Al Taweelah B power station – electricity and water for Abu Dhabi

Al Taweelah B power station on the coast of Abu Dhabi, United Arab Emirates, has six steam turbosets and six seawater desalination lines for the supply of urgently needed fresh water and electrical energy to the region. German-based ABB Kraftwerke AG acted as main contractor, leading a consortium with SIX Construct JV, Abu Dhabi, Fisia/Italimpianti SpA and ABB SAE Sadelmi, Italy, as well as two sub-consortia with Hartmann & Braun AG and Babcock-Lentjes Kraftwerkstechnik GmbH of Germany. Al Taweelah B is able to provide up to 346,000 m³ of fresh water daily. Besides the six steam turbine-generator sets, ABB also delivered the 132-kV substation, I&C equipment and the balance of plant equipment for the power station. The six turbines have a nominal rating of 122 MWe in extraction/condensing mode, each producing 146 MWe in simple condensing mode. Following successful trial operation, all six units are now running under guarantee.

An abundance of natural oil and gas has helped to make Abu Dhabi, United Arab Emirates (UAE), not only a wealthy nation with one of the highest per capita incomes in the world but also a country in which its people can live comfortably in spite of a harsh climate. The keys to this success story on the Gulf are electricity and water. These two vital commodities are produced by combined heat and power processes, usually in gas-fired power stations, which work in tandem with huge seawater desalination plants.

Growing demand for these two resources threatens to cause a shortage of both. The *Water and Electricity Department* (WED) therefore decided in 1992 to build a new, large-scale complex consisting of a power station with six steam turbosets, each with an electrical output of 122 MW, connected to six desalination lines. In addition to generating approximately 17.5 million kWh of electricity per day, the main task of the facility is the daily production of up to 346,000 m³ of fresh water.

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The invitation to tender for this major project was prepared with the help of the Belgian consulting engineer Tractebel. ABB Kraftwerke AG, Germany, was chosen as general contractor, and subsequently formed a main consortium consisting of SIX Construct JV, Abu Dhabi, Fisia/Italimpianti SpA and ABB SAE Sadelmi, Italy, as well as Hartmann & Braun AG and Babcock-Lentjes Kraftwerkstechnik GmbH, both of Germany, in subordinated consortia.

The planned facility combines six steam generators, turbosets and desalination lines relatively independently for maximum flexibility and availability in the production of electricity and water. The order sum was approximately US$ 1.7 billion.

The design of the power plant focused on maximizing the production of drinking water. This priority was due mainly to the fact that water also had to be supplied to the Al Ain oasis, some 140 km away in the middle of the desert. A reliable supply of electricity and water has helped Al Ain develop over the years into a large, sprawling city dominated by green spaces.

A construction site larger than 500 football fields

Construction work began in 1994 on a site four square kilometers in size, situated directly on the coast. At right angles to the 300-m long machine hall with the six turbosets, and parallel to each other, are the six steam generators with their 70-m high exhaust stacks, for the most part of outdoor design **1**. Between the boilers and the sea are the six seawater desalination trains, also arranged in parallel. They are the largest of their kind built to date. Between boilers 2 and 3 and linked directly to the machine hall is the fully air-conditioned building containing the process control equipment and the central control room. Separate control desks for the power gen-

Al Taweelah B steam power plant in Abu Dhabi. Behind the row of pumps in the water inlet pool are the six seawater desalination lines with the interposing control room buildings. The mosque can be seen on the far right, at the height of the six steam generators. **1**

eration units and the desalination lines, arranged in groups of two, make the central control room the 'nerve center' of the complex.

Grouped around the main building are gas reducing stations for the fuel supply, the seawater extraction station, a 132-kV and a 400-kV switchyard, tanks for the treatment and storage of the fresh water, plus restaurants, offices and recreational facilities. A large mosque, with its hall of prayer aligned exactly with Mecca, was also part of the turnkey delivery.

Table 1:
Technical data of the six steam turbosets installed by ABB Kraftwerke AG in Al Taweelah B

Steam turbines		
Number		6
Type		Extraction/condensing
Shaft speed	rev/min	3000
Live-steam conditions	bar/°C	93/535
Max. cogenerated steam heating for desalination	Gcal/h	170
Max electrical output		
full desalination	MW	122
no desalination	MW	146.5
Generators		
Number		6
Rating	MVA	175
Cooling		Air
Frequency	Hz	50

Steam for electricity and water

Six natural circulation boilers with 12 front gas burners each supply up to 650 t/h of live steam at 97 bar and 538 °C. This maximum continuous output is demanded from the boilers whenever they have to work in 'twin unit mode', ie when together they have to supply steam for two desalination lines. In this mode they require 43,530 Nm^3 of natural gas with a heating value of 33,600 kJ/m^3 per hour **2**. Fuel oil (max 34,000 kg/h per boiler) is provided as standby, being supplied without delay if the gas supply should be interrupted.

