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BREAK

HIGH EFFICIENCY - COAL and GAS (HE-C&G), A Hybrid Power Plant Concept integrating ABB's GT24/GT26 Gas Turbines with Conventional Steam Power Plants for competitive power generation with high dispatch flexibility

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ABSTRACT

The electric power generation world is currently confronted with new challenges: deregulation, open competition, new players entering the business, new regulations governing the return on investment, increased complexity and risk.
In order to maintain or enhance their competitive position the electricity generators have as main objectives to lower generating costs, increase operating and dispatching flexibility and manage fuel related risks: availability, supply diversification, prices and price escalation and finally to capture value added profits .
In order to meet new requirements of electricity generators, ABB has developed a *hybrid* power plant concept integrating the sequential combustion gas turbines GT24/GT26 with existing or new conventional steam power plants : the *High Efficiency Coal and Gas* (HE-C&G).

The HE-C&G, with its unique design, operating and dispatching flexibility, provides our customers with the benefits of competitive power generation: the owner/operator can optimise *-on line-* the plant fuel and O&M costs, increase the availability, extend economic life and lower the environmental impact of the power plant. And even more , the HE-C&G creates the ability to benefit of the market opportunities : buy cheaper fuels and sell the electricity when profitable.
This paper evaluates the feasibility of combining conventional steam power plants with sequential combustion gas turbines GT24/GT26 and recommends the HE-C&G as one of the most competitive alternatives for power generation, especially for re-evaluation of existing assets and positioning in the competitive environment.

NOMENCLATURE

C_{OE}	Electricity generating costs
CSPP	Conventional Steam Power Plant
GT	Gas Turbine
HE-C&G	High Efficiency - Coal and Gas
LEV C_{OE}	Levelized electricity generating costs
LHV	Lower Heating Value
NPV	Net Present Value
O&M	Operating and Maintenance

INTRODUCTION

The HE-C&G is a hybrid power plant concept combining steam and gas turbine plants [1], [2] . The gas turbine exhaust gas energy recovered in the heat recovery steam generator provides condensate and feedwater preheating for the steam cycle and generates steam corresponding to the live steam conditions of the main boiler as a second steam source for the steam turbine.
The major advantages of the HE-C&G concept are the very high design flexibility, high efficiency including at part load *-by decoupling the efficiency of the load in the operating domain-*, low generating costs and capability for *optimising on-line the fuel and O&M costs*. These features provide *added value* to existing steam plants making them more competitive, more flexible and less vulnerable to risks related to availability, price and price escalation of fuels. HE-C&G is a low capital investment option which is amply rewarded by market opportunities especially in a deregulated environment, where cheaper fuels can be bought - short term contracts, on spot or tolling - and electricity can be sold to the pool when profitable.

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HE-C&G CONCEPT

The HE-C&G [1], [2], is a hybrid power plant combining conventional steam power plants coal, oil or natural gas fired and the sequential combustion gas turbines GT24 (183 MW, 38.3 %, 60 Hz) or GT26 (265 MW, 38.5 %, 50 Hz).

The GT24/GT26, *Fig.1*, offer an extremely high power density (electrical output related to the air mass flow) and an excellent simple cycle efficiency thanks to the reheat cycle. Additionally the three stages of variable guide vanes at the inlet of the compressor and the high exhaust temperature (reheat cycle) provide an uncommonly high efficiency versus load characteristic in combined cycle application. These features are beneficial when integrating gas turbines and conventional steam cycles, especially because sub- or supercritical steam can be generated even at low gas turbine load (*Fig.2*).

The conversion into a HE-C&G by integrating the sequential combustion gas turbine GT24/GT26 and heat recovery steam generator into a conventional steam power plant is shown in Fig.3. The heat recovery steam generator partially recovers the gas turbine exhaust energy and provides condensate and feedwater preheating in parallel with the existing regenerative preheaters and generates superheated steam at the same pressure and temperature as the main boiler (second steam source for the steam turbine).

By preheating partial flows of condensate and feedwater, the steam turbine extractions will be reduced correspondingly and the expansion of additional steam in the steam turbine will generate extra power at the generator terminals.

The *low* energetic level of the gas turbine exhaust recovered in the heat recovery steam generator, economisers section II-III and III-IV, (*Fig.3*), will be converted into electricity by replacing the heat supplied by the steam extracted from the steam turbine for preheating.

Additionally the heat transfer in the economiser section takes place with low temperature difference and correspondingly with low exergy losses, [1]. By contrast, the low and high pressure regenerative preheaters are condensers operating -on the steam side- with constant pressure, i.e. with high temperature difference and consequently with high exergy losses. This is the first reason for the cycle efficiency enhancement provided by the HE-C&G concept; the low and high pressure economisers of the heat recovery steam generator can be assimilated with a highly efficient "*multipressure*" heat recovery system [1].

The steam generated in the heat recovery steam generator and supplied to the steam turbine will enable the main boiler load to be reduced while keeping the steam turbine volumetric flow characteristic (swallowing capacity) within admissible limits. The fuel used in the main boiler -coal for instance- will be reduced and replaced by the natural gas fired in the gas turbine with very high efficiency -*the Combined Cycle Contribution-*; this being the second major cycle improvement.

HE-C&G combines advantages of both sequential combustion gas turbines and conventional steam plants providing additional benefits:

* *design flexibility*: a strict matching of the gas turbine with the steam turbine is not required. A minimum steam turbine size (output) is recommended in order to keep the *coal "contribution"* and correspondingly the main boiler at an acceptable load level. As a rough indication, the minimum steam turbine output will be 400 MW for conversion with a GT26/50 Hz and 300 MW for a GT24/60 Hz. There is no upper limit of the steam turbine output and the conversion into HE-C&G with one or more gas turbines is possible all at once or in phased construction.

The conversion into HE-C&G is easy to plan and implement due to the low complexity and simplified interfaces: only condensate and feedwater pipes, one live steam pipe and electrical and control equipment. There is no reheat split (pipes, control equipment, pressure losses and correspondingly penalties on the performances) and the complexity is kept low.

The reheat is performed only in the main boiler and the superheater/reheater temperature control is realised by one or more methods in combination: gas bypass, burner control (tilting), attemperation, gas recirculation, excess air control, controlled circulation in split furnace etc.

