GAS TURBINE BASED POWER PLANTS

REPOWERING REDUCES EMISSIONS AND INCREASE EFFICIENCY OF EXISTING PLANTS WHILE RE-UTILISING AVAILABLE ASSETS.

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INTRODUCTION

ALSTOM has a very long tradition in the gas turbine business. Since the first gas turbine plant developed by BBC (now ALSTOM), was commissioned in Neuchatel, Switzerland in 1939, ALSTOM (Former BBC/ABB Power Generation) has developed a wide range of gas turbines for every application. The upcoming competition in power generation market is bringing new life to older power plants.
Environmental concerns are playing a more and more important role in today's business environment and every day life. Power generation is no exception and the emissions of CO2 and other effluents from power stations are in focus worldwide. With the Kyoto Protocol being honored by an increasing number of governments there is a strong pressure to reduce the emissions from power plants. At the same time there is an increasing pressure to improve the efficiency for aged power plants as they are facing competition from new and more efficient power plants in the deregulated market.
Due to this transformation of the market, utilities are becoming increasingly involved in the field of re-engineering their existing steam turbine plants. Since steam turbine plants can remain operational for many decades, it is a very attractive proposition for older plants to be repowered. Repowering will drastically improve environmental emissions through improved efficiency. Total power plant output can also be increased. The paper will describe the basic technologies involved with Repowering and outline the economical and environmental benefits.
Site conditions are normally an important issue for Repowering projects. Space is normally limited and normally the power plant owner would like to minimize the interruption of the present power production while Repowering work is carried out.

Manuscript Received on April 30, 2003

First BBC gas turbine started up 1939

There are two main options available when deciding to repower:
Full Repowering or Hybrid Repowering.
Full Repowering converts the present plant into a highly efficient conventional combined cycle unit by making use of the existing steam cycle. Alternatively, Hybrid Repowering utilizes both the present boiler and steam cycle to create a flexible plant, both in terms of power output and fuel arbitrage. These two concepts are discussed in this paper.

WHAT IS REPOWERING?

Repowering is the transformation of an existing steam power plant into a combined cycle system by adding one or more gas turbines and heat recovery capacity. It is a cost-effective way to improve performance and extended unit lifetime while adding capacity, reducing emissions and lowering heat rejection and water usage per kW generated.
The main advantages of Repowering relate to:

Increased output capacity – typically the output will increase by a factor 2 - 2.5
Improved efficiency – typically the efficiency will

improve by approx. 50% , making the plant capable of being competitive in the deregulated market

Fuel flexibility – a hybrid repowered solution allows fuel arbitration (coal, oil or gas), where the optimal mode of operation is determined not only by electrical pool price, but also by fuel price

Operating flexibility – adaptation to power demand with short start up times and quick load up

Repowering produces **lower emissions** – Not only in specific mass per kWh, but also in absolute terms, despite the increase in power output. This is shown in Fig 1

Lower specific cost of electricity – By utilising existing equipment, a lower capital investment against a new plant allows plant owners to regenerate existing equipment to compete with Greenfield sites.

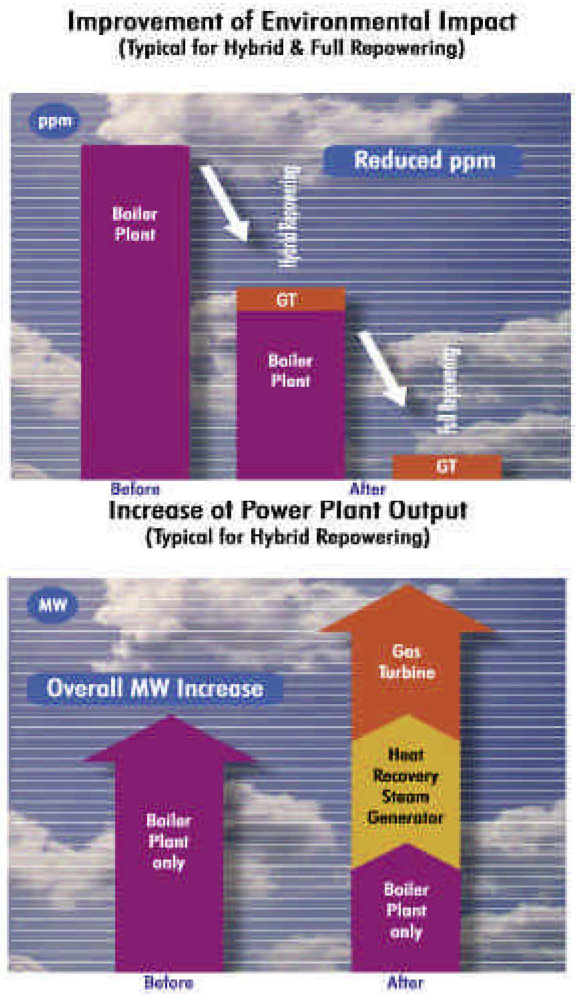

Fig 1: Market Situation Requirement

There are two main types of Repowering that can recreate a competitive plant:

- **Full Repowering**
- **Hybrid Repowering**

Hot windbox- and cold windbox Repowering are alternative solutions for very special applications but in general not recommended by ALSTOM Power

REPOWERING SOLUTIONS

In Repowering every cycle is different. There is not a standard solution for every plant. However through our experience we have seen that certain configurations are more competitive than others.

FULL REPOWERING

Full Repowering consists of the decommissioning of the existing boiler, and replacing it with a highly efficient gas turbine and an HRSG (Heat Recovery Steam Generator).

