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Blackstone: flexible and environmentally friendly power plant

Two single shaft combined cycle blocks - each with centrally-mounted generator and SSS Clutch

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Blackstone combined cycle near Boston, MA, is the first in service of five merchant power plants, based on ALSTOM's GT24 single-shaft combined cycle block, which are planned for New England by American National Power. Environmental regulations have inspired some unusual measures to reduce noise and emission levels to create one of world's cleanest combined cycle plants.

The arrival of the British IPP developer, International Power, in the United States back in 1996 was quite different from their first overseas investments which had initially focused on large coal and oil-fired steam plants in Asia and a combined cycle plant in Turkey with their participation being as the plant operators.

Their entry into the North American market was on an altogether larger scale with the creation of American National Power, (ANP) first to manage a number of gas-fired CHP and small combined cycle plants which they initially took over, and then to develop a series of merchant power plants based on one or more 250 MW single-shaft combined cycle blocks based on ALSTOM's GT24 gas turbine using the unique high efficiency sequential combustion principle, and a once-through HRSG operating at a much higher steam pressure than is normally used for a combined cycle.

So far ANP have filed application for seven merchant plants with a total of 21 single shaft blocks: Midlothian (6) and Hays County (4) in Texas; both of which are now in commercial operation; Blackstone (2) and Bellingham (2), both in Massachusetts; Goreham (3), in Maine, which has been delayed; and Brookhaven (2) and Ramapo (2) in New York State which are subject to planning consent and on which work is expected to start next year.

In choosing a system based on the GT24, ANP were impressed by the high part-load efficiency of the sequential combustion machine. This would be important if it had to carry significant spinning reserve.

ALSTOM were also breaking new ground with a single-shaft block, in a market which has traditionally favoured multi-shaft combined cycle systems. Blackstone might have been in a three shaft layout from another manufacturer. Instead it has two single-shaft blocks and the advantage of this is that if they have to shed load, running both units down to 50 % would be more efficient than in the alternative arrangement with one gas turbine shut down and the other kept running with the steam turbine at part load.

Blackstone, about 80 km southwest of Boston is the first of the ANP New England plants to come into operation and has been running commercially since the end of last year, despatched by ISO New England as a base load plant. A similar plant in the neighbouring town of Bellingham is on a construction schedule running about nine months behind Blackstone and will be in operation for the coming winter.

Insofar as it uses the same power train, Blackstone can be said to be a common design with the other ANP plants, but beyond that the similarity ends, because this region of New England has some of the strictest environmental rules in the country. Noise control is particularly severe requiring extensive sound insulation on the HRSG, steam pipes to the air condenser, the transformers, and fuel gas compressors to attenuate sound in specific directions from the site towards housing areas.

NOx limits are also severe, with a requirement at the stack for less than 2 ppm. The GT24 has exceptional low NOx characteristics, but as in all American combined cycle plants a catalyst is also installed in the HRSG. This is a combined ammonia system for NOx and a precious metal plate system for CO which is placed just ahead of the LP section where the gas temperature is about 350°C.

Backing this up is the stack emission monitoring station which keeps a continuous reading of the NOx and CO emissions from both stacks to ensure that they stay within the prescribed limits. It means, too, that there is an additional staff member whose job is that of Environ-mental Officer with responsibility to take emission readings and prepare the station's environmental reports.

Air condensers provide for cooling, which is a general tendency in New England to avoid extended planning applications and intractable arguments with green factions over water abstraction in securing construction permits. Public water supply, however, is used for make-up of the steam cycle.

Flexibility in operation

In a Merchant Plant environment with no long-term power sales contracts, each station is despatched by a regional power grid, according to its availability and efficiency. But it is in regard to availability that the GT24 single shaft blocks are in a class of their own. This is mainly due to the once-through HRSG, which with its low water volume, and absence of drums, gives it a lower thermal inertia than the traditional tri-pressure, horizontal, natural circulation designs favoured by

Fig.1 This view of the HRSG shows the once through section , with heavy sound insulation. The long tube in the centre of the picture is the pressurizer with the blow down tank at left.

Fig.2. The steam turbine HP i n its acoustic housing with the 160 bar steam entering from the left. The gearbox, which drops the speed from 8900 to 3600 rev/min, is at right.

others and the capability to start up quickly if running on a daily load cycle.

In this operating pattern the unit would be shut down at, say 8.00 pm and a damper in the bottom of the stack would close to retain heat in the boiler, the SSS self synchronizing clutch would be open and the steam turbine behind it would be turning on its barring gear. At 6.00 am the next morning the button could be pushed to open the stack damper and start the gas turbine using a static starting device forcing the generator to act as a motor until the gas turbine has reached a sustained firing speed, whereupon the generator reverts to type and is accelerated up to synchronous speed. This takes about 20 minutes.

