Compact, medium-size combined cycle plants for cogeneration

Combined cycle power plants today achieve efficiency figures of between 50 and 58 percent, with cogeneration facilities posting fuel utilizations of almost 90 percent. These characteristics, plus low first-time costs and short construction times, make medium-size combined cycle plants an interesting option for decentralized power and heat production. The heart of such plants is the GT10 industrial gas turbine, a rugged, lightweight unit rated at 25 MW that has become a market leader in recent years in the medium power class.

Ever since ABB built the world's first combined cycle plant in 1956, this technology has been dominated by the development of ever-larger gas turbines with increasingly higher combustion temperatures for improved cycle efficiencies. Combined cycle plants are now able to offer efficiencies of between 50 and 58 percent, with the possibility of 60 percent being reached within the next few years.

Even at 58 percent efficiency, 42 percent of the thermal energy is wasted. This energy mainly consists of low-data steam/water which cannot be utilized in steam turbines. However, by using it to produce industrial process steam or steam/hot water for district-heating networks, a total fuel utilization of around 90 percent can be obtained. An example is the ABB combined cycle cogeneration plant supplied to the municipal utility in the town of Ängelholm in Sweden. When operating in district-heating mode, this plant exhibits a fuel utilization of 87 percent. In a cold-condensing application, ie one in which only electrical energy is produced, this medium-size plant would run with a net electrical efficiency of 50 percent 1.

Compared with the enormous improvement in fuel utilization of a combined cycle cogeneration plant over a combined cycle plant used purely for power generation, the efficiency advantage of a large combined cycle plant over a medium-size one is relatively small. Since heat cannot be transported over long distances, it is usually more economic to build a number of smaller-scale combined cycle cogeneration plants near the heat consumers rather than one very large, central plant, as might be the case when only electricity is to be generated 2 [1].

This has been a key factor in the transformation of a technology which was once considered to be mainly suitable for very large gas turbines and steam turbines. The last decade has seen a sharp rise in the number of combined cycle plants rated from 20 to 50 MW being installed across the world in a variety of applications.

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Distributed generation

Cogeneration is not, however, the only reason for the rising use of smaller-scale combined cycle plants. A crucial role is being played by the worldwide deregulation of the electrical power industry that is taking place, and which has created new opportunities for decentralized and independent power production.

As a result of deregulation, large industrial power users have been able to realize considerable cost savings and boost revenues by installing either combined cycle cogeneration or pure cogeneration plants. Heat-intensive industries, such as paper, oil and chemicals, can benefit from having their own cogeneration plants. Even where the need for heat is greater than that for electricity, a relatively large power generation capability might be considered, since income from the sale of surplus electricity can shorten the payback time significantly.

ABB has supplied cogeneration plants to oil refineries around the world. One is the power plant at a refinery in Corinth, Greece. It uses waste gases to generate process steam and power for its own use, and exports surplus electricity to the public grid 3.

The new regulatory environment has brought about major structural changes in the power supply industry. For example, companies which previously only distributed electricity – these include municipal utilities – have now gone over to generating it in relatively small-scale plants.

In the Swedish town of Linköping, the public service corporation, *Tekniska Verken i Linköping AB*, recently converted its

GT10 combined cycle plant at Ängelholm, Sweden **1**

waste-fired heat plant at Gärstad into a combined cycle cogeneration plant **4**. When the plant was built in the early 1980s there was little economic incentive for *Tekniska Verken* to generate its own electricity, so no steam turbine was installed. Following the installation of a gas turbine and steam turbine, the plant's thermal output has increased from 73 MW to 83 MW, with an additional 49 MW of electricity being generated. The current high price of electricity in Sweden has made the upgrade good economic sense.

Large utilities have also developed new strategies in order to compete in the new environment. Some power companies have become energy providers. For example, the Dutch utility *PNEM* recently installed three ABB combined cycle cogeneration plants **5** which supply heat under long-term contracts to the Heineken brewery at Hertogenbosch, a Philip Morris plant at Bergen-op-Zoom, and a fertilizer plant at Helmond.