Conversion of existing or new advanced steam plants is feasible; the high GT24/GT26 exhaust temperature (650 °C) allows generation of sub-, super- or ultrasupercritical steam.

* compact layout - proximity of the steam turbine / main boiler is not an absolute requirement -, *easy installation* with short delivery time and the *availability of power during the construction*. A short shut down is required for interconnections and recommissioning of the plant.

* *operating flexibility* as a result of simplified but easy-to-handle interfaces: HE-C&G can be operated in different modes [1], [2]: conventional mode with the main boiler and steam turbine in operation; hybrid mode with the gas turbine / heat recovery steam generator, the main boiler and the steam turbine in operation; pure combined cycle with the gas turbine / heat recovery steam generator and the steam turbine in operation (the reheater is bypassed in this mode) and, if required, the gas turbine in open cycle by bypassing the steam generated in the heat recovery steam generator to the condenser/dump condenser or bypassing the gas turbine exhaust gases (bypass stack and diverter valve).

* *fuel flexibility and fuel mix capability*: *on-line coal/gas contribution variation* i.e. optimisation of fuel and O&M costs, switching to low(er) quality fuels without

performance penalties (for instance low grade coals , orimulsion etc.).

* *high efficiency improvement inclusive of part load.* By conversion into HE-C&G the *single line* efficiency versus load characteristic is replaced by an *OPERATING DOMAIN* with free choice of coal and gas contribution independently of the load (*Fig. 4*).

The performance map of a conventional steam power plant converted into HE-C&G is dependent on the original efficiency and the steam to gas turbine output ratio . *Figures 5* and *6* present the overall efficiency improvement as a function of the output and efficiency of the existing steam turbine for a conversion into HE-C&G with one or two GT24/GT26.

The overall efficiency of a power plant converted into HE-C&G will be enhanced by 8 to 34 % multiplicative, gross, based on lower heating value, which corresponds to a net Heat Rate reduction of 600 to 1'800 kJ/kWh depending on the performance data of the steam power plant before conversion.

The natural gas marginal efficiency will be close to 60 % net, based on lower heating value, or higher for conversion of advanced steam cycles.

* *very high operating and dispatching flexibility*: the converted power plant can be operated economically in peak , intermediate or base load, load following or frequency support mode. Operating the gas turbine in base load will provide the *maximum natural gas marginal efficiency*, i.e. taking maximum benefit of natural gas/combined cycle contribution. However the gas turbine is far more flexible and able to respond faster to a particular load change than the main boiler; keeping the main boiler load constant at a certain load and following the demand with the gas turbine will be the *" normal" operating mode.*

The minimum demand will require shut-down of the gas turbine and operation of the main boiler at *minimum economic load,* while the maximum demand will require the gas turbine load to increase to 100 % and the main boiler the maximum load admissible by the steam turbine (swallowing capacity).

* *high availability of power during conversion,* with very short shut down for interconnections and recommissioning. After conversion the availability of power will be drastically improved by the fact that *two different, independent steam sources can feed the steam turbine.* During maintenance or the retrofit/rehabilitation of the main boiler the power and correspondingly the revenues will be provided by the gas turbine and steam turbine, namely combined cycle operation with an efficiency equivalent to the state-of-the-art of combined cycle technology.

* *short constructian time/fast capacity on line and easy extension of existing steam plants .*

The conversion of an existing steam plant into HE-C&G provides additional capacity corresponding to the gas turbine output and - in certain cases- a few percentages of the steam turbine output. Even if the additional capacity is not the main driver the conversion into HE-C&G is amply rewarded by reduction of operating costs (see below) and extra benefits of peak power, spinning reserve and remote capacity.

* *low generating costs* :

* *low capital investment*: the scope of conversion include one or more gas turbines with heat recovery steam generators, piping interconnection, electric and control equipment.

The original steam turbine, condenser, cooling, balance of plant, generator and transformer will be used -generally- without modification. Depending on the age and condition of the existing steam plant the capital investment to be considered for the economic evaluation is the addition of the residual capital to be amortized and also the investment for retrofitting, rehabilitation or life extension.

* *low fuel cost* thanks to the high efficiency enhancement (please refer to the previous page). The flexibility of coal/gas contribution variation, i.e. optimisation, independently of the load, offers excellent ability to benefit from fuel market opportunities: short term contracts, spot prices, tolling; for instance a short term fuel contract could provide 5 to 10 % price reduction; the spot market could offer even more. For a particular load/demand, the HE-C&G provides free coal and natural gas contribution allocation and consequently *on-line optimisation of fuel costs* and related O&M costs.

If the demand is constant, the coal and NG contribution could be optimized by taking into account fuel prices, partial efficiencies of different components, auxiliary consumption and O&M costs (load and fuel dependent) etc.

Based on market input (e.g. current fuel price) an *"internal" decision* could change the partial load of the main boiler and gas turbine, keeping the electricity generation constant, if required . The increase or decrease of electricity demand could be realized by keeping the specific fuel costs and O&M costs constant or "promoting" the natural gas or the coal contribution.

* low gas turbine / heat recovery steam generator start-up costs: the gas turbine exhaust gas energy is recoverable and usable at very low gas turbine load levels, i.e. even from early start-up the exhaust gas energy is recovered and used for condensate and feedwater preheating, enhancing the steam cycle efficiency [1].

* low operating and maintenance costs: an integrated steam turbine, main boiler and gas turbine maintenance concept could be developed.

* environmental benefits by switching from coal, a CO_2 intensive fuel to natural gas which has lower carbon content, less CO_2 production and burns with very high efficiency. By lowering the main boiler load, emissions (SO_x and NO_x) will be reduced correspondingly.
If $DeSO_x$ and/or $DeNO_x$ retrofitting is required by more stringent emission legislation additional capital savings (30 % or more) can be achieved by conversion into HE-C&G , i.e. switching coal to natural gas and operating the main boiler at part load.