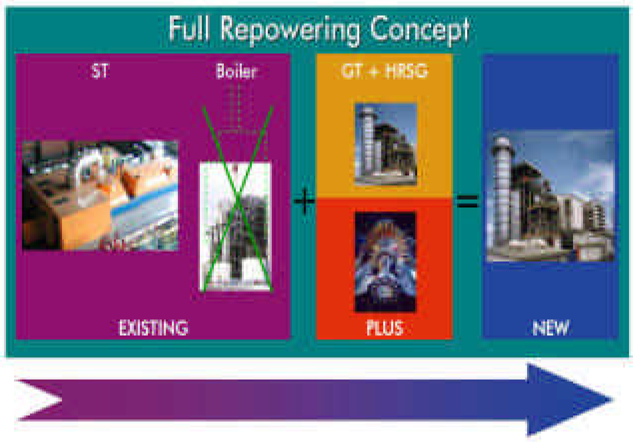

Fig 2: Full Repowering Concept

In addition to that, the present configuration of the water-steam cycle should be carefully considered, as the loading of the steam turbines will not be the same in the new cycle as it was in the old.

The advantage of full Repowering is the high efficiency that the plant achieves, and the corresponding low NOx emissions. When considering that most conventional or combined cycle plants' fuel costs are around 60% of the cost of electricity, this efficiency jump causes a considerable reduction to the cost of electricity.

HYBRID REPOWERING

Hybrid Repowering utilises the existing boiler, but with the addition of a Gas Turbine and a HRSG. (Fig. 3). Hybrid mode provides the most flexible option, in terms of specific fuel cost and absolute power output. With Hybrid Repowering, an optimal match between the energy available from the exhaust gas of the gas turbine, and the steam generated by the existing boiler is achieved.

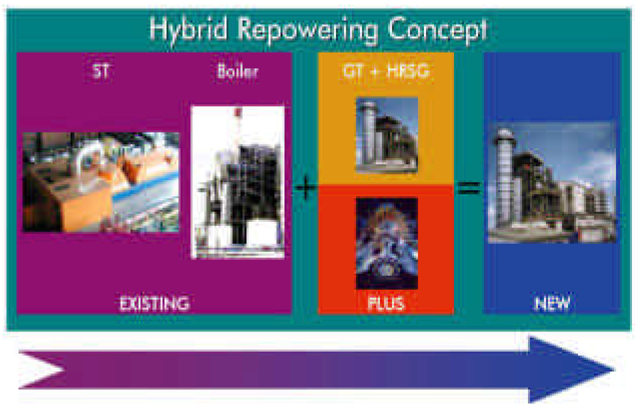

Fig 3: Hybrid Repowering Concept

There are four main operating modes:

- **Original Mode** – conventional steam cycle: the plant can still be run in its original mode, utilising the boiler 100%, but with the gas turbine out of operation.

- **Hybrid Mode** – all systems (Gas Turbine, Heat Recovery Steam Generator, Boiler, Steam Turbine) are utilised to provide maximum power output. The existing boiler is running at part load, and the reduced heat input to the boiler is compensated by the exhaust gas of the gas turbine through the HRSG.
- **Combined Cycle Mode** – the existing boiler is not in operation, but the gas turbine is running at full load, providing steam to the steam turbine through the HRSG. The steam turbine is not utilised to the highest load, but the efficiency of the plant is at its highest.
- **Open Cycle Mode** – the gas turbines are installed with bypass stack and operating in open cycle mode for peaking.

Switching between these modes provides flexibility.

The plant configuration is again specific for each individual plant, although there are certain changes common to most hybrid plants. An example of the final configuration of a plant is shown below in Fig. 4

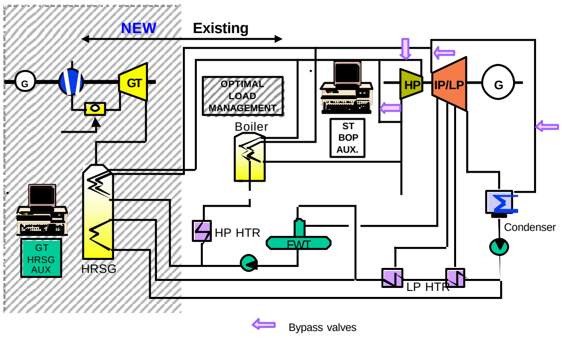

Fig 4: Hybrid Repowering Concept

REPOWERING OPTIONS

The decision whether to pursue the alternative to repower an existing facility, and if so for which option, depends heavily on the economic evaluation of each plant.

Some conditions required to meet the advantages of Repowering:

- Secure supply of natural gas at a known price
- The existing plant presently running on natural gas, or natural gas pipeline near to existing plant
- Boiler near the end of its lifetime, or large repair work required.
- Plant does not meet the local emission constrains (pollutants)

Hybrid plants on the other hand suit a slighly different market environment.

- Coal or oil and natural gas for the hybrid cycle are available
- Large fluctuation in power demand
- Reliance on the initial fuel

DESIGN PRINCIPLES OF REPOWERING

As most of the conventional plants are based on a single reheat cycle and, with modern reheat combined cycles resulting in the best efficiency, the Repowering scheme will be based on a reheat cycle. In contrast to live steam pressure levels typically between 140 bar and 250 bar within a conventional cycle, the optimum live steam pressure level for the combined cycle will be somewhere between 90 to 160 bar. This means that the live steam pressure of the converted cycle will be normally below the original design. Modern gas turbines together with the HRSG are able to maintain the original live steam temperature and this will be retained for the repowered design. The live steam will be expanded as in the original cycle through the HP section before it enters the reheat section of the HRSG.

RESULTING CHANGES OF THE REPOWERING SCHEME

In contrast to the conventional cycle where steam is taken out of the HP turbine-, cold reheat-, IP turbine- and LP turbine extraction, the repowered combined cycle is actually adding steam at the cold reheat. This is because condensate and feedwater preheating is moved from the existing condensate and feedwater heaters into the HRSG for optimized plant efficiency. Therefore all heaters are taken out of operation. Feedwater tank, feedwater pumps and condensate pumps may be reused depending on their economical benefits. As there is no extraction steam, the steam flow increases on its way through the steam turbine because of the addition of IP steam and LP steam. (Fig.5) This will change the operating steam conditions substantially from that of the original conventional design value which does not allow optimum internal efficiency of the steam turbine.