In 1996, ABB handed over two combined cycle cogeneration plants to *Gas-Edon, Emmen*, a joint venture between *Gasunie* and *Edon* of the Netherlands, at its Erica and Klazienaveen power stations. The heat generated is being supplied to local commercial greenhouses. In all of these projects the proximity of large customers for heat/steam has been critical for their economic viability.

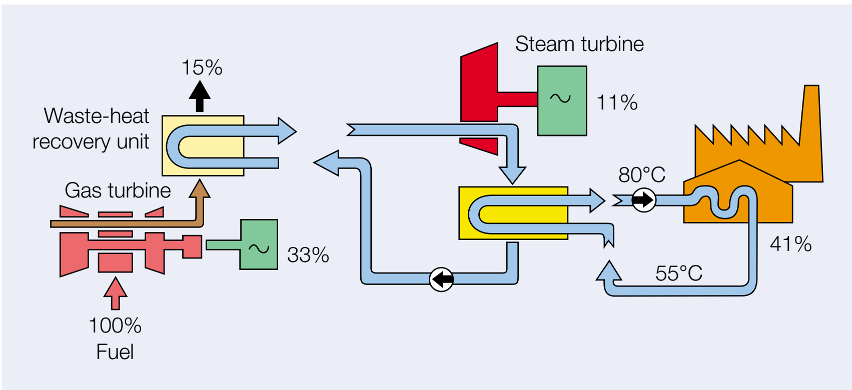
Another important development has been the growing interest in the concept of distributed power, particularly in the deregulated US power market. The main advantages of this include the avoidance of costly investment in transmission infrastructure and the reduction of transmission losses. Even without cogeneration, medium-size combined cycle plants offer a number of advantages to utilities. Construction costs are relatively low and the plants are very flexible in operation: different types of fuel can be used and start-up times are short.

The result of the trend towards decentralized power generation and cogeneration has been a growing demand for medium-size combined cycle plants. As the technology and the market develops, it is anticipated that other opportunities will emerge, such as on islands and large offshore platforms as well as on cruise ships and fast cargo ships with electric propulsion systems.

GT10 gas turbine

All the combined cycle cogeneration plants mentioned above are built around the GT10 gas turbine, which has become

The combined cycle cogeneration concept **2**



Cogeneration plant in a refinery in Corinth, Greece, equipped with 2 type GT35 gas turbines **3**