ADDING VALUE TO EXISTING ASSETS BY CONVERTING INTO HE-C&G

The economic feasibility of converting existing or new Steam Power Plants into HE-C&G is investigated in this section. The decision to convert is influenced by a multitude of interacting criteria governing a highly complex domain. In order to simplify the task, the conversion of a 500 MW coal-fired plant with 1xGT26 is analysed for the Asia / 50 Hz economic environment.
This exercise is performed in two steps. The first part is an attempt to answer the question: *What is the ideal age of a conventional steam plant to be profitably converted into HE-C&G ?* The second step is a case study quantifying the economic advantages of the conversion of a particular plant.

The generating cost is one of the main criteria governing the economics in the deregulated, competitive electricity environment. The profitability of a particular steam power plant is measured by its ability to generate power at lower cost than the competitors and maximize the revenues. There is a high diversity of generating facilities e.g. type of plants, ages, performance data, fuels and sites. Based on the initial investment (market price level) the exchange rates and the depreciation scheme of a particular generating company it is rather difficult to perform an accurate valuation of an existing asset . That is why our approach is to define a *present Replacement Value* which is the real, intrinsic value of a particular steam plant.

The Replacement Value is the cost of reproducing the same asset today or the translation of the "age" into dollars today taking into consideration the residual capital to be amortized, the remaining life, the current performance and the change in prices over time. The replacement value is used as present capital to be amortised in the future following a depreciation strategy.
All parameters are "actualized": today's value of money, fuel prices, electricity tariffs, escalation rates, etc.
Table 1 details the assumptions used for the comparison of several 500 MW coal-fired conventional steam plant with different Replacement Values before and after conversion into HE-C&G with 1xGT26. The comparison criterion is the levelized busbar generating cost (LEV C_{OE}). The LEV C_{OE} was chosen because the capital cost or the replacement value and the cycle time vary in a wide range.

The comparison of the LEV C_{OE} of an existing or new conventional steam power plant with different replacement values is shown in *Figure 7* with the assumptions detailed in *Table 1*. The LEV C_{OE} of older plants are lower than those of younger or new ones.

A generating cost break down in levelized fuel and capital costs is shown in *Fig. 8*. The cost of capital of older steam plant with low replacement values is very low while the fuel costs are high corresponding to the lower efficiency (historical, plus degradation in time).
By contrast, the recent or not yet built steam plants exhibit high efficiencies and correspondingly low fuel costs but high capital cost as a result of high residual capital to be amortised. The higher capital investement required to pay the higher efficiency and the environmental compliance.

Notice: for comparison purposes the O&M costs are considered equal, i.e. no distinction was made between old and recently installed steam power plants.

Fig. 8 also clearly sets the main targets for positioning in a competitive / deregulated environment: older plants require lowering of fuel costs without excessive capital investment in order to remain or to improve their competitive position; recently built or new plants have to keep the fuel costs low and to lower the capital contribution to the generating costs.

With the assumptions detailed in *Table 1* the LEV C_{OE} after conversion into HE-C&G with 1xGT26 is shown in *Fig. 9*. The generating costs are lower but the old-new profile is the same as for the non-converted plants.

The comparison of LEV C_{OE} before and after conversion -*Fig. 10* - exhibits a clear reduction of generating costs for the full range of replacement values.

Notice: the capital cost for the new plants and for the conversion into HE-C&G is a lump sum, turnkey basis but excluding the project and financing development costs. As the capital costs (labour and equipment costs) and fuel prices are very regionally dependent, for the comparison Asia / 50 Hz economic conditions were considered.

Fig. 10 also shows that by conversion younger or new steam power plants become far more competitive than older non-converted CSPPs, inverting the current situation. This is the incentive to convert into HE-C&G steam power plants with high replacement value.
The explanation of this statement is given by the LEV C_{OE} breakdown in *Fig. 11*: for plants with low replacement value and high fuel costs the conversion lowers the fuel costs by enhancing the efficiency while keeping a low capital cost contribution.
The conversion of younger/new steam plants maintains low fuel costs and reduces the capital contribution to the generating costs. This is realized by an extra investment ! *Fig. 11* also explicitly demonstrates the fact that for the whole range of old to new steam power plants , the conversion into HE-C&G lowers the generating costs. This is also the answer to the question ...*when to convert... ?*

The previous results are based on the assumption that the utilization factor will be 75%. In the deregulated environment one of the uncertainties is the capacity factor directly correlated to competitive dispatching. A particular steam power plant will be operated when the generating costs are at least equal to or lower than the pool/cost.

The following section is a case study which considers the capacity factor as a sensitivity parameter for feasibility evaluation of the conversion into HE-C&G. *Table 2* summarises the performance data for different operating modes of an existing 500 MW coal-fired steam plant candidate for conversion into HE-C&G with 1xGT26. The coal-fired 470 MW and 39.5% net, based on lower heating value, steam plant converted with 1xGT26 exhibits 727 MW and 47.8 % net, based on lower heating value, meaning 257 MW additional capacity at commissioning time and an overall efficiency increase of 8.3% points, net, LHV, or 21% multiplicative, equivalent to a heat rate reduction of 1580 kJ/kWh.

The economic assumptions and the LEV C_{OE} before and after conversion are shown in *Fig. 12* versus utilization factor. The generating costs are lower for the full range of utilization factors: 25 to 90%.

Assuming that the *pool entry price* will be 5.5 ¢/kWh the non-converted steam power plant requires a minimum 40-50% utilization factor to be dispatched and higher to be profitably dispatched. If converted the minimum utilization factor will be less restrictive approximately 30-35% depending on the coal and natural gas prices.

The natural gas marginal LEV C_{OE} corresponding to the additional investment is shown in *Fig. 13* with as sensitive parameters the utilization factor and the amortization time: 5 and 15 years. The natural gas marginal LEV C_{OE} is lower than the overall, hybrid plant generating costs and the amortization time has stronger impact for low utilization factors and less when higher utilization factors are considered. The natural gas marginal generating costs are very competitive compared to those of greenfield combined cycle plants.

The economic benefits of conversion are quantified using the Discounted Cash Flow technique. The Net Present Value comparison of the steam power plant before and after conversion is performed and presented in *Fig. 14* versus utilization factor with a fuel price sensitivity.

Considering a financial assessment period of 15 years the Net Present Value, in case of higher utilization factor exhibits hundreds of M$ difference between converted and non-converted plant.
The minimum utilization factor required for a positive Net Present Value is 45-60 % in case of non-converted power plant versus 30-40 % for the converted into HE-C&G steam plant.

