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Huntorf Air Storage Gas Turbine Power Plant

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ENERGY SUPPLY

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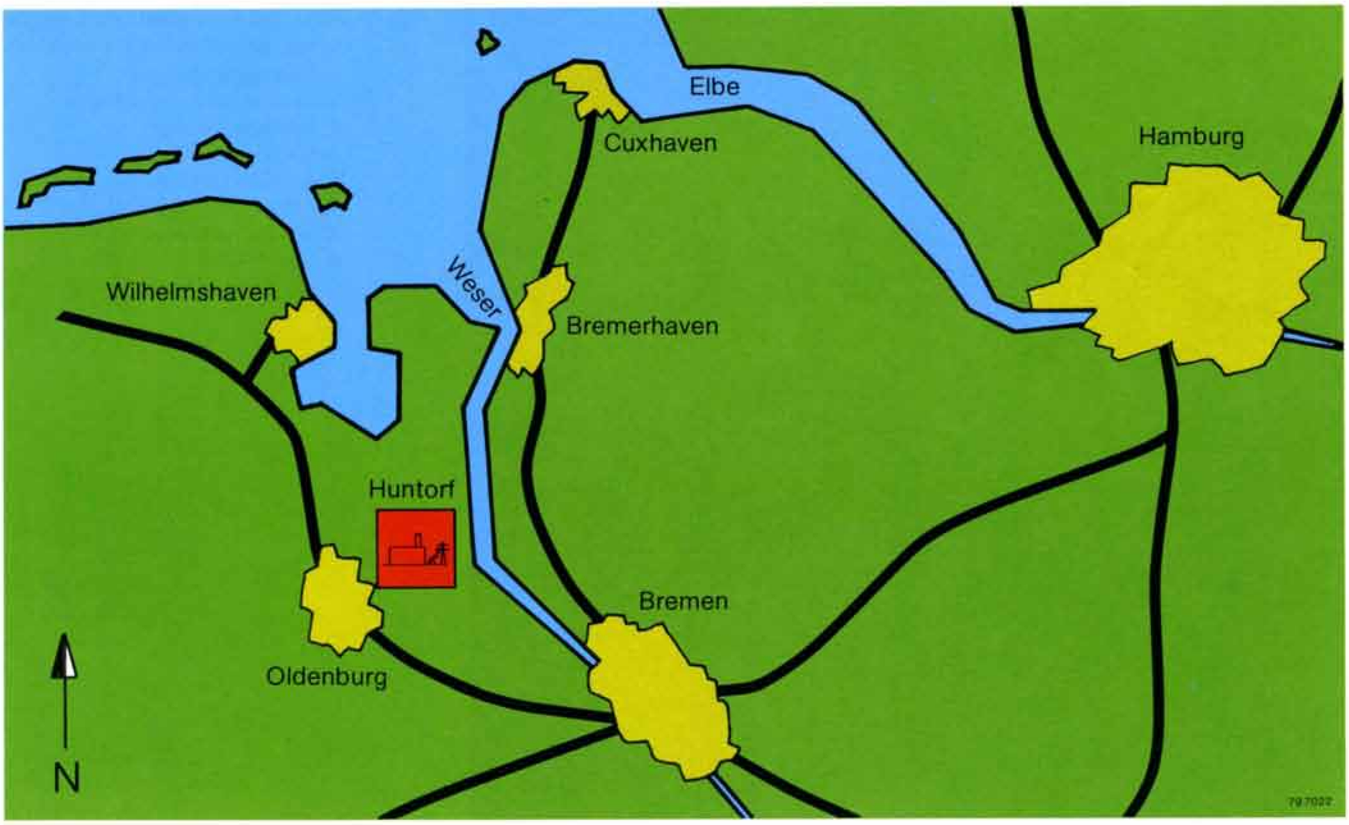


Fig. 1 The first air-storage gas turbine power plant in the world is situated near Huntorf, Niedersachsen, approx. 30 km north west of Bremen.

The first air-storage gas turbine power plant in the world, situated at Huntorf, Niedersachsen, was commissioned at the end of 1978. The plant utilizes high pressure compressed air stored in salt caverns for the combustion process of a two stage gas turbine, and enables an economical form of peak energy to be produced.

The utility operating the 290 MW Huntorf Power Plant is the Nordwestdeutsche Kraftwerke AG, Hamburg.

BBC Mannheim designed the plant, and supplied the turboset as well as the electrical equipment.