Steam turbosets

The ABB double-casing, extraction/condensing turbines are designed on the one hand for optimized production of fresh water over the whole year and on the other to meet the fluctuating seasonal demand for electricity. The turbines are designed for 122 MWe in extraction/condensing mode with 100 percent heat extraction (198 MJ/s). In simple condensing mode each of the six turbosets produces 146 MWe **3** (*Table 1*). Modern, multi-channel electrohydraulic protection and control systems, as well as the hierarchically organized unit control system and the various bypass stations, ensure high reliability and availability for the units, which are run with a fixed pressure.

ABB steam turbines – proven technology for reliable operation

Each steam turbine consists of one high-pressure (HP) and a combined intermediate-pressure/low-pressure (IP/LP) section. The live steam (156.2 kg/s) flows with a pressure of 93 bar and a temperature of 535 °C to the single-flow HP turbine with control wheel and reaction blading. Three uncontrolled extraction outlets in the HP section provide steam for the HP preheater and the feedwater tank. During controlled extraction (2.5 bar) the majority of the HP exhaust steam (89.6 kg/s) flows to the seawater desalination plant. A smaller, partial flow is for LP preheater 2; 16.3 kg/s of steam pass via two crossover pipes (top and bottom) to the single-flow IP/LP turbine. Another partial flow is taken off for LP preheater 1, while the rest is precipitated after expansion to 0.072 bar in the seawater-cooled (35 °C) condenser.

High-pressure turbine

The single-flow HP turbine is of a proven, highly robust design to ensure maximum availability. The single-shell, axially symmetrical casing with the blade carriers is split horizontally along the turbine axis and bolted together by expansion bolts. This design minimizes the thermal stresses occurring during start-up, shut-down and load changes. Cast blade carriers are used for the stator blading due to the different steam extraction pressures. These carriers are also split along the turbine axis and connected to the casing by means of expansion bolts. The axial thrust of the moving blades is absorbed by a staged balancing piston with radial labyrinth seals to prevent steam from escaping. The shafts of the HP turbines are manufactured from solid, single-piece forgings and have an integrated coupling section. Solid steel forgings are also used for the moving blades (ie, the T-root, airfoil and shroud).

Gas supply line to one of the six steam generators at the Al Taweelah B power plant **2**

IP/LP turbine

Also of single-flow design, the combined IP/LP turbine has a cast IP and a welded

LP outer casing as well as two suspended stationary blade carriers **4**. Depending on the operating mode of the turboset, the HP exhaust steam flows through the top crossover pipe, entering in front of the first blade row, and in addition through the bottom crossover pipe, entering behind the third row of blades, into the IP/LP turbine. The rotors of the LP turbines also have balancing pistons and labyrinth seals to absorb the horizontal thrust and prevent loss of steam. Unlike the solid HP turbine shaft, the shafts in the LP turbines consist of three forged steel discs, welded together with integrated coupling sections.

Bearings and lubrication

The anchor point for the shaft train of the turboset is the combined journal/thrust bearing located between the two turbine sections. The HP rotor expands in the direction of the front journal bearing, the LP rotor in the opposite direction towards the generator. Constructing the turboset in this way minimizes the axial expansion between the rotor blading and the stationary blades.

The general adoption of the 'single-bearing' principle ensures clearly defined bearing loads in all the operating ranges and under all load conditions. In this arrangement, the rotors of the turboset rest on the front-end journal bearing, the combined journal/thrust bearings between the two turbine sections and the two generator bearings.

The main oil pump, which is driven by the turbine shaft, is located in the front bearing unit and lubricates the turboset during normal operation of the turboset. The automatic turning gear, mounted on the front bearing unit, works together with the high-pressure bearing lubrication system to ensure continuous rotation of the shafts before and after load operation.