The *Return on Investment* being one of the sensitive criteria when analysing the opportunity to invest, particularly in deregulated environments (no guaranteed returns), the conversion into HE-C&G is the option which enhances the competitive position of an existing asset and manages the risk on return on investment.

Similarly a Net Present Value on a marginal basis and a financial assessment period of 5 and 10 years is shown in *Fig. 15* versus utilization factor and for different natural gas prices. The recovery of the capital invested in conversion is assured even with very low utilization factors and very aggressive amortization: 5 - 10 years.

SUMMARY and CONCLUSIONS

The HE-C&G is a *hybrid power plant concept* combining conventional steam and combined cycle power plants developed by ABB in response to the most challenging requirements of the power generation world.
The concept, exhibiting very high design flexibility, integrates the ABB high performance *Sequential Combustion gas turbine* GT24/GT26 technology into a wide range of existing or new conventional steam power plants.

The major benefits provided by the conversion into HE-C&G are:

* low electricity generation costs:
* low first cost option and therefore low risk related to the return on investment
* very high marginal efficiency on natural gas and high overall plant efficiency enhancement, including at part load, and consequently: low fuel cost, low risk related to the fuel price escalation and low gas turbine / heat recovery steam generator start-up costs.
* high operating and dispatching flexibility with fast dynamic response of the gas turbine for the load change over a wide loads range and high turning down ratio, from a few % gas turbine load to the maximum steam turbine plus gas turbine base load.
* on-line optimization of fuel cost and O&M costs
* high availability of power with very high operating flexibility - coal only, coal and gas, gas only - and *multi source steam* supply.

And also availability of revenues generated during the installation of the gas turbine / heat recovery steam generator by operating the conventional steam power plant and minimum down time for interconnections and re-commissioning [1],[2].

* lower the environmental impact:
  * lower the CO_2 emissions by switching from coal to natural gas and integrating the gas turbine with advanced emissions control technology , burning "cleaner" fuel with very high efficiency *...HE-C&G helps the coal to burn more efficient with lower environmental impact....*
  * capital saving if $DESO_X$ and/or $DENO_X$ have to be installed for environmental compliance.

The HE-C&G is recommended particularly in very competitive environment as the preferred option by its intrinsic features: *lower sensitivity and risk on fuel cost escalation and return on investment , access to the market opportunities like short term* *fuel contracts , spot prices , tolling and capability to sell peaking or spinning electricity .*

The HE-C&G is the low cost option for *adding value to the existing assets* and positioning the electricity generators for competition. For the whole range of steam power plants from old to new, the conversion into HE-C&G -by its *BUILT-IN FEATURES-* creates the *fuel mix* and the *unique integrated generation portfolio at one single site.*

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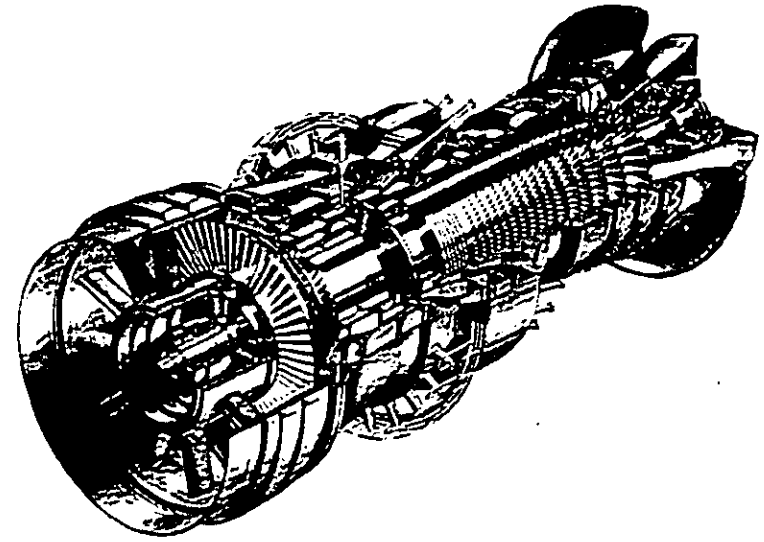

Fig. 1 - Sequential Combustion gas turbines GT24/GT26 with reheat cycle and triple compressor variable guide vanes (VGV's) provide high exhaust temperature and high full and part load efficiency in simple and combined cycle being the ideal candidates for conversion of existing steam power plants. The GT24 is rated 183 MW, 38.3 %, 60 Hz while GT26 provides 265 MW, 38.5 %, 50 Hz.

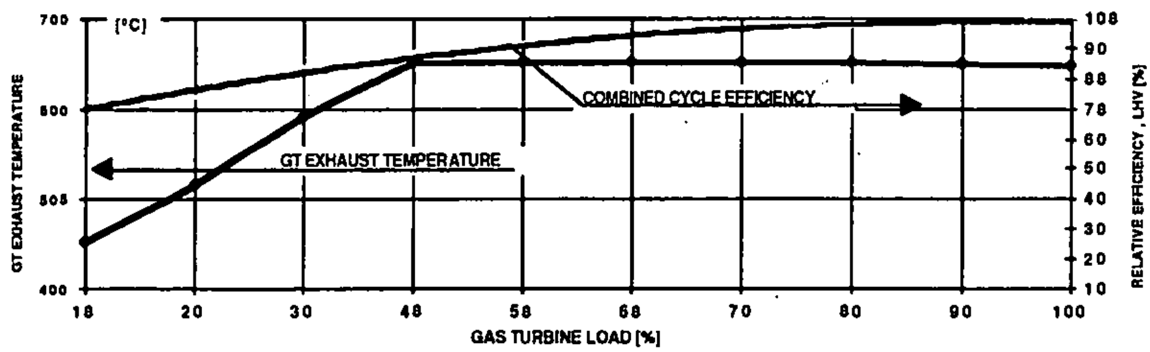

Fig. 2 - GT24/GT26 exhaust gas temperature and combined cycle part load efficiency versus gas turbine load characteristic.