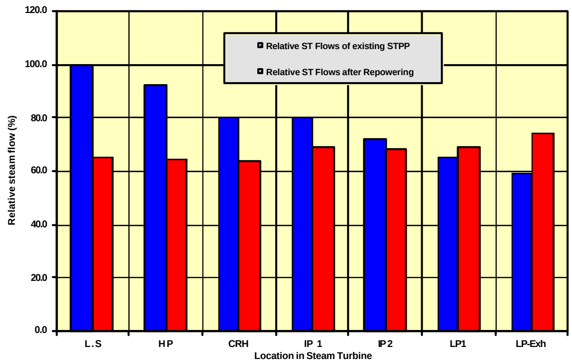

Fig 5: Typical relative steam flow distribution before & after Repowering

- blue columns: before Repowering
- red columns: after Repowering

Our experience also shows that with an existing, relatively old, steam turbine, a good net plant efficiency can be achieved. Of course, the plant output can be still further improved by performing a turbine retrofit to optimize internal efficiency with the adaptation of the steam path to the new design conditions.

DESIGN PRINCIPLES OF A REPOWERED STEAM CYCLE

Increase of output and efficiency of various repowering solutions

	FW Pre-heating	Hot Windbox	Hybird	Full Re-powering
Increase of output	**<25%**	**<50%**	**<50%**	**<50%**
Increase of efficiency	**<10%**	**<20%**	**>40%**	**Up to 50%**

ADVANTAGES OF ALSTOM GT24 / GT26 FOR REPOWERING SOLUTIONS

The two individual controlled combustor chambers of the GT 24 / GT26 sustain high efficiency and low emissions at part load operation through manipulation of air flow by three variable guide vanes. The vanes allow reduction of air mass flow to 60% of the full load level while maintaining the exhaust gas temperature of the gas turbine at nominal level. This ensures that the thermodynamic quality of the sequential combustion combined cycle remains nearly constant maintaining its high level steam temperatures. The high exhaust temperatures of the GT24 / GT26 allows to maintain high live steam and medium pressure steam temperatures for the existing steam turbine generator without duct firing. Duct firing then is only necessary if additional power output is needed.

THE ALSTOM GT 24 / GT 26 HISTORY

ALSTOM created two similar sequential combustion gas turbines: the GT24 for the 60 Hz market and the GT26 for the 50 Hz market.

The ALSTOM GT24 A series was launched in 1995. By the time the uprated GT24B version was introduced in late 1999, the main technology differentiator – the sequential combustor – had already proven itself in GT24/GT26A units.

The “B” version included higher output through revised EV burners and improved turbine aerodynamics and cooling.

In fact, three of these units each achieved more than 30,000 fired hours by the end of 2002.

ROBUST WELDED ROTOR TECHNOLOGY

The GT24/GT26 utilizes the welded rotor technology that has been used for more than 50 years in large gas turbines.

ALSTOM is the only OEM to use welded rotors for gas turbines of this size, providing a considerable advantage in the robustness of this component.

There is no center bearing and no disk bolts, which means that disassembly and re-stacking is not necessary during overhauls.

The maintenance of the rotor is minimal and in some older GT types ALSTOM has experience that the same rotor has been operating (without refurbishment) for more than 130’000 hours.

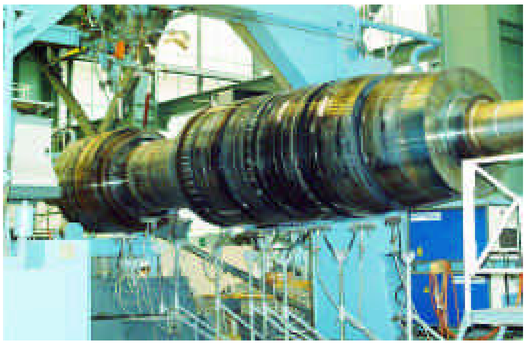

Fig 6: Manufacture of a welded rotor in Birr, Switzerland

INTRODUCTORY ISSUES

Three technical issues became evident at different stages of the first 250,000 hours of B series operation and needed closer attention. (see Fig. 7)

- First Combustor Liner - known as the EV liner
- Low Pressure Turbine Row 2 Blade Shroud
- Low Pressure Turbine Row 1 Cooling Improvement

The first two issues (EV Liner and LPT 2 Blade Shroud) were identified on the first B unit within the first year of operation. Both issues have been rectified since August 2000, and fleet implementation is complete.

The third issue involving LPT 1 surfaced in the latter part of 2001, and was less critical.

Low Pressure Turbine Row 2 Blade Shroud

The LPT 2 Blade Shroud deformation was detected on the first GT24B in mid-2000. This issue caused deformation of the shroud section of blade row 2, due to a lack of impingement cooling from the heat shield on the stationary side.

The unit was opened, the root cause identified, and a modification developed, which consisted of drilling additional impingement cooling holes in the stationary heat shield.

The first unit went back into operation following modification just six weeks after initial detection of the problem.

However, by the time the problem was identified and understood, around 30 units were already in the field or in transit to site and had to be modified.

Low Pressure Turbine Row 1 Cooling Improvement

The final issue – LPT 1 cooling – was discovered during destructive testing. This constitutes part of ALSTOM’s standard fleet feedback process when components that have been taken out of running units are returned to technology headquarters.

During this process, it was observed that low cycle fatigue could begin to occur after around 200 starts of the Gas Turbine.

ALSTOM defined a solution to this issue and has implemented it as needed since early 2002.

A RESPONSIBLE CORRECTIVE STRATEGY

Of all three issues, the LPT row 2 blade problem was potentially the most critical for ALSTOM and its customers, because the units in question were installed and operational. A fix with 100% certainty had to be implemented rapidly to ensure minimum disruption to customer operations.