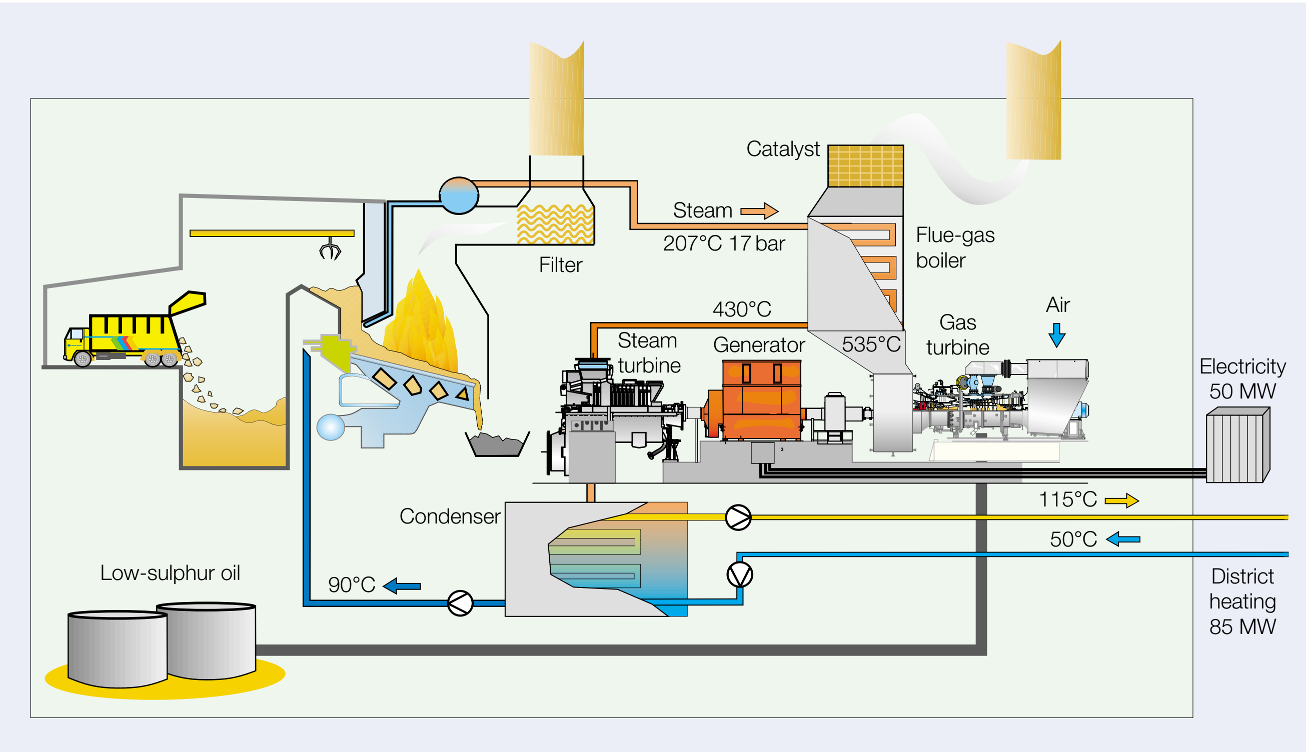
a market leader in medium-size applications over the last few years. The GT10 is a lightweight, heavy-duty industrial gas turbine rated at around 25 MW with a 34 percent open cycle efficiency. Combined cycle efficiency is just over 50 percent. It utilizes ABB's dry, low-NO_x combustor system, resulting in 25 ppmv No_x at 15 % O_2 and low emissions of CO and UHC (unburned hydrocarbons).

The robustness of the GT10 makes it suitable for long, continuous operation. Availability is high due to the long time between overhauls and the modular design, which allows servicing to be carried out on site. For example, the combustion chamber can be replaced as a module to reduce the lifting weight during maintenance **6**.

Improved economy

One inherent problem of smaller plants is their relatively high cost per unit of capacity. To make its medium-size com-

Gärstad combined cycle plant in Linköping, Sweden. Schematic showing the plant, with a GT10 gas turbine, integrated in the waste incineration plant **4**



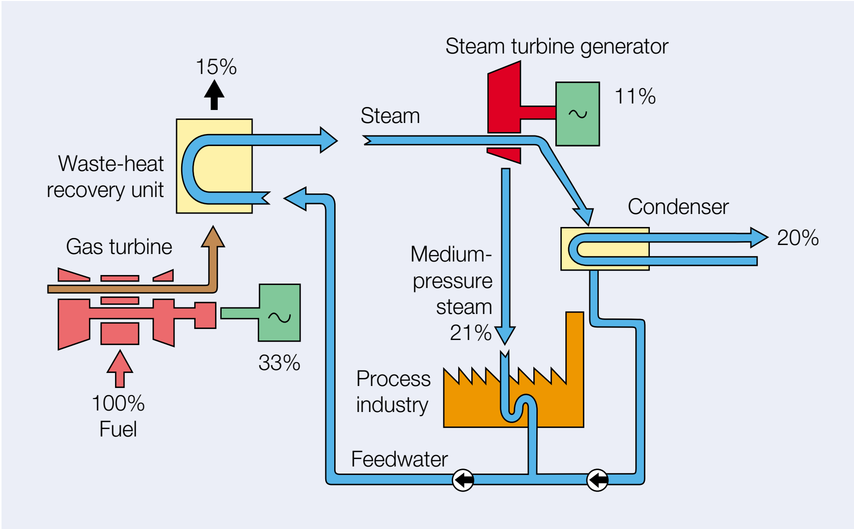
bined cycle plants as economical as possible for the operators, a number of technical solutions have been introduced by ABB STAL.