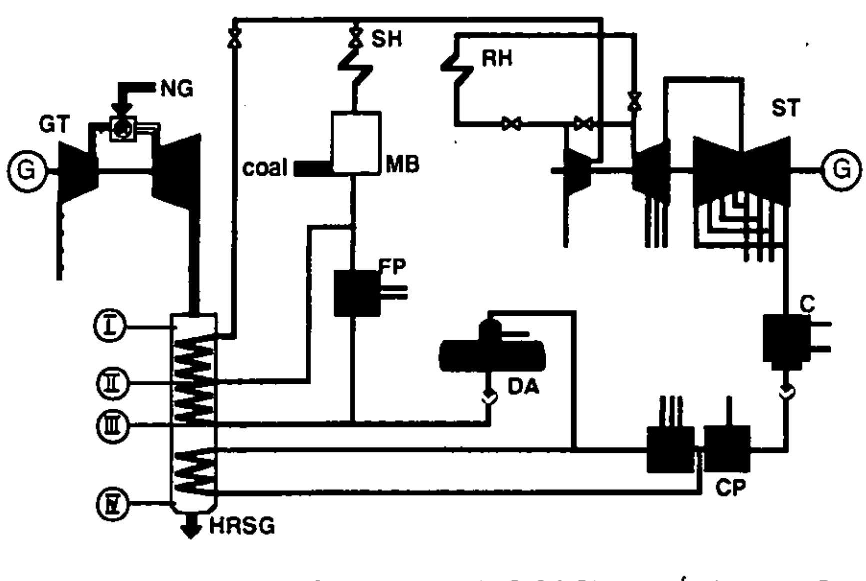

Fig. 3 - Principle of the High Efficiency Coal and Gas (HE-C&G) : integration of a Sequential Combustion gas turbine GT24/GT26 and HRSG with a Conventional Steam Power Plant (CSPP) : MB - Main Boiler; SH - Superheater ; RH - Reheater ; ST - Steam Turbine; C - Steam Condenser ; CP - Condensate Preheaters; DA - Deaerator ; FP - Feedwater Preheaters; HRSG - Heat Recovery Steam Generator ; GT - Gas Turbine; NG - Natural Gas.

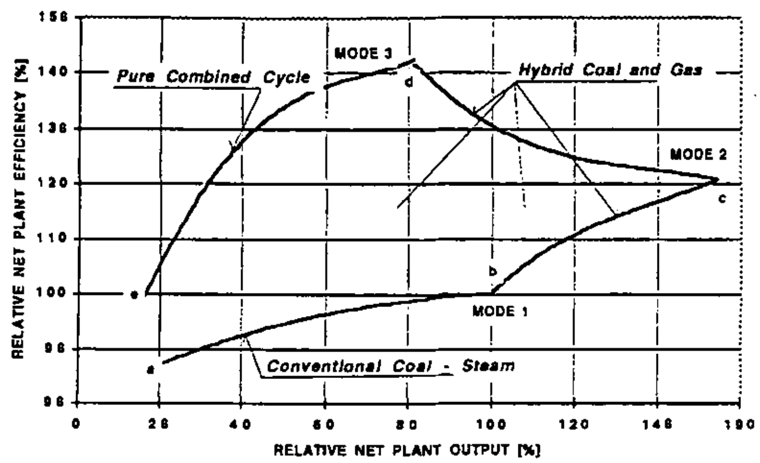

Fig. 4 - Efficiency versus load characteristic of a 500 MW CSPP converted into HE-C&G with 1xGT26. The ***Operating Domain*** is defined inside the surface limited by the curves **ab-bc-cd-de** with **ab** - conventional mode : **bc** , **cd** and the surface inside the operating domain - hybrid , coal and gas and **de** - pure combined cycle mode

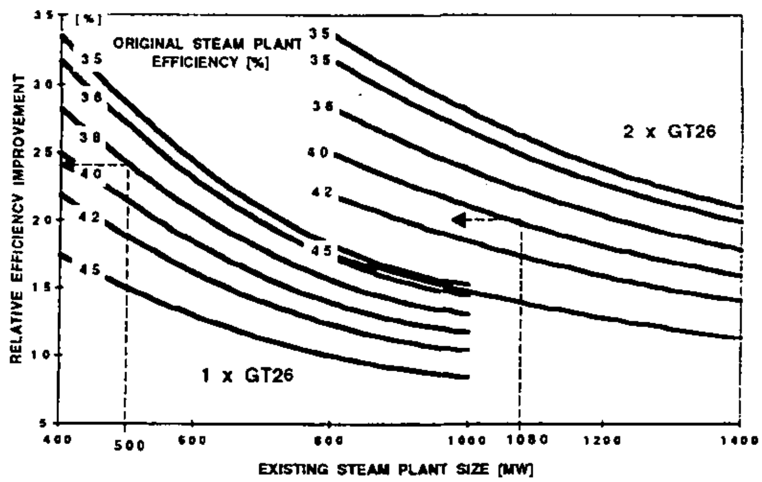

Fig. 5 - Conversion of existing CSPPs / 50 Hz with one or two GT26 : efficiency improvement versus steam plant output and current efficiency . Examples : the conversion of an existing 500 MW with 38 % efficiency steam plant with 1xGT26 will enhance the efficiency to 38 x 1.24 = 47.12 % , gross , LHV , and the additional power output will be 260 MW. A 1080 MW and 40 % efficiency converted into HE-C&G by integrating 2xGT26 will improve the efficiency to 40 x 1.2 = 48 , gross , LHV , and add 520 MW capacity .

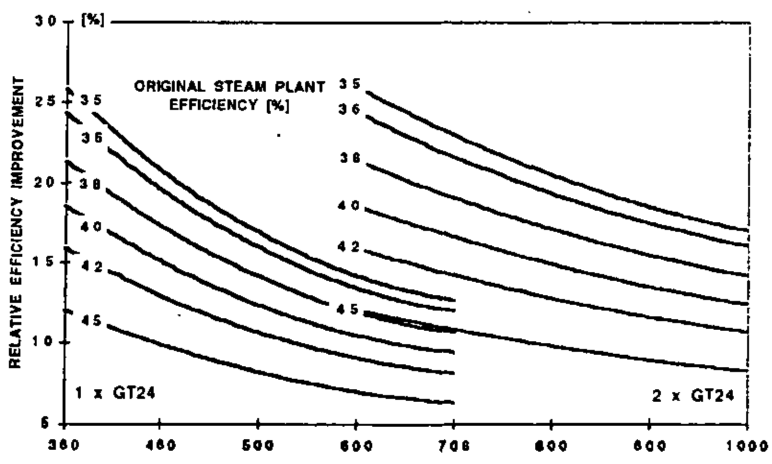

Fig. 6 - Conversion of existing CSPPs / 60 Hz with one or two GT24 : efficiency improvement versus steam plant output and current effieciency .