1. Peak-load Power Plants

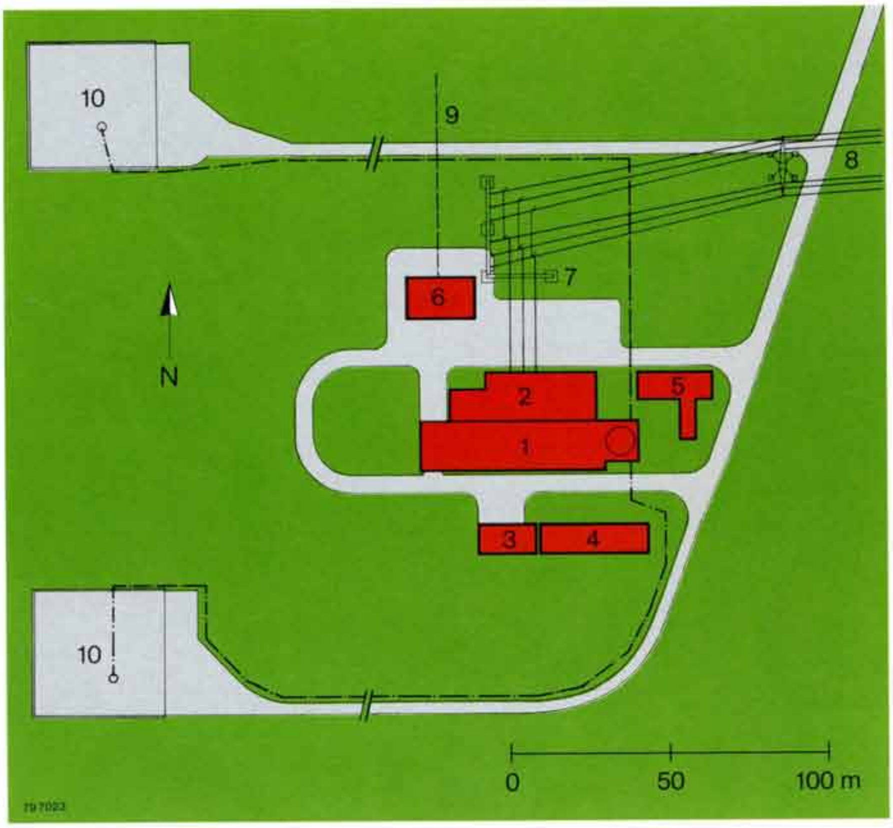


Fig. 2 Site plan of the Huntorf Power Station

1. Turbine House
2. Switchgear Building
3. Cooling Water Pumphouse
4. Refrigeration Plant
5. Entrance Building
6. Auxiliary Building
7. 220 kV Outdoor Switchgear
8. 220 kV Transmission Line
9. Gas Pipeline
10. Air-Storage Caverns

Utilities state the following demands for peak-load power plants: The plants must be readily available for operation and must exhibit a high reliability and availability. In addition, a simple method of control and maintenance is required.

Until now the utilities have used conventional gas turbines and hydraulic pumped storage schemes for peak lopping purposes. In this respect the hydraulic pumped storage power station, in addition to the high power output, offered the additional advantage over the conventional gas turbine in producing the possibility of displacing the peak power generating periods during times of low load demand. This means that excess power produced during low load periods may be utilized for storage purposes and then returned to the system during peak load periods.