The gas turbine is then loaded to about 50 MW and held there with the HRSG dumping steam to the condenser until it is of sufficient quality to supply the steam turbine which then accelerates to 3600 rev/min. At this point the clutch engages to create a single shaft and the complete power train can start loading. By 7.00 am the block is already delivering full output into the network. From start-up to full load on a warm start after an overnight shutdown has taken less than an hour.

On a completely cold start, as after a maintenance outage, the steam turbine is also starting from rest and requires steam for gland sealing and condenser evacuation. This can only come from the HRSG and thus adds to the starting time as the steam turbine is gradually warmed up to start loading. In these circumstances, start-up takes about 105 minutes to full load.

HRSG design

Combustion Engineering, now the ALSTOM Power Boiler Division, have a long history of involvement with once-through boilers. Seventy years ago they were the first licensee of Sulzer who were the original developers of the once through design for large steam boilers. Their once-through HRSG for the GT24 has an HP output at 160 bars, which is higher than achieved with a drum type natural circulation HRSG, but is a common steam pressure in many coal and oil-fired power plants still operating around the world.

The once-through HRSG is a two pressure device and in appearance resembles the competing tri-pressure type, with a horizontal gas path leading to an end mounted stack. The LP system is a conventional natural circulation design and is separated from the HP section by the catalyst.

It is in the HP section that there are the differences which account for much of its flexibility. This is the once through section which is nothing more than a finned tube with a stable temperature gradient sustained along it. There is no drum and unlike the conventional horizontal boiler in which the tubes are hanging and therefore supporting their own weight, in the once-through section they are installed horizontally across the direction of gas flow and supported in tube plates suspended on the main structure.

This is the design principle which has been used in the vertical HRSG's developed in Europe. The tube plates support the horizontal tubes which form a series of parallel serpentine paths which are free to expand. At the tube ends expansion joints link individual tubes above and below in the matrix. HRSG's of this design have been used for the past 30 years in Europe in combined cycles which have performed mid load duty with daily or weekly starts in some countries in

Fig 3. The gas turbine is housed in a spacious acoustic enclosure shown here looking towards the HRSG with the fuels manifold of the first combustor stage at centre and the cooling air bleed pipes leading off to the OTC units.

support of a large nuclear base load.

Though it is in principle steam-filled when it is operating, the once through boiler requires a pressurizer. This is a vessel which is attached at a position corresponding to the start of the HP evaporator in a conventional HRSG. At start up it contains water which gradually evaporates as the temperature and pressure build up so that when the 160 bar operating pressure is reached it is filled with steam.

The pressurizer is also where the steam from the gas turbine OTC units enters. Air is taken from the GT24 compressor at two bleed points and has to be cooled before it can be sent to the turbine blades and vanes. The OTC units are simple once-through coolers which are connected in parallel on the steam side, which is at 160 bars, and are isolated from each other on the air side. One unit takes air from the compressor discharge at 30 bars and after cooling it sends it on to the HP turbine vanes: the other takes air from the 16th stage and passes it through the cooler to the first and second stages of the LP turbine section.

Fig 4. General view of an HRSG showing sound insulation on the once through section. The yellow hut beside the nearer stack is the emission monitoring position which collects data from both stacks to see that NOx is less than 2 ppm

Feed water for the OTC's is taken from the HP economiser stage and returns to the pressuriser at about 480°C. With such a high pressure differential from steam to gas there is no risk of gas leaking into the steam cycle and moisture detectors on the gas side can find any leaks should they occur.

The HRSG is not the only novelty in this combined cycle. The steam turbine is also different being a 2-speed design with a 25 MW HP section running at 8900 rev/min. This is coupled through a Flender Graffenstaden gearbox to a combined IP/LP cylinder turning at 3600 rev/min.

This turbine design is based on that of the VAX system which was developed in Sweden in the 1970's. Some of the earliest examples of these steam turbines have been installed in industrial CHP schemes in the United States, some are in combined cycle schemes, and others in coal- or oil fired steam power plants using the same steam conditions as applied here.

For the GT24 combined cycles, at full load the HRSG is delivering steam at 160 bars, 565°C to the HP cylinder which discharges to the reheater at 37 bars. The reheated steam at 565°C is sent to the IP. Because of the 2-speed turbine design, which even allowing for the gearbox is more efficient than a conventional single speed turbine of the same capacity, there cannot be a straight through axial condenser. The LP exhausts to the side to the ducts which lead it up to the air condenser.