Conventional Steam Coal-Fired Power Plant *before* conversion							
Net Electrical Output *	MW	470	470	470	470	470	470
Net Efficiency, LHV *	%	35	35	36	38	39	42
Replacement Value	M$	133	200	300	400	500	600
Specific Capital	$/kW	284	426	636	651	1063	1277
Construction time	month	0	0	0	0	36	36
Amortization period	years	10	15	15	20	25	25
Steam Coal-Fired Power Plant *after* conversion into HE-C&G							
Net Electrical Output *	MW	722	722	722	722	722	722
Net Efficiency, LHV *	%	44.5	44.5	45.2	46.5	47.3	49.3
New Replacement Value	M$	223	290	390	490	590	590
Specific Capital	$/kW	296	385	516	651	784	917
Construction time	month	12	12	12	12	36	36
Amortization period	years	10	15	15	20	25	25
* including degradation							

Economic Assumptions		
Utilization Factor	%	75
Discount Factor	% p.a.	9
Inflation Rate	% p.a.	2
Tax Rate	% p.a.	0
Fuel Prices		-
Coal	$/MBTU	1.75-2.5
Natural Gas	$/MBTU	2.75-3.5
Fuel Price Escalation	% p.a.	2
Fuel Externalities	$/MBTU	0
O&M Costs		-
CSPP coal-fired	¢/kWh	0.65
Combined Cycle	¢/kWh	0.3
O&M Costs Escalation	% p.a.	0

Table 1 - Economic assumptions used for comparison of 500 MW coal-fired CSPP with different Replacement values before/after conversion into HE-C&G with 1xGT26 .

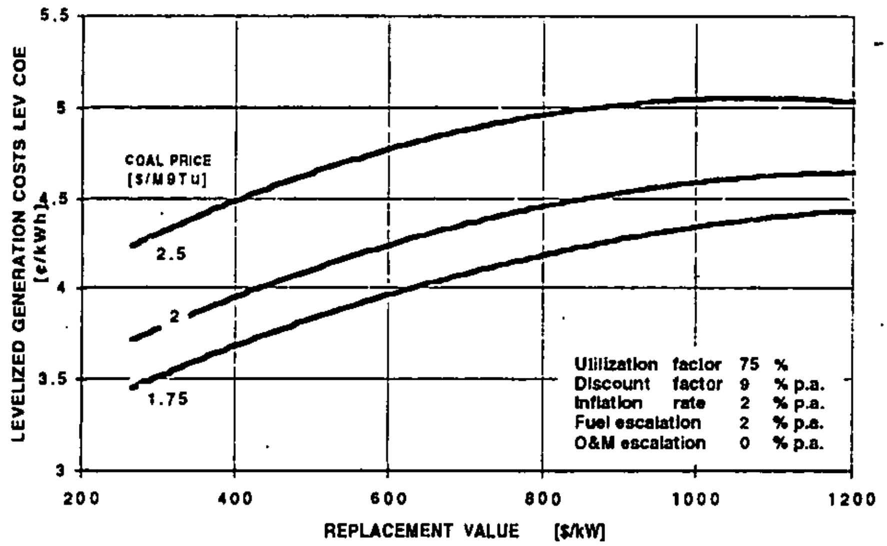

Fig. 7 - Levelized electricity generating costs (LEV COE) of Steam Power Plants with different Replacement values before conversion into HE-C&G .

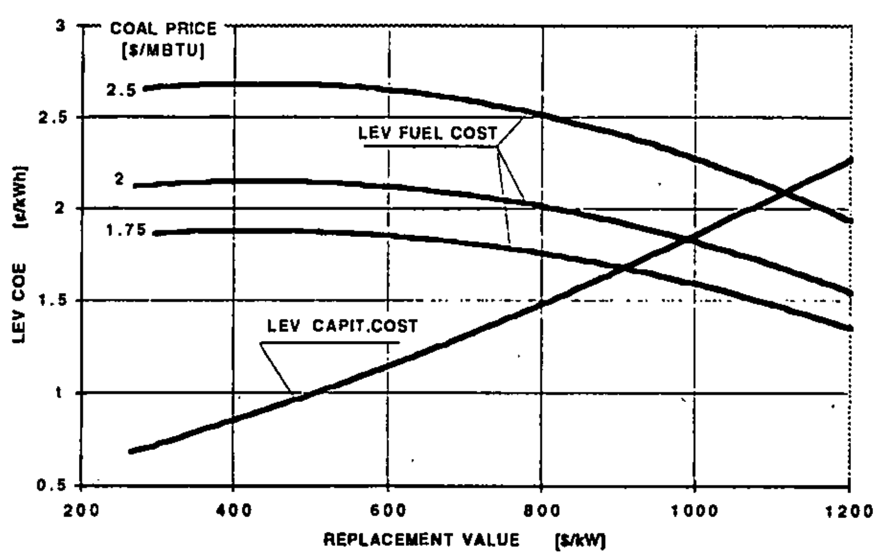

Fig. 8 - The levelized generating cost breakdown : fuel and capital costs of Steam Power Plants with different Replacement values before conversion into HE-C&G .