The manufacturing and erection procedures have been rationalized in order to minimize start-up costs and delivery times. For example, the cogeneration plant for the town of Ängelholm was in commercial operation just 15 months after the order was placed. Many of the components used by ABB in combined cycle plants are standardized or are modular, ensuring both high reliability and low costs. Each customer, site and application is different, and plants are therefore tailored to specific circumstances. Generally speaking, it is easier to tailor small-scale plants than large-scale ones to individual applications.

An important factor which must be taken into account when designing combined cycle plants is the lack of space at many users' sites, which are often located in established industrial areas. Sometimes, the plants have to be fitted into existing buildings in order to minimize construction costs. Work aimed at reducing the plant 'footprint' has led to various solutions, such as the single-string layout concept **7**.

Single-string and multi-string arrangements

When ABB STAL started to look into optimizing the layout of the GT10 combined cycle plant, the experience the company had gained from its steam turbine plants proved to be useful. One of the VAX (geared, axial-flow) steam turbine applications utilizes a high-pressure and a low-pressure steam turbine driving a common generator, one from each end, in a so-called 'single-string' arrangement. Since the high-pressure steam turbine generally operates at a higher speed than the low-pressure unit, a gearbox is used between the high-pressure turbine and the generator.



GT10 combined cycle cogeneration concept, as applied by PNEM in plants in the Netherlands **5**

In a combined cycle, single-string layout, a gas turbine and a steam turbine share a generator which is driven from each end **8**. This solution is not unique, but for the smaller range of plants it has not been common **9**.

Generally, the gas turbine must be geared down to the speed of the gener-

Assembly of the GT10 combustor **6**

A GT10 gas turbine being lifted into an existing building on the premises of the Massachusetts Institute of Technology in Boston, USA. **7**

ator. Although this entails losses of around one percent, they are more than offset by the fact that smaller turbine diameters can be used, so there are fewer losses within the turbine, resulting in higher efficiency for the system as a whole.

ABB STAL has a long tradition of supplying gears for marine and mechanical drive applications as well as for use in power plants. In typical combined cycle, single-string arrangements, the gearboxes which are used are relatively simple, small-scale units that utilize parallel, rather than epicyclic, gears.

One of the advantages of the single-string arrangement is that the layout becomes more compact. The space saved is significant, being typically around 10 percent. This has a positive impact on costs, since both foundations and buildings can be reduced in scale.

A single, large generator is less expensive and more efficient than two smaller generators. The cost of the ancillary electrical equipment is also reduced for a one-generator design. In particular, the high-voltage equipment required for a single-generator arrangment is less than that required for two units, even if the power level is higher.

In cases where one gas turbine and one steam turbine are involved, the single-string arrangement is usually the most economical. When more than one gas turbine is used, however, the situation is different because the saving is greater when one steam turbine is used instead of two.

When two gas turbines have been installed on the same site, it has generally been found that the least expensive solution is to equip one of the gas turbines with a generator which is also driven by the steam turbine common to the two units, and with the second gas turbine driving its own generator **10**.

There are, of course, exceptions to this, and in Germany ABB has built a number of plants with two gas turbines and two steam turbines around standard single-string units.

