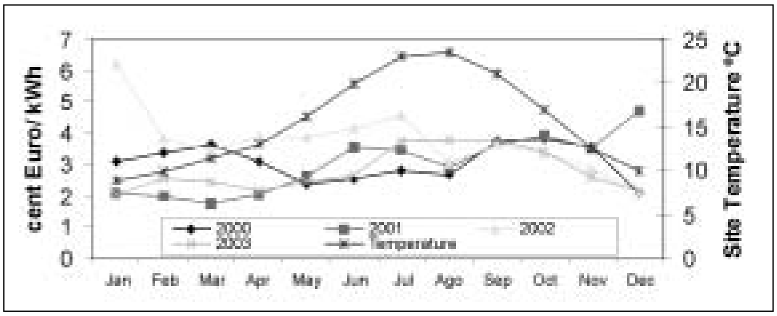
The influence of ambient conditions on the performance and power output of the combined cycle gas turbine is well known and predictable. Based on the available data for the 2002, a curve has been plotted showing accumulated hours and temperature



Real inlet temperature when the cooling system is in operation



Real cooling down effect is shown in the above curve



Pool market prices distributed during the years and the average temperature at the site - Figure 1

heat exchanger

- Ethylene glycol storage and solution preparation
- Seawater pumping system.

Only the LNG vaporizers will be located at the LNG terminal. For sizing the equipment, an average mass flow at the inlet of the gas turbine must be considered. This depends on the GT supplier and the ambient conditions. For analysis a mass flow of 650 kg/s has been considered.

A temperature drop of 10°C of the inlet air mass flow has been used, and eating medium conditions have been fixed at 12°C (LNG vaporizer inlet) and 2°C (LNG vaporizer outlet). The heat duty of each exchanger at GT inlet is 6,500 kW and 13,000 kW for the single LNG vaporizer. The amount of LNG that can be vaporized is approximately 85,000 Nm^3/h. This depends on the real LNG composition, but the amount is not relevant versus de LNG processed by the terminal (capacity will be 1,650,000 Nm^3/h per hour).

Final numbers should be tuned according to the selected GT supplier. But in any case, the cold provided by the LNG consumed by the GT is more than its requirements. The heating medium will be pumped at low pressure, approximately 2.5 bar, from the expansion vessel, which also acts as hold-up tank.

It is not foreseen that a dedicated vaporizer for the CCGT plant is required, as the operation of the power generation facility will be led by 'power market' conditions. The estimated investment is five million Euros. The scheme is illustrated in the process flow diagram below.

Ambient conditions

The design conditions of the plant are the flowing:

Average dry temperature : 17.2° C

Maximum dry temperature : 35°C

Minimum dry temperature : 5°C

Relative humidity for average dry temperature : 72 %

Relative humidity for average dry temperature : 80 %

Relative humidity for minimum dry temperature : 40 %

Atmospheric pressure : 1.013 bar

The influence of ambient conditions on the performance and power output of the CCGT is well known and predictable. The average temperature in 2002 was 17.4°C, which is close to the historical average. This data can be considered as the expected distribution during the year in performing the economic evaluation. Also using 2002 data, the real inlet temperature when the cooling system is in operation has been plotted. As already indicated, a minimum inlet temperature of 5°C has been used.

In summary, for more than 60 per cent of the time, the cooling equipment is working at 100 per cent capacity, for 20 per cent of the time it is working at 80 per cent load and for the remaining 20 per cent of the time, is working below this range.

The same calculation has been made for a minimum inlet temperature of 3°C and the result was: over 80 per cent of the time the cooling equipment is working at 100 per cent capacity, 10 per cent of the time is working at 80 per cent load and for the

MILLION EURO

Operating Hours	5,500	6,500	7,000	7,500	8,000
Gain in power output due to lower temp	1,94	2,53	2,72	2,92	3,11
Loss in power output due to inlet air system pressure drop	-0,31	-0,40	-0,43	-0,47	-0,50
Loss in heat rate due to inlet air system pressure drop	-0,22	-0,28	-0,31	-0,33	-0,35
Total	1,41	1,84	1,98	2,12	2,26