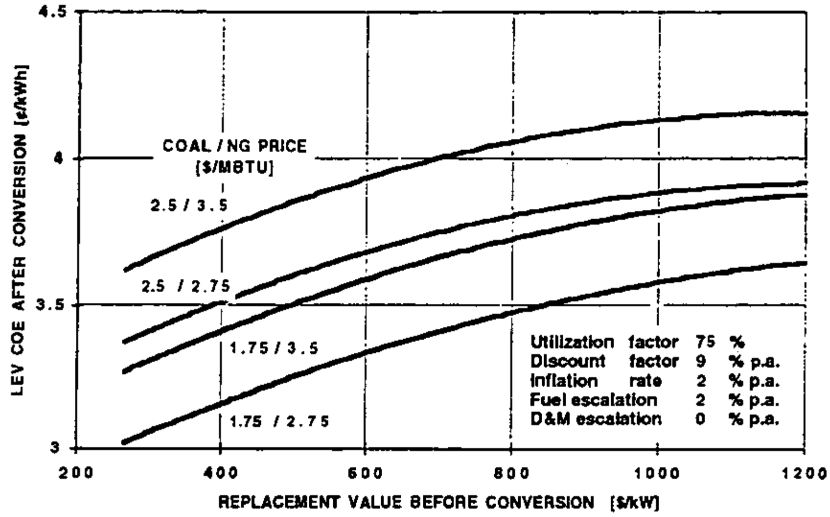

Fig. 9 - Levelized generating costs after conversion into HE-C&G with 1xGT26 of a 500 MW CSPP with different Replacement values.

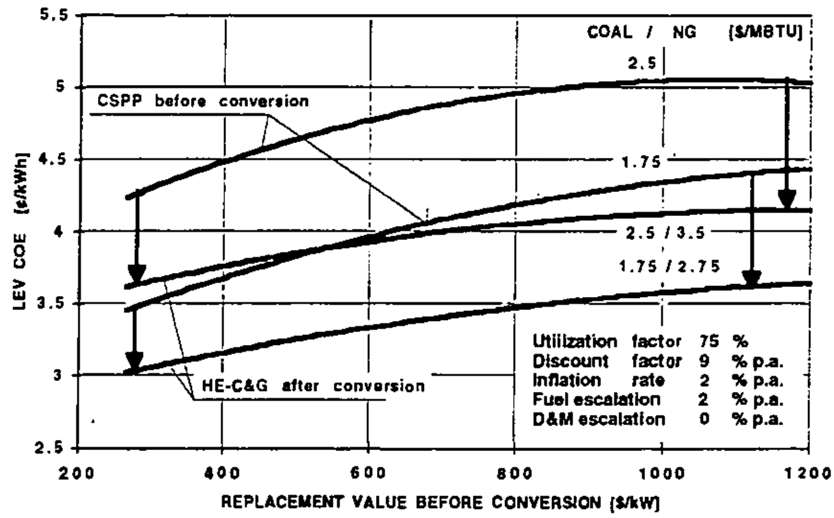

Fig. 10 - Comparison of LEV COE before and after conversion into HE-C&G vs. initial CSPP Replacement value.

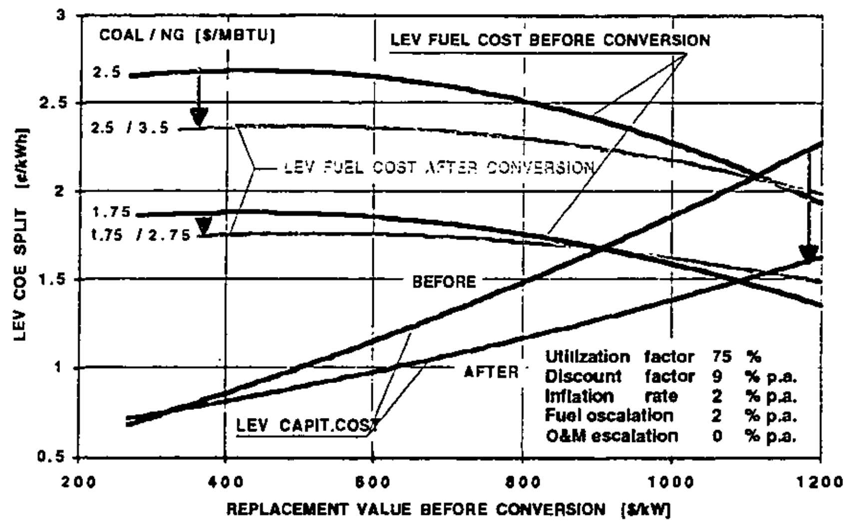

Fig. 11 - Comparison of levelized fuel and capital cost before and after conversion into HE-C&G with 1xGT26 vs. initial Replacement value.

OPERATING MODE		MODE 1	MODE 2	MODE 3
Coal consumption , LHV	MJ/s	1'190	843	0
Natural Gas consumption , LHV	MJ/s	0	679	379
Total fuel consumption , LHV	MJ/s	1'190	1'522	679
Steam Turbine output , gross	MW	500	500	130
Gas Turbine output , gross	MW	0	257	257
Total output , gross	MW	500	757	387
Efficiency , gross , LHV	%	42	49.7	57
Auxiliaries consumption	MW	30	30	6
Net electrical output	MW	470	727	381
Net efficiency , LHV	%	39.5	47.8	56.1
Net Heat Rate , LHV	kJ/kWh	9'120	7'540	6'410
NG net marginal efficiency,LHV	%	-	58.5	56.1
NG net marginal Heat Rate,LHV	kJ/kWh	-	6'160	6'410

Table 2 - Conversion of a 500 MW coal-fired CSPP into HE-C&G with 1xGT26 : performance data for different operating modes .

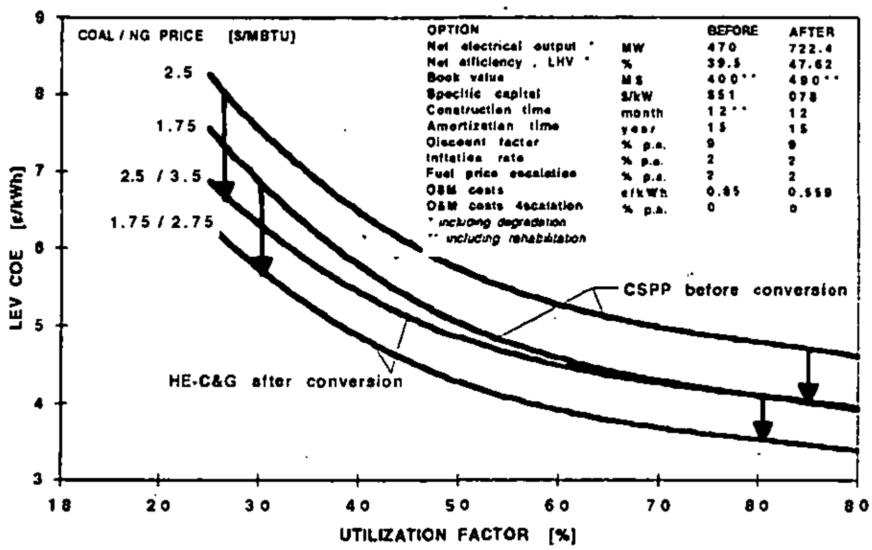

Fig. 12 - Levelized generating costs (LEV COE) before and after conversion into HE-C&G versus utilization factor .