While on the matter of availability, an important component of the single-shaft block is the SSS clutch which is placed between the generator and the steam turbine. The clutch is rated to the steam turbine and is of the new locking pawl type specially developed for the single-shaft application. With this design as soon as the generator starts to slow down and drop out of synchronous speed, the clutch opens and, as the pawls lift out of engagement they are locked in position so that there is no risk of their dropping to reengage when the gas turbine and generator are at rest and the steam turbine is

still running down on its barring gear.

This feature was very important for certain operators, such as Enfield (November/December 2001, page 29) who had to run a series of boroscopic inspection outages during their trial run of the modified cooling arrangements. These could be done on a week end, shutting down Friday night with the unit cool enough to access on Sunday make the inspection, and have everything back on full load by 10.00 am on Monday. Similarly the clutch imparts freedom for short outages to fix gas turbine or electrical auxiliaries over weekends.

Group operations

ANP have a large plant inventory with new and existing power plants. In Massachusets they have, besides Blackstone, Milford a 2-2-1 combined cycle arrangement with W501D's, which they took over as an operating plant, and Bellingham which is in the final stages of commissioning and will be in commercial operation later this year: three power plants within a 50 km radius. Consequently they are to be operated effectively as one production unit with seven generating sets.

Under this arrangement each plant has its normal operating team of 15 with three people on five shifts and supporting technical staff for instrumentation, water chemistry, and daily maintenance, etc.; but the management team will in some areas be shared. There will be one accounts office dealing with staff salaries and purchases for all three plants; and there will be one environmental officer monitoring emissions at all three sites. Each site will bid its power into the New England pool at 24 hours notice.

Another economy is in the use of trailer mounted water treatment plants, which can be moved from site to site. The low make-up demand of the once-through HRSG means that a store of demineralised water can be held for both units on site and when the tanks need to be topped up, the treatment unit is called in again. Raw make-up water is taken from the public supply.

Walking around the site it is very noticeable how relatively spacious it is, partly because there are a lot of shared facilities between each block and the absence of any permanent

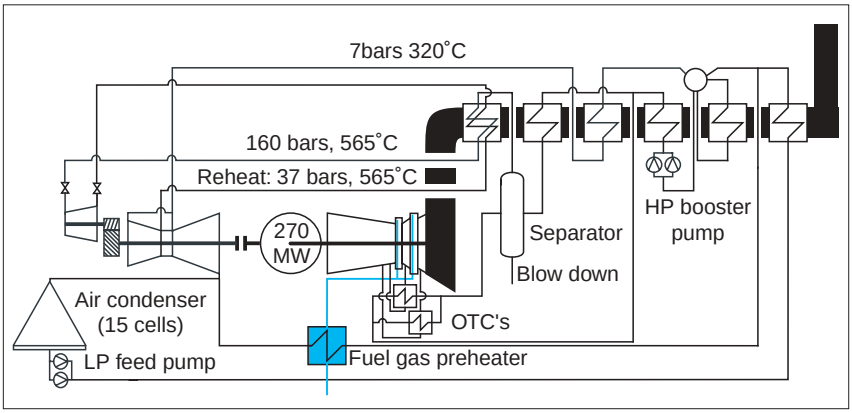

Fig.5 Schematic of the steam cycle of one of the Blackstone blocks. Two-pressure steam cycle, using once-through HRSG for good operational flexibility with much faster starting times than competing HRSG designs in the United States.

Fig.6 The air condenser for each block, by Balcke Dürr has 15 cells and is also heavily insulated both in the fan chambers and for the steam pipes, at right of picture, which send the exhaust steam up to the three rows of cooling cells

water treatment plant. Noise reduction is not so much realised by having the power train mounted indoors as by the heavy sound insulation provided in key areas of the outdoor equipment.

Measures include location of the gas turbine and generator and the high speed HP section of the steam turbine in acoustic enclosures. But there is no acoustic lining of the walls and ceiling of the building itself. The steam ducts up to the air condensers which each have 15 large fans are heavily insulated as are the HRSG's with external insulation as well as internal baffles to damp down resonance. Noise levels as low as 35 dBa must be achieved in certain areas.

With two blocks a number of auxiliaries can be shared. There is only one static starting device which is wired to both generators either of which can be selected. There is only one compressor washing system: a Turbotect on-line/off line system. Both gas turbine intakes have all the nozzles in place and plumbing connections back to the dosing skid located in Unit 1. There is also only one fuel gas compressor, a single-stage centrifugal unit by Atlas Copco with a Siemens electric motor driving it, and housed in its own acoustically insulated building

Despite significant climatic differences between the northern and southern United States, the entire electric power system is summer peaking due to warm summers and heavy air conditioning loads.

Blackstone expect to be running in base load between June and September. The inherent flexibility of the GT24 block and its high part load efficiency suggest that it could be running in mid load for many hours in a style which is all to familiar to ANP as they hark back to their European origins.

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