High flexibility for desalination and power generation

Each of the station units, consisting of the steam generator, turboset and seawater desalination train, can be operated in three different modes:

- 'same priority' production of electricity and fresh water
- power generation only (condensing mode)
- seawater desalination only

Besides these possibilities, any two units can be connected together, with one unit producing electricity and operating two desalination trains and the other producing electricity at maximum output. All the variants are designed to meet demand as economically as possible and ensure high reliability for the supply system. At temperatures of 45 °C in the shade, rising at times to 50 °C, keeping air-conditioning plants and water pumps running is just as important as having a reliable supply of drinking water. Relia-

View of the approximately 300 meters long power house of the Al Taweelah B plant with the six fully enclosed steam turbosets **3**

bility becomes even more important considering that each emirate in the UAE has to be able to meet its own electricity demand in isolated operation; this is because there is no UAE-wide supply network covering all the emirates at the present time.

Control system for fully automatic operation

The concept of flexible operation also has to be mirrored by the installed control system. Planned by ABB and executed by Hartmann & Braun, Germany, the chosen system is responsible for fully automatic start-up and shut-down of Al Taweelah B as well as for the control of all the different operating modes. It features separate systems for the six power station units. The top level in the hierarchical automation concept, which has five levels in all, is in each case the 'unit coordinator'. At the next lower level are the coordinators for the steam generator, the turboset, the desalination plant and the ancillaries and various drives. Below this are the function and sub-function groups, and at the lowest level the individual controlled drives.

Hartmann & Braun installed in Al Taweelah B the Contronic process control system. This system allows the complete facility to be controlled from one central control room.

Video display units provide an overview of the plant processes. More than 1,100 control and disturbance signalling circuits as well as over 4,200 drives have to be controlled and supervised, with no fewer than 10,000 signals requiring processing during plant operation.

Pushbutton start-up

The design of the control system software enables the entire plant to be started up at the push of a button, with the steam generators, turbines and desalination lines all starting in their correct sequences. The function group 'one-pushbutton operation' monitors each individual step and sets back-up systems in operation as necessary. As already mentioned, each unit can be operated separately or in combination with an additional desalination train. This involves connecting the units in the order 1 + 2, 3 + 4 and 5 + 6. Programs for all of the different modes of operation are provided in the coordinators.

Assembly work being carried out on one of the six steam turbines. Hanging from the crane is the top outer casing of the low-pressure turbine, the last blade row of which can be seen in the foreground. **4**

Example of a process sequence

In this example, starting from normal operation, units 1 and 2 are to be connected together: in unit 1 the turboset is to be operated in extraction mode and supply steam to the respective desalination train; unit 2 is to produce fresh water only.

After the interconnecting header has been prewarmed by opening the isolating valves, the injection water header isolating valves are also opened. At this stage, the operation coordinator has interconnected the steam ends of boiler units 1 and 2. The load of boiler 2 (steam production) is reduced by gradually closing the fuel control valves while the live-steam pressure remains constant.

To avoid both boilers working at the same pressure level, the output of the master controller of boiler 2 is 'frozen' through continuous supervision of the control deviation, while the live-steam pressure is controlled by the master controller of boiler 1. Due to the reduction in output of boiler 2 the live-steam pressure at the boiler outlet and in the live-steam header drops. In parallel with this, the master controller of boiler 1 increases the firing rate to ensure that the steam conditions continue to correspond to the setpoint values.

The output of boiler 2 decreases to the minimum of 130 t/h. At lower steam flow rates, the boiler can no longer be controlled, since the fuel flow control valves are closed and the firing rate can only be regulated by means of the fuel start-up valve.

Al Taweelah B steam power station in full commercial operation **5**

The minimum load of 130 t/h live steam still being supplied by boiler 2 to desalination line 2 cannot be supplied immediately by boiler 1. Because of this, the turbine bypass valves of unit 2 will gradually be opened – providing the turbine can be operated in condensing mode – until the steam output of boiler 2 corresponds to the steam flow in the turbine bypass. If this is not possible, the boiler start-up valve of unit 2 is gradually opened to 60 % to ensure that the steam produced by boiler 2 is no longer supplied to desalination line 2 prior to closing of the isolating valve 'live steam to desalination line 2'. Desalination line 2 is now supplied with live steam from boiler 1.

The boiler units supplying steam to the desalination plant also receive the condensate produced by its evaporator. The corresponding shut-off valves of the condensate header are opened as soon as the output ends of steam generators 1 and 2 have been connected together. A level check function incorporated in the shut-off valves ensures the right level in the feedwater tanks. An interlock system prevents both valves from being closed at the same time. The control system ensures that when two units are operated together the two feedwater tanks have the same levels for the same pressures.