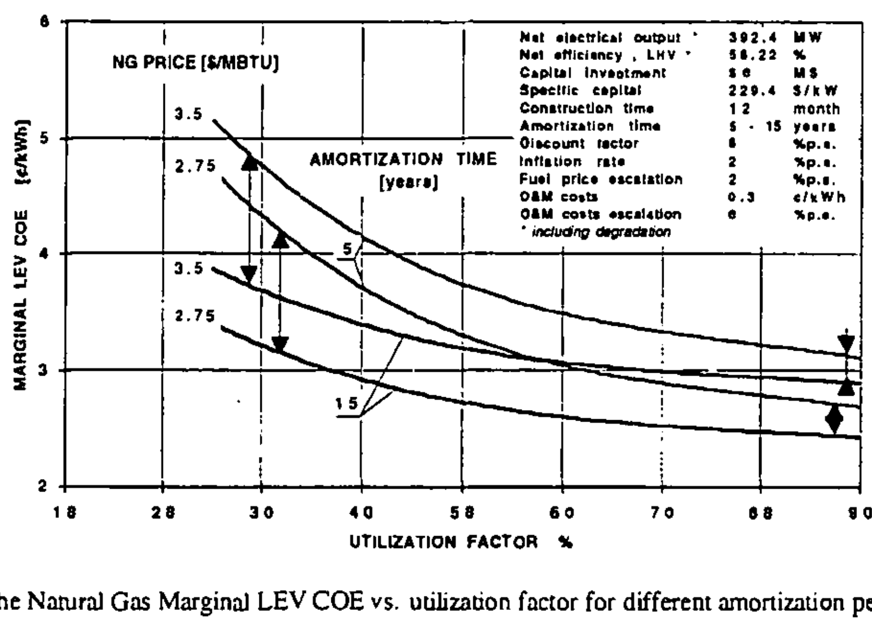

Fig. 13 - The Natural Gas Marginal LEV COE vs. utilization factor for different amortization periods (5 and 15 years).

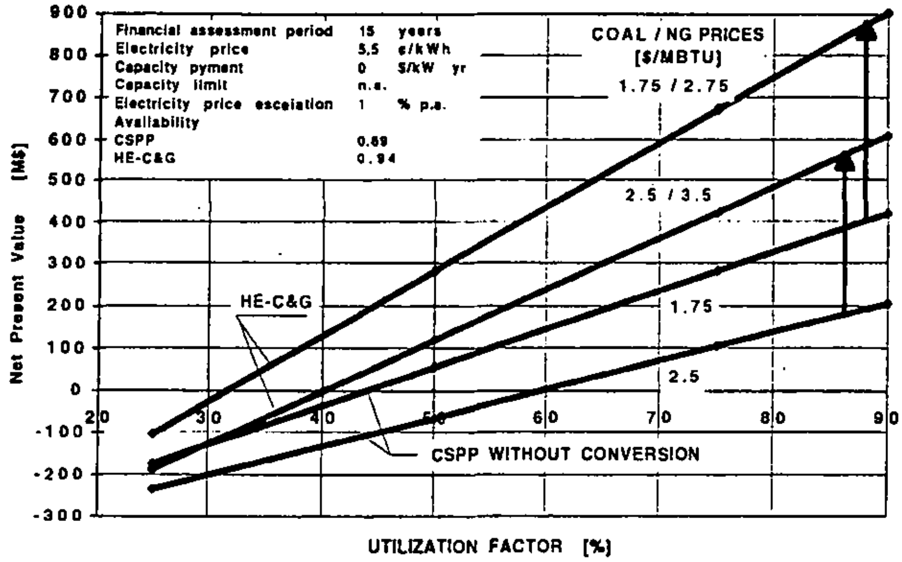

Fig. 14 - The Net Present Value (NPV) vs. utilization factor with and without conversion into HE-C&G with 1xGT26 of a 500 MW coal-fired CSPP .

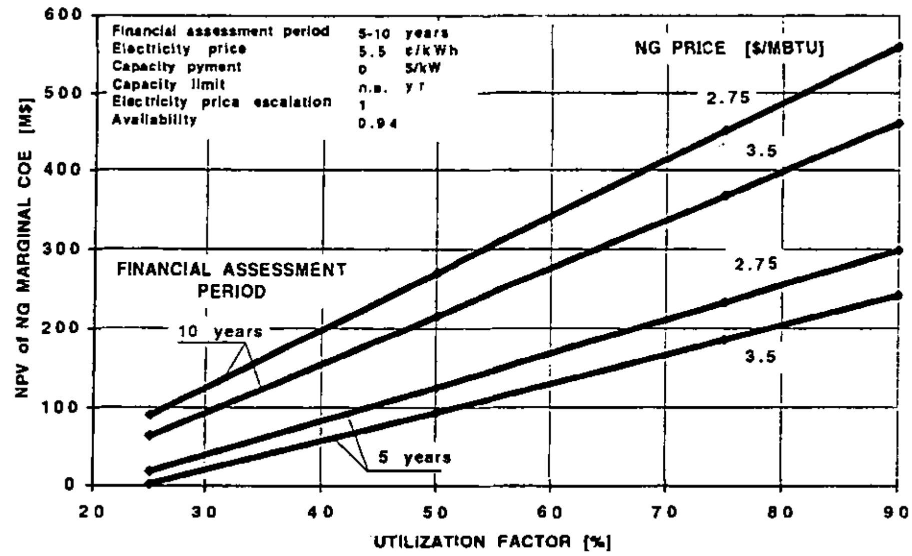

Fig. 15 - The NPV of the Natural Gas Marginal contribution vs. utilization factor and a financial assessment of 5 and 10 years .