When a plant is to have more than two gas turbines installed in it, the single-string concept anyway becomes less attractive. The KA10-3 combined cycle plant in Rostock, Germany, for example, has three standard GT10 gas-turbine generator units, each with one boiler, with a free-standing steam-turbine gen-

GT10 combined cycle, single-string installation **8**

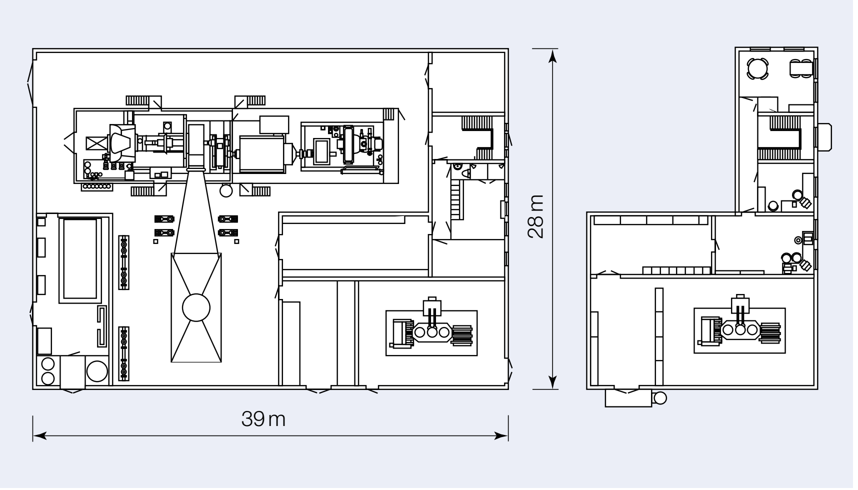
erator receiving steam from all three units.

Calculation of the rotor dynamics

A consequence of the single-string arrangement is that the rotor strings can be quite long. In the GT10 combined cycle plants for *GasEdon, Emmen*, for example, the gas turbine drives the generator via its standard gear from one end while a train of two steam turbines drives the generator from the other end. The steam turbines comprise one medium-pressure unit (MP10) and one low-pressure unit (LP10). The LP10 drives the generator direct, while the MP10, which runs at a higher speed, is connected to the back of the LP10 via a gear. These rotor systems are around 30 m in length.

A long rotor string will usually have more resonance speeds, which will have to be taken into account to avoid running into critical speeds. It is therefore necessary to carefully calculate the rotor dynamics in order to ensure that each string works without any problems. Some manufacturers buy in this expertise from outside, but ABB STAL undertakes the work itself. The use of in-house expertise means that the company can always provide fast and appropriate support for the customer.

The experience gained by ABB STAL during construction of nuclear plants in Finland and Sweden during the 1970s has made the company a storehouse of knowledge for the calculation of rotor strings up to 70 m long. Other important know-how stems from the experience the company gained from its earlier marine steam turbine activities. In more than 300 AP-type marine propulsion systems, two steam turbines were coupled to a propeller shaft via epicyclic gears, long, slim shafts and a large parallel gear. More recently, added experience has come from the VAX steam turbine range.