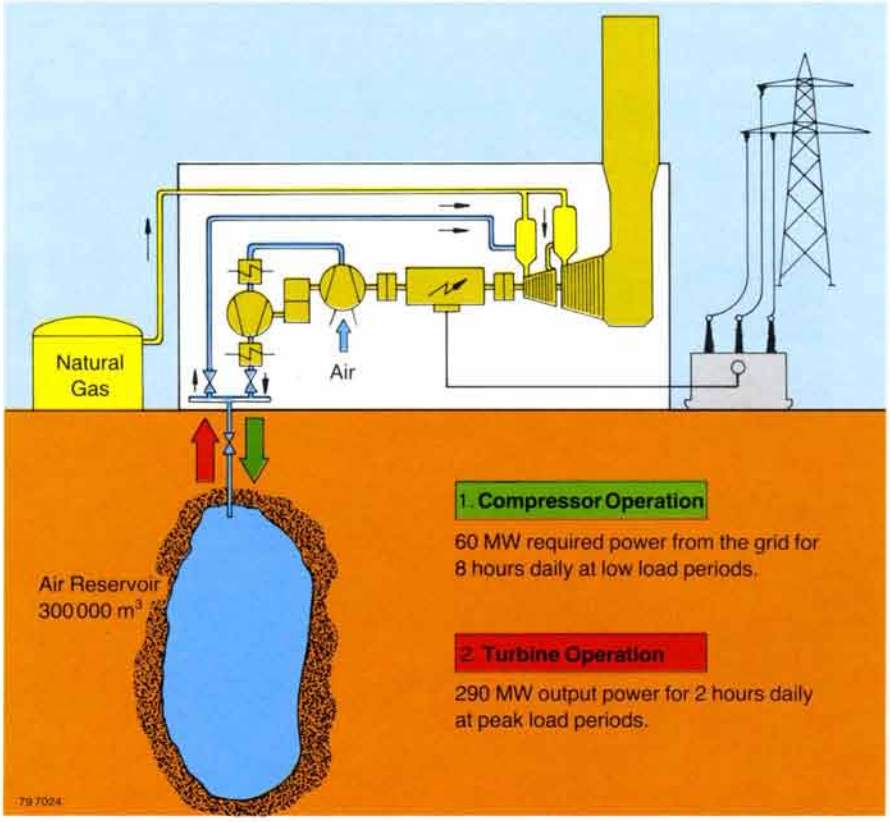
However, up till now, these advantages must not only be counterbalanced with the higher capital costs as opposed to the conventional gas turbine, but also with the location, since a difference in geodetic height is necessary for a hydraulic pumped storage power plant. These conditions have therefore, up to the present, imposed a restriction on the advantages of energy storage in areas having flat terrains.

The commissioning of the first air-storage gas turbine power plant in the world at Huntorf has fulfilled for the first time the desire of having a storage power plant in flat areas. This power plant has the common advantages of peak load gas turbine power plants and that of pumped storage schemes.

In contrast to conventional gas turbine operation, the air-storage gas turbine compresses and expands the working medium air at different times. This separation offers the advantage of having the entire power of the gas turbine available for useful power during periods of peak load demand, whereas the energy for compression may be taken during low load periods.

2. Operation of the Huntorf Air Storage Gas Turbine Power Plant

Fig. 3 Operating modes of the Huntorf Air-Storage Gas Turbine Power Plant



The Huntorf power plant operates on the same principle as traditional pump storage plants. The storage medium is, however, air, instead of water. The air is pumped into two caverns which have a total volume of approx. 300 000 m³. The caverns are formed by leaching out salt deposits which lie between about 650 m and 800 m below the earth surface. During periods of peak load demand, the high pressure stored air in these caverns is used for the combustion processes in a two stage gas turbine. A generator is then driven by the turbine to produce the electrical power.

Both of the following operating modes – Compressor Operation and Turbine Operation – are provided for the normal case. Other possible operating modes are described under Start-Up Behaviour.

Compressor Operation

During the low load periods of the base load power plants i.e. usually at night, the generator/motor operates as a motor taking low-cost power from the grid to drive the compressor. This takes in air from the atmosphere, compresses it, and then delivers it to the underground store.

The air storage caverns in Huntorf are operated in sliding pressure mode, which allows a max. of 10 bar/h discharge during a two-hour turbine operating period. The pressure range is thereby 20 bar, the pressure in the store slides. Charging takes approx. 8 h. After completion of the charging process the air pressure in the storage caverns is max. 72 bar.

Turbine Operation

The stored energy is used during the periods of peak load demands, mainly midday and evening, to supply the gas turbine with precompressed air. It flows with a reduced pressure of 42 bar into the high pressure combustion chamber of the two-stage gas turbine where it is heated by the combustion of natural gas. The combustion gases flow into the high pressure section of the turbine which drives the generator now coupled. The combustion gases, which are still rich in oxygen, leave the high pressure part of the gas turbine and enter the tandem low pressure combustion chamber. Combustion of natural gas reheats the combustion gases which are then further expanded down to atmospheric pressure in the low pressure section of the turbine. Following this process the combustion gases leave the stack through a silencer.

3. Plant Concept

The Nordwestdeutsche Kraftwerke AG, Hamburg, built the first air-storage gas turbine in the world over a salt deposit near Huntorf in Niedersachsen between Bremen and Oldenburg, West Germany. The 290 MW power plant took up commercial operation at the end of 1978.

BBC Mannheim received the contract to design the power plant equipment, and to supply the 290 MW gas turboset as well as the heavy electrical and process control equipment. Construction of the cavern equipment was carried out by Kavernen Bau- und Betriebs-GmbH, Hannover (KBB).

Design