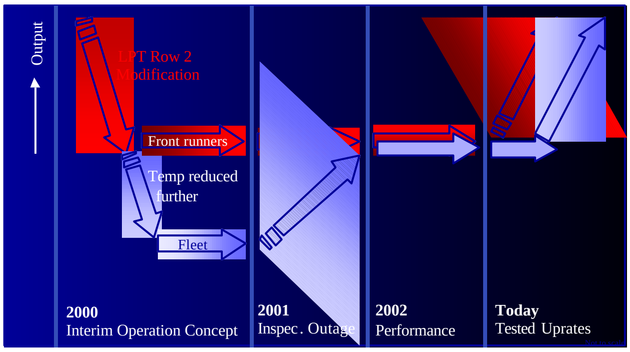

Fig 7: Front Runner Program

To achieve this, ALSTOM used the Front Runner approach (see Fig. 7). While the same physical modification was made to all units, the way the units ran differed.

Since the first three units to be modified were expected to accumulate hours of operation fastest, they were monitored by inspections on a monthly basis for about six months.

For the rest of the fleet, the same modifications were implemented but the firing temperature was reduced further.

After some six months of operation the front runner units were opened and their blades removed for destructive testing.

Positive results from these tests gave ALSTOM the confidence to increase the firing temperature for the rest of the fleet to front runner level.

Through the Front Runner approach and continuous monitoring, ALSTOM ensured that throughout the introduction of the B machines no outage was caused by blade loss or similar event, while at the same time ensuring all system insurance issues were also fully addressed.

POSITIVE TRENDS IN 2002

ALSTOM has now sold a total of 80 GT24/GT26 units worldwide, 51 of which are GT24 units. In addition, full 74 units have been commissioned to date, 22 units in 2002.

One of these recently commissioned plants is the Termobahia plant in Brazil, a CoGen plant which provides power generation from the gas turbine and uses exhaust gas to provide the energy for steam production in the neighbouring oil refinery.

Of the remaining 21 plants commissioned in 2002, all are standardized single shaft reference plants with similar layouts.

This has enabled ALSTOM to transfer its implementation and operational experience across plants, further benefiting customers by increasing speed of construction, commissioning and reliability.

One good example of this is the Monterrey III plant in Mexico. The company successfully erected and commissioned all three KA24 combined cycle blocks in the record time of fifteen months from foundation to mechanical completion, with a very short seven-month commissioning phase for all three blocks.

ALSTOM's operating data for GT24/GT26 units clearly shows that operating hours have increased rapidly following the introduction of the more technically advanced B machines in September 1999, reaching more than 500,000 fired hours today.

The accumulation of an additional 250,000 fired hours' experience over the last twelve months has been extraordinary – equal, in fact, to the combined total of the preceding six years, a testament to the robustness of the GT24 product.

PROVEN PERFORMANCE

The A units introduced in the mid 1990s have demonstrated beyond doubt that sequential combustion can produce both advanced performance and low emissions.

The three lead units, all base load plants, have each accumulated more than 30,000 fired hours – this is equivalent to around 4 years of continuous operation.

Taranaki, ALSTOM's first single shaft unit in New Zealand, is the lead unit of the GT24/GT26 fleet, and consistently provides reliability figures in the 99% range.

The Agawam and Enfield plants, meanwhile, were the first GT24B and GT26B units respectively. Since Agawam is a merchant power plant, which only dispatches according to market demand, another plant, Midlothian in Texas, has actually accumulated similar hours.

In addition to these three, twelve B version units have already broken through the important milestone of more than 8,000 fired hours. (i.e. 1 year of continuous operation)

OPERATIONAL MONITORING

Reliability and Availability

During the course of 2002, ALSTOM has monitored 24 KA24 plants in commercial operation.

We understand that for our customers, as well as for ourselves, it is important to consider the whole plant, and not just the gas turbine.

As part of its commitment to guaranteed performance, ALSTOM also continually monitors system availability for each month of the year.

Even though this is only the first year of operation for many plants, many units are already reporting excellent availability and reliability.

The graph below (Fig. 8) shows statistics for accumulative reliability of 25 GT24 combined cycle power plants. As can be seen a consistently high reliability has been maintained over the year 2002.

As an example, the GT26 Gas Turbine at the Enfield plant in the UK has achieved an average reliability of 99.8% in 2002.

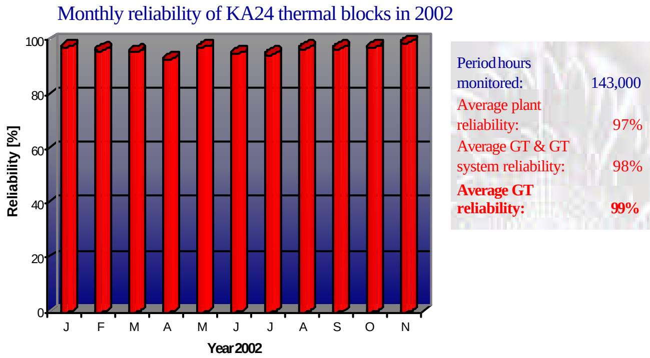

Fig 8: Plant Reliability for 2002

Midlothian, ALSTOM's biggest plant with six thermal blocks, achieved availability in the high-90% range for the summer peak.

All six blocks went commercial in spring 2002, and figures for the first four months of complete plant operation show availability well above 90%, with September registering above 99%.

In fact, the average plant reliability is already 97%, although this value increases still further as the scope is more clearly defined. If figures take into account the gas turbine and its corresponding systems (control systems, oil pumps, valves, etc), reliability is 98%.

If the GT24 thermal block is considered alone, reliability increases to 99%. These reliability, availability and maintenance statistics clearly demonstrate that this unique technology has become a real workhorse for ALSTOM customers.

In a similar fashion, the availability of the units has also increased over time. This is due to constant monitoring and fleet experience feedback that allows ALSTOM to predict when the machine needs to be opened for maintenance.

PERFORMANCE HIGHLIGHTS

Operational Flexibility

In a modern market the Operational Flexibility of a power plant is a key factor, which is crucial for the commercial success in a dynamic market environment. Since its start in commercial operation the GT24 and GT26 power plants have shown excellent operational flexibility. This is due to several advantages of the GT and plant concepts:

- Excellent Start Up Behaviour
- High Part Load Efficiency
- Dual Fuel Flexibility

Start Up Behaviour

The Start Up Behavior of a power plant is determined by the Start Up Time and the Start Up Reliability. The Start Up Time of the Gas turbine is short in comparison to other gas turbines of this size. With the correct plant concept it has been shown to reach combined cycle full load within 50 minutes with a GT24, while the simple cycle plant can start up in around half an hour.