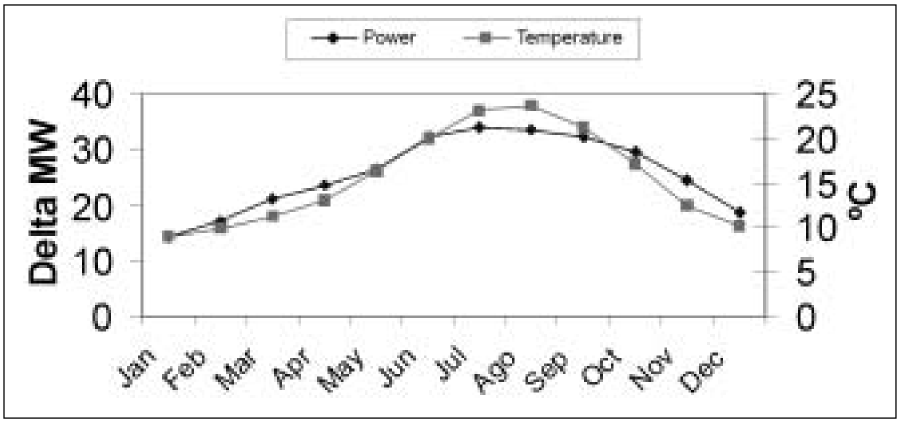
Calculation of economic profit of the cooling effect

remaining 10 per cent is working below this range.

Power prices

Spain has a 'pool market', where the generation units are bid on an hourly basis. This market has been operating for more than six years, but it is not possible to perform a correlation between temperature and power prices. It can be shown in the attached graph that the 'peak' prices have been in winter time or summer time, as the 'peak demand' also changes from winter to summer according the extreme weather conditions.

The attached graphs show the pool market prices distributed during the years and the average temperature at the site. It is concluded that it is not possible to correlate any advantage due to the cooling effect during summer times versus winter time.



The above curve shows the relation of power output to ambient temperature

Economics

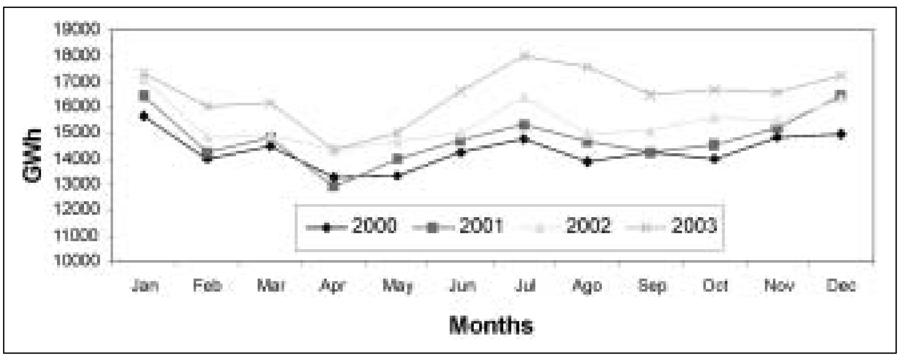
The final part of the work addresses the economic analysis of the proposed equipment. The following assumptions have been made:

- Average final power price: 38 Euro/MWh
- Variable (natural gas) costs 60 per cent of the final power price
- Heat rate: 6,500 kJ/kWh
- Gas price: 13.6 Euro/MWh (LHV)
- Net power output: 2 x 400 MW

The increase of power output (both units) due to the cooling effect is given in the table. Degradation of the power output due to the air inlet system pressure drop caused by the chiller is constant and it is equal to 4.08 MW for both units. Degradation of the heat rate due to the air inlet system pressure drop caused by the chiller is constant and it is equal to 15.6 KJ/kWh. A homogeneous distribution of the operation hours during the year is assumed.

The economic impact of the delta in power generation (increase and degradation) due to cooling effect is evaluated using 40 per cent of the power price, as natural gas consumption will be required due to the delta in power generation.

The economic impact of the heat rate degradation due to pressure drop of the chiller is evaluated using 60 per cent of the power price, as additional gas consumption will be required to balance the heat rate degradation.



Pool market prices distributed during the years and the average temperature at the site - Figure 2

Using the previous assumptions, the economic profit of the cooling effect has been calculated; it ranges from 1.4 to 2.3 million Euros.

Conclusion

Process integration of cold energy recovery from the receiving terminal in the power plant gives a highly reliable and operable facility with enhanced economics. The economic improvement shows a gain between 1.4 and 2.3 million Euros per year, conditioned by the operating hours of the facility. This gain means a payback of the installation in the range of 2.2 to 3.5 years.

This economic evaluation has been made on a conservative basis: for example, high pressure drop of the chiller; no increased price for power during summer. This means that the real improvements may be higher than those resulting form this evaluation. Power market predictions show that the peak power prices will be in the summer season, as demand grows due to air conditioning systems year by year. Under this scenario, the advantages of the proposed equipment will be more relevant. ■

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Courtesy: Foster Wheeler.
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