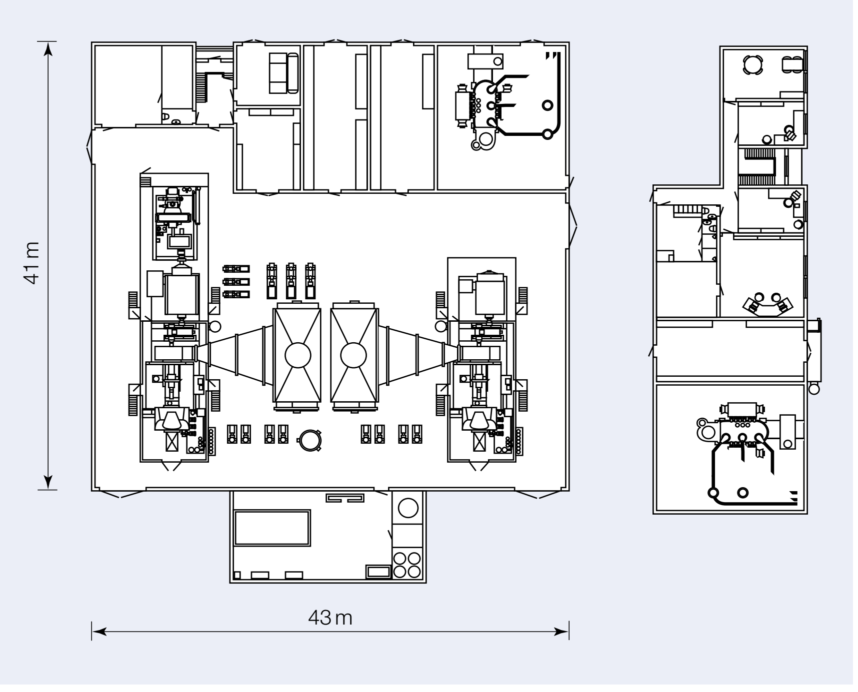


Standard layout showing one GT10 gas turbine and one steam turbine in a single-string arrangement **9**

On the basis of this experience, ABB STAL, which is also the ABB Group's 'Center of Excellence' for the calculation of rotor dynamics, has developed software to handle rotor string calculations. The ability to calculate, within the same program module, the torsional and bending behaviour as well as the impact on the rotor systems of two-phase and three-phase short circuits in the generator represents the cutting edge of this technology.

The fact that the rotor train in a single-string, combined cycle plant comprises a number of separate components makes the calculation process easier in some re-

Plant layout showing an arrangement with two gas turbines and one steam turbine **10**



A VAX steam turbine installation with the high-pressure turbine and gear on one side of the generator and the low-pressure steam turbine and condenser on the other **11**

spects, but the alignment becomes more critical. Flexible couplings are used at some points, for example between the turbine rotors and gears, in order to take up some dislocations which cannot be avoided entirely. The vibration monitoring equipment for the GT10 is of the simple accelerometer type and is very reliable in operation.

Smooth operation of the train depends on careful balancing of the various rotor parts. ABB balances all of its rotors at operating speeds in its own balancing facility. To this end the pits have to be evacuated to nearly absolute vacuum. Balancing at the operating speed ensures smooth running.

Since the entire rotor string cannot be balanced in the workshop, capability for balancing in the field is essential. The GT10 is equipped with five balancing planes which are easily accessible. Field balancing of the steam turbines is also possible when required. ABB has, over the last two decades, refined the art of field balancing, not only of turbines but also of motors and generators.

The bearings in the GT10 combined cycle plants are all of the hydrodynamic type, ie with tilting pads in the turbines and sleeves in the gear and generator. These oil film bearings have a self-damping function, ensuring smooth operation and minimizing the attention that needs to be given to them. In contrast, the aero-derivative gas turbines utilize the non-friction type of bearing – ball and roller bearings – with external oil dampers sometimes being fitted to ensure smoother running.

Operating experience

Operating experience with ABB STAL's single-string plants of all types has been extremely good.

The experience with the very long turbine strings built by ABB for Finnish and Swedish nuclear plants has been excellent, and no rotor problems have been encountered. In terms of reliability, these plants head Nuclear Engineering's list of plants worldwide, with those in Finland at the very top.

Experience with long shaft strings in the VAX installations is also very good. Only minor problems have occurred. In some cases, for example, gears have had to be repaired. The first VAX installation entered service in 1984 and currently well over 100 units from the VAX range are in operation worldwide, with a total of over five million operating hours so far accumulated **11**.

Single-string, combined cycle plants having been available for a shorter time, experience with them is more limited. Today ABB has around 30 installations of this type in operation, the accumulated operating hours totalling about 300,000. The lead installations, such as that at Ängelholm in Sweden, have so far accumulated over 25,000 operating hours. The single-string arrangement is therefore well established in ABB medium-size combined cycle plants.

Outlook

The successful development of innovations such as the single-string concept has helped to improve the economic profile of medium-size combined cycle plants. It is anticipated that this will contribute to the growing proportion of global power capacity accounted for by these plants at a time when great opportunities are being created by the continuing deregulation of the world's power markets.

Reference

[1] B. Svensson: Environmentally sound combined cycle and cogeneration plants. ABB Review 5/93, 11–18.

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