This short Start Up Time allows to realize revenues almost immediately after the decision to turn on the power plant.

One good example being the Lake Road merchant power plant in Connecticut, USA. This plant consists of three KA24-ICS blocks, which went into commercial operation in mid-2002. Being a merchant plant, electricity demand dictates dispatch, and results in 150-250 starts per year for each unit. Since March 2002, the Lake Road Plant has demonstrated that hot start-up between push button to combined cycle base load can consistently be achieved in 50 minutes.

Additionally the good Start up Reliability of the GT24/GT26 plays an important role, since market changes can only be followed with a machine with a foreseeable behavior.

The Start Up Reliability for the GT24B/GT26B is at average >95%.

The short start-up times and high start-up reliability of the KA24 block have the potential to increase each unit's revenues from between 150 - 250 hours against other technologies, which depending on the plant economics could represent millions of dollars of additional operating revenues per year.

High Part Load Efficiency

The GT24/GT26 in combined cycle can achieve an unrivaled Part Load Efficiency. This high Part Load Efficiency is important to reach a high Operational Flexibility.

Part load operation reduces the number of starts during low price periods and therefore decreases the associated starting costs.

Additionally the lifetime consumption that is related to the number of starts of the Gas Turbine can be controlled by freely choosing whether the Gas Turbine is shut down during low price periods or not. This is an important advantage, which increases the flexibility in outage planning significantly.

Low Emissions and good pulsation characteristics

There are two reasons for the low emissions that the GT24/GT26 produces. The robust EV burner (the first combustor) and the sequential combustion.

The EV (see Fig. 9) was developed in the late 1980s and has accumulated millions of operating hours across all of ALSTOMs large Gas Turbine range.

Each burner is manufactured identically, and no further changes are necessary to the hardware during the commissioning period.

In addition, the unique feature of sequential combustion in the GT24/GT26 burns natural gas for a second time in an oxygen deficient environment.

The result of these two combustion systems create Nox emissions regularly measured at lower than 9ppm (at full load with no additional water or SCR) and CO emissions of below 5ppm (at full load).

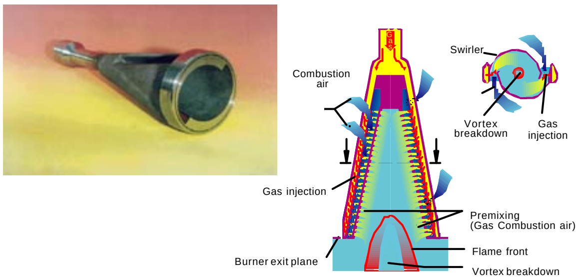

Fig 9: EV Burner Principle

An additional advantage of having a multiple combustion system is to select an optimal operating concept to minimize pulsation issues. As a result, Alstom's GT24/GT26 can quickly resolve any issues due to pulsations.

NEW PRODUCT DEVELOPMENTS

During the course of 2002, ALSTOM has not only been gaining experience with these systems out in the field, but has been working in-house on product development, a continuous process that's part of ALSTOM's strong commitment to R&D. With 500,000 operating hours of experience, and very high and improving levels of availability, the ALSTOM Reliability Assurance Program is based on a very firm foundation.

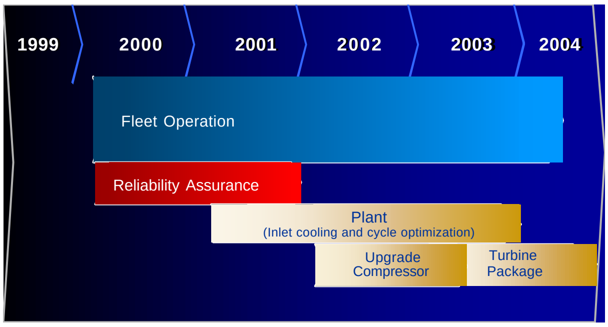

Fig 10: Development Program

While many development programs are underway, three have made substantial progress in 2002:

- The Gas Turbine Compressor Program
- The High Fogging Development Program
- The Dual Fuel Capability Program.

The Gas Turbine Compressor Program

ALSTOM's 22-stage compressor has been designed for increased mass flow of 5%, which is aimed to give a similar increase in the power output. This has been achieved through both optimised aerofoil design and – principally – a re-staggering of the blades. This means ALSTOM's engineers have developed a design which requires virtually no modifications to the rotor.

ALSTOM has its own full GT26 test facility located in Birr, Switzerland. The GT26 simple cycle machine runs as a complete power station and when operating dispatches more than 260 MW to the Swiss grid. Additionally ALSTOM has its own 57 MW GT8C2 test machine that runs at the same site – also able to dispatch full load to the grid.

In terms of operating hours it is possible to run these machines to the limits of the operating envelope with regards to temperature, pulsations and so on– something that is not commercially possible with any of the customer-installed engines.

Data from the Birr tests confirmed the expected improved results:

Increase of mass flow by 5-6%, resulting in a combined cycle power increase of around 4-5%. Operation in all required modes including dual fuel, with machine able to start up from the very first test.

In February 2003, the first GT24 field unit completed commissioning with the upgraded compressor, and the initial results showed output to have increased to the expected values.

The High Fogging Development Program

A second development program focuses on the high fogging inlet system. The advantage of using an inlet cooling system to provide additional power is that no hardware change is required in the core gas turbine.

The water evaporates during compression, reducing compressor power consumption and generating a similar thermodynamic effect to inter-cooling.

The operating envelopes for this system were tested at the Birr test facility with engineering for the GT26B delivered mid-summer 2001.