Project management experience is essential for turnkey installations

A good idea of the size and complexity of such a project, and of the demands it made on the management team, is given by some facts and figures. First there is the sheer physical scale of the plant, with its six power generating units and six seawater desalination trains. Also, the consortium partners brought with them their own organizations, which had to be coordinated. At times, as many as 10,000 people were working on the site, all of whom had to be provided with accommodation and catered for in accordance with their religions and customs.

22,000 design drawings and documents were required just for the planning of the construction work; each individual document had to pass through precisely defined approval procedures and be certified 'ok' by both WED and the consulting engineer. All formats, notations, symbols and classification systems had to be compatible, since documents were prepared as far apart as Milan, Brussels, Mannheim and Abu Dhabi.

In order to obtain general approval of the planning from WED as soon as possible, all members of the consortium were requested to submit their schedules for deliveries immediately after the consortium had been formed. This also helped to define clear, unambiguous interfaces. Subsequent to this, ABB, as main contractor, proceeded with the design, working together with WED and bringing in the consortium partners as they were needed. Several hundred minutes of reports describing some 1,500 commitments, initialled by the customer and his consulting engineer, were necessary before the layout could be sanctioned and orders placed with sub-contractors.

All the participants began their detailed planning on the basis of this conceptual design. For each subsystem lists were drawn up which defined exactly who had to prepare which documents, what they had to contain and when they were to be supplied, plus which documents had to be submitted, appropriately signed, to the consulting engineer. Some 15,000 documents were finally needed.

Scheduling and progress reports

An agreement between WED and ABB called for a monthly report of the progress being made on the construction site. These reports were to be submitted to WED, the consulting engineer and all consortium partners. Weekly reports and previews, prepared by the site management, supplemented the monthly report and showed up schedule violations or warned of their possibility.

Individual schedules drawn up by each of the consortial partners for the planning of their own work were coordinated by ABB into a 'Master Time Schedule' (MTS). 400 sequences of operations, the 'milestones' of site progress, as well as the assembly work most critical to scheduling, were contained in the MTS, which allowed a comparison of the reference and actual dates, etc, at any time. A second, more detailed time schedule comprised some 3,500 individual jobs, including the preliminary design, manufacturing and delivery schedules, and the erection and handover data. Each of the consortium partners was also responsible for drawing up and monitoring his own time schedules with his sub-contractors.

Quality assurance

Stringent quality standards were specified for Al Taweelah B and were binding for all the consortium partners. Inspection and test programmes, with the respective time schedules, provided the basis for the consortium and allowed WED to review the separate components and materials before they left the manufacturers' works. The components and systems were released after special inspection certificates had been signed by the consulting engineer. In all, the quality assurance documentation, with all the inspection reports and certificates, filled more than 2,500 files.

Erection and commissioning

It is essential for any large-scale project such as Al Taweelah B to keep precisely to all the agreed delivery and assembly time schedules. A delay in the delivery of a single component automatically causes delays in the overall process. If the basic schedules along the critical path are threatened, the project manager has to intervene immediately and introduce counter-measures. For example, components may have to be transported by air rather than by sea, as originally planned, to save costs, even if this means specially chartering a wide-bodied aircraft. Taking the broader view of the project and possible penalties, such decisions tended usually to be the more economical option.

Experienced commissioning engineers took charge of the start-up of the power station units and the individual components and systems. Specialists, who know the problems that can occur and where they will be located, were able to make decisions quickly and improvise when necessary. Their understanding of how assembly crews work was also a great advantage on the Al Taweelah B construction site, where workers from 40 different nations were employed.

Availability and guarantee periods

Successful trial operation of the first power station unit in June 1996 was followed by trial runs of the other five units, on average at intervals of one to two months.

In the meantime, the units are producing electricity and drinking water with high reliability **5**. Demand for electrical energy rose to the design capacity during the summer months, reaching 7.8 million MWh by the end of July 1998.

Drinking water was produced over the whole year almost continuously at the upper limit of production capacity – being restricted only by the contractually agreed inspections and the capacity of the water transportation network. Total production by the end of July 1998 was 174 million m^3 of drinking water.

All six power plant units, including the ancillaries, are working to the full satisfaction of the owner. On the basis of this, WED prepared all of the preliminary acceptance certificates. The plant is currently running under guarantee.

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