- Injection of up to 6.5kg/s water – equivalent, for the GT24, to around 4 kg/s. This represents 1.2% of air intake massflow
- This provided a power output increase of 5-6%
- Additional advantage of a slight decrease in NOx of 1ppm

Most importantly, the Birr tests, both in the GT8C2 and GT26 confirmed that system can run with minimal risk in the field. This led to the first field implementation of the system in a GT24, which took place in 2002 and produced similar results.

Dual Fuel Capability Program

This program finished on target in 2001, when testing was completed at the Birr test site.

To ensure optimum performance in the new units, a new nozzle was chosen, producing smaller droplets and providing the best possible distribution of liquid fuel.

At the beginning of 2002, the first field GT24 unit was equipped with the new nozzle. The gas turbine base load was achieved, and optimal emissions and pulsation windows have been reported.

- Target: 42ppm NOx for liquid fuel
- Achieved: 20ppm

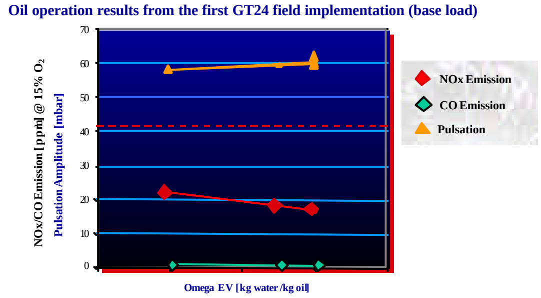

Fig 11: Dual Fuel Capability - Field Results

UPGRADE POTENTIAL

There are several other features that ensure the competitiveness of the GT24/GT26 can be maintained in a modern electricity market environment.

ALSTOM offers different forms of Power augmentation, including evaporative coolers, chillers and high fogging.

A HIGH-PERFORMANCE WORKHORSE

After more than 500,000 hours of operating experience, the performance and robustness of ALSTOM's GT24/GT26 have been thoroughly proven.

All modifications have proved successful, and ALSTOM is currently experiencing highly competitive running reliability with upward trends. The GT24/GT26 has become a dependable, high-performance customer workhorse.

THE ALSTOM GT13E2 HISTORY

The first GT13E rated at 147.9 MW was commissioned in 1987 at the Hemweg/NL facility, owned and operated by UNA. It's design was based on a 21-stage compressor and a 5-stage turbine, both with low stage loading.
A single 'silo' type combustor with a large single burner provided for a rugged and flexible engine, which is still in service as of today.
Subsequently, a total of twenty-six GT13E were put in operation. The need for higher thermal efficiency and Dry-Low NOx technology with emissions below 25 ppm soon lead to the development of the GT13E2 in 1991. This engine, while retaining the fundamental aerodynamic and mechanical design features of the GT13E as well as many of its parts, is characterized by the successful matching of ALSTOM's EV (EnVironmental) dry low NOx burner with a fully annular combustor, which replaced the GT13E's single, top-mounted 'silo' combustor.
These modifications yielded a GT output of some 165 MW and combined cycle efficiency values of more than 53% (triple pressure configuration). These performance characteristics, along with an outstanding availability and an excellent maintainability, made the GT13E2 the market leader in its class for combined cycle and co-generation applications.

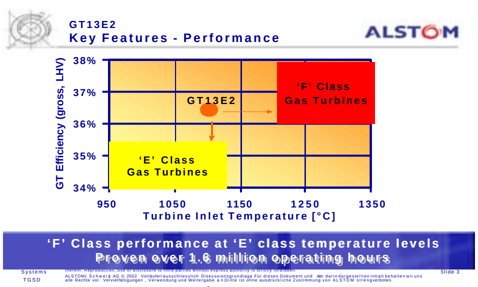

Fig 12: GT13 E2 Performance Close to F-Class

More than 90 units have been sold to date. Some 70 units in commercial operation have acumulated more than 1'600'000 operating hours and more than 11'000 starts.

THE GT13E2-M UPGRADE

Today's GT13E2, incorporates a number of further technical enhancements as the result of a careful continuous product improvement process (CIP). It features an ISO performance rating of 172.1 MW at 36.4% simple cycle efficiency on natural gas, the latter being almost one point above its nearest competitor. In achieves an impressive 53.1% combined cycle efficiency if matched with a dual pressure water/steam cycle configuration or even 54.2% with a triple pressure cycle. The extended maintenance interval configuration of the engine allows for up to 36,000 EOH between hot gas path inspections, thereby reducing variable maintenance cost by more than 30%.

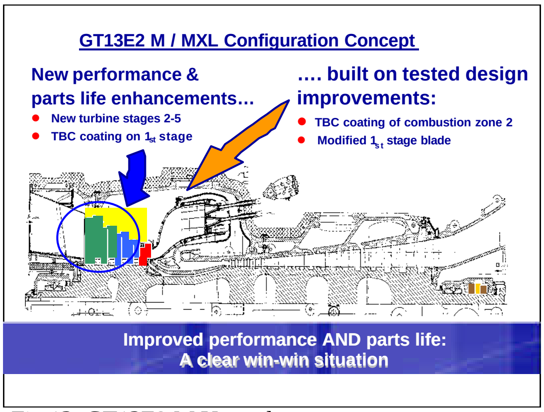

Fig 13: GT13E2 M Upgrade

The GT13E2, an unique combination of mature technology and superior performance, is a market leader for good reasons.

TWO TYPICAL ALSTOM REPOWERING PROJECTS

VALLE DE MEXICO HYBRID REPOWERING BRINGS MORE POWER TO MEXICO-CITY

The Valle de Mexico project is a good example of the hybrid Repowering concept in practice. In autumn 2000 ALSTOM has signed a contract worth around 200 Million Euro with the Mexican State Utility, Comision Federal de Electricidad (CFE), for the Hybrid Repowering of the 300 MWe Unit No. 4 of the Thermal Power Plant Valle de Mexico. The plant is located 38 km North of Mexico City, at an altitude of 2'283 meter above sea level. Under the contract ALSTOM is supplying three (3) GT 11N2 gas turbine generator units and three (3) heat recovery steam generators (HRSG), all with their auxiliary equipment, the electrical and control system, the high voltage switchyard, civil works, along with engineering, site preparation, erection and commissioning.
The repowered Unit 4 will provide additional power to Mexico City. The plant has been fully operational in October 2002. PAC for open cycle operation of the first GT11N2 was end of April 2002 and PAC for the second and third GT11N2 for open cycle operation was in May 2002. Valle de Mexico is the first combined cycle plant in Mexico where the design allows the owner to operate the unit in pure combined cycle or hybrid mode.

Fig 14: Valle de Mexico power plant

In Hybrid mode the three new gas turbine generators and the three HRSG's will operate at base load while the existing boiler will run at 50% load to ensure that the existing steam turbine unit is running at full load. The Repowering of Unit 4 increases the original output from 300 MW with 36.8 % efficiency to about 550 MW with 43.8 % net efficiency at the design point and in Hybrid operation. In combined cycle operation the plant output is 372 MW with 48.2 % net efficiency.
To maximize efficiency of the new HRSG, condensate and feedwater preheating is moved from the existing condensate and feedwater heaters into the new dual pressure HRSGs. Therefore all existing heaters are taken out of operation. The feedwater tank, feedwater pumps and condensate pumps may be re-used depending on the economics. As there is no extraction steam, the steam flow increases on its way through the turbine because of the addition of IP steam and LP steam.
The new flow distribution means that the HP turbine is operating at part load. Therefore if the HP is designed without a control stage (full arc admission), it is more efficient to operate the Repowered plant at sliding pressure with the turbine inlet valves fully open, rather than operate at the original live steam pressure with permanently throttling inlet valves. If the HP turbine is designed with a control stage (partial arc admission), it has to be determined on a case by case basis whether it is more efficient to operate at full live steam pressure or, for example, with three of four valves fully open and sliding pressure. When it comes to efficiency and/or output, the differences are relatively small.
When operating at sliding pressure, on one hand the HRSG can be designed for a lower pressure, but on the other hand lower pressure also requires larger volumetric flows and larger pipe diameters. For the HP turbine control stage, sliding pressure with all valves fully open means less stress.
The operation of a steam turbine without its extractions will obviously change the axial thrust. Each case has to be analyzed carefully to find out whether safe operation is possible or whether any corrections are necessary. In most cases, where the partial turbines are designed with individual balancing pistons, no problems are expected. Adjustment is possible by, for example, removing one stage of the blading.
The results show that, even with a relatively old steam turbine, a good net plant efficiency can be achieved. Further gains can be made by performing a turbine retrofit, e.g. a LP turbine retrofit with a larger exhaust area together with a condenser retrofit.

SENOKO, THE FIRST GT26 FULL REPOWERING PROJECT IN ASIA

Senoko Power Ltd, one of the largest power generation companies in Singapore operates the 210 MWe Pasir Panjang power station as well as the 2'460 MWe Senoko plant, which is capable of supplying nearly half of Singapore's electricity needs. At the Senoko Power Station there was until recently, 1'610 MWe of steam plant and 850 MWe of combined cycle plant. This included the most efficient units in the system as well as some of the oldest. The three oil fired units of Senoko Stage 1 steam plant were commissioned some 25 years ago and were approaching the end of their useful physical and economic life. Senoko Power therefore decided to Repower the facility using ALSTOM's GT26B gas turbine generator units and a contract was signed with ALSTOM Power, who, as main supplier, is providing overall project management for the engineering, procurement and construction of the facility.
The Repowering concept involves replacement of the existing oil fired boilers with new GT26B gas turbines and heat recovery steam generators (HRSG's). The main fuel for the gas turbines is natural gas, with diesel oil No 2 as back up. The waste heat from the hot exhaust of the gas turbines is used to generate steam in the triple pressure HRSG's to drive the existing steam turbine generators fitted with a complete new HP/IP section and the LP section equipped with new rotating and stationary parts.
The project is carried out in two phases. In the first phase, the first of the three units of Stage 1 was Repowered The contract for phase 1, with a option for phase 2 was signed in March 1999. The total project cost of phase 1 & 2 is around 475 Million USD including O&M contract. This gives 720 MWe of additional power to the Singapore National Grid. The Letter of Acceptance for the Repowering of the second and third unit was signed in March 2001. In 2005 the 3 x 120 MWe of low merit, low efficiency oil fired steam plant comprising Stage1 of Senoko will have been transformed into 3 x 360 MWe high efficiency natural gas fired combined cycle plants with significant reduced emissions.

Fig 15: Arial view of Senoko Power Plant (space for Repowering phase 1 & 2 is marked red)

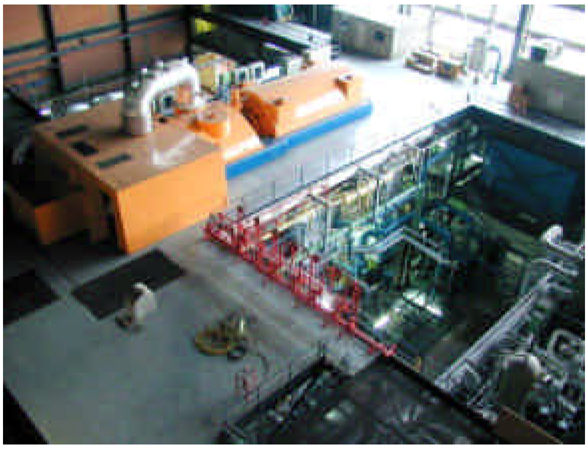

Fig 16: View of Steam Turbine Hall, Phase 1 Repowering

The schematic of the repowered steam turbine plant shows that it follows the general principle of ALSTOM combined cycles with GT26B gas turbines using a triple pressure natural circulation boiler, which is supplemented by heat recovered from gas turbine cooling air.

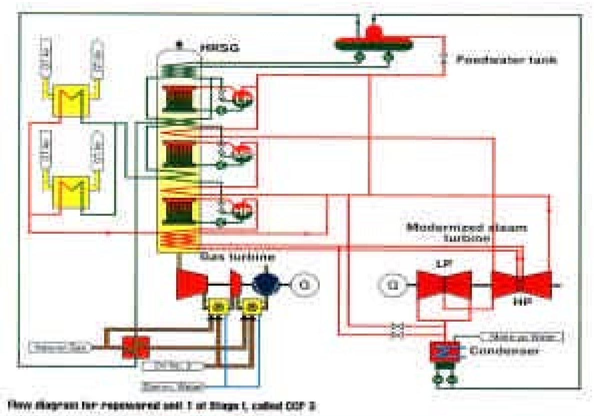

Fig 17: Water / Steam Cycle of Senoko Phase 1 Repowering

PHASE 1 ERECTION IN RESTRICTED SITE AREA

To minimize interruption to the operation of Stage 1 and electricity supply to consumers, a phased construction program was adopted. It was planned to use a great part the existing civil structure and equipment, after some modification and refurbishment.

Of particular interest is the HRSG, which is a vertical natural circulation boiler. The boiler is made of 12 pre-fabricated, insulated modules containing the shop welded tube bundles connected to their headers. For this boiler there are 12 modules arranged in three stacks of four.
The erection is similar to that of any vertical HRSG. The modules are suspended form 28 jacks on the top of the boiler frame, and only when the complete heat transfer section has been assembled with twelve modules, is the whole raised to its final position, an operation lasting a maximum of 15 minutes.
With this method the HRSG can be assembled much more rapidly. In Senoko it took 26 days to assemble the twelve modules into the frame and lift them up to their final position.
This erection method was significant given to the restricted site area, because maneuvering of the modules was very difficult and access to site for the erection of other large components was not possible during the time necessary for boiler erection.

Fig 18: Lifting of prefabricated HRSG modules

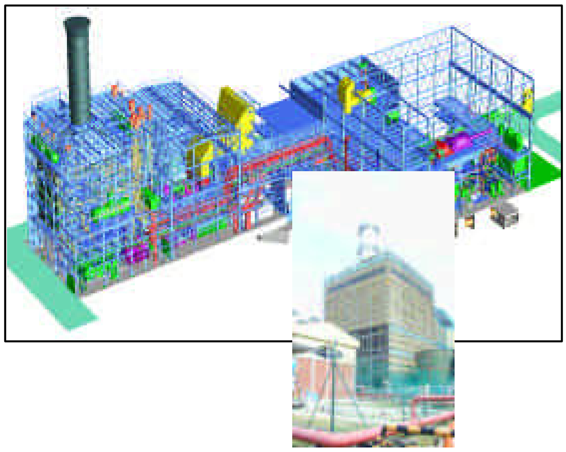

Fig 19: 3-D planning Senoko Phase 1

The ALSTOM contract also provided for the refurbishment of the existing steam turbines.
Normally, Repowering assumes that the steam turbine is out of service and that the original boiler and its auxiliaries can be removed as part of general site preparation, but not in the Senoko project The set being repowered had to be available until March 2000. This meant that the gas turbine and heat recovery steam generator had to be erected alongside an operating boiler and that there were only 15 months in which to refurbish the steam turbine, and to modify existing buildings to enable the new equipment to be joined to the old and to complete commissioning.
Since the GT26B-version gas turbine has a rating of 265 MW the capacity of the repowered set would be more than the total of the original steam plant, so that the other two sets could be shut down. Senoko Power still has about 25 MW more than before and at an efficiency nearly double that of the old steam plant: 56% against 38% gross efficiency for the best steam set.

CLOSING REMARKS

Summary of Benefits for the Power Producer

- **no need for extra permits (PPA, site)**
- **power output increase**
- **reduction of production costs**
- **better use of primary energy**
- **optimal operation flexibility**
- **fuel management independence**
- **increase remaining lifetime of existing plant**
- **limited loss of power generation during installation**
- **improvement of environmental conditions by lowering emissions**
- **no plant component demolition costs**
- **limited amount of extra cooling water required**

The upcoming competition in the power generation market is bringing new life to older steam power plants. Environmental concerns are playing a more and more important role in today's business environment and every day life. Power generation is no exception and this transformation of the market has seen utilities become increasingly involved in the field of re-engineering their steam turbine plants. Since steam turbines can remain operational for many decades, it is a very attractive proposition for older plants to be Repowered.

Repowering aged steam plants by replacing the old steam boilers with GT's and HRSG's or adding GT's and HRSG's in parallel to the existing steam boilers will increase the power plant output and efficiency and will also improve the environmental effects. A further advantage is that these conversions also require very limited extra cooling water, sometimes a bottleneck for new capacity additions

Repowering offers the potential to match the demands of the deregulated markets. The existing assets may provide a basis for Repowering to become more competitive than a Greenfield power plant. The book value of the plant is often well known, and for a plant 25-30 years old, is probably zero or close to zero as it has already been depreciated. Important for the owner is to place the contract for the repowering with one single contractor covering the total power plant. Only by doing this, the owner can be assured of an optimization of the total power plant, and a total guarantee could be given.

ALSTOM Power utilizes an economic model to discuss the best potential project choice with clients. This ensures that existing assets are optimized.

However, the hidden value of a plant may be higher than first perceived. With Repowering this value will be utilized to increase the benefit for the owner.

It is such hidden values that make plants attractive to Repowering.

REPOWERING REFERENCE LIST

Plant Name	Output	GT	Country	PAC
UNA MK10	100 MW	2 x GT9D1	NL	1978
Lage Weide 5	271 MW	1 x GT11D5	NL	1986
Hemweg	635 MW	1 x GT13E	NL	1987
Midland	1370 MW	12 x GT11N	USA	1989
Martinlaakso	200 MW	1 x GT8C	FI	1994
Rheinhafen	361 MW	1 x GT26	GE	1998
Gorzow	65 MW	1 x GT8C	PL	1998
Senoko 1	340 MW	1 x GT26	SG	2001
Bayside	265 MW	1 x GT24	CA	2001
Valle de Mexico	552 MW	3 x GT11N2	MX	2002
Senoko 2	680 MW	2 x GT26	SG	2005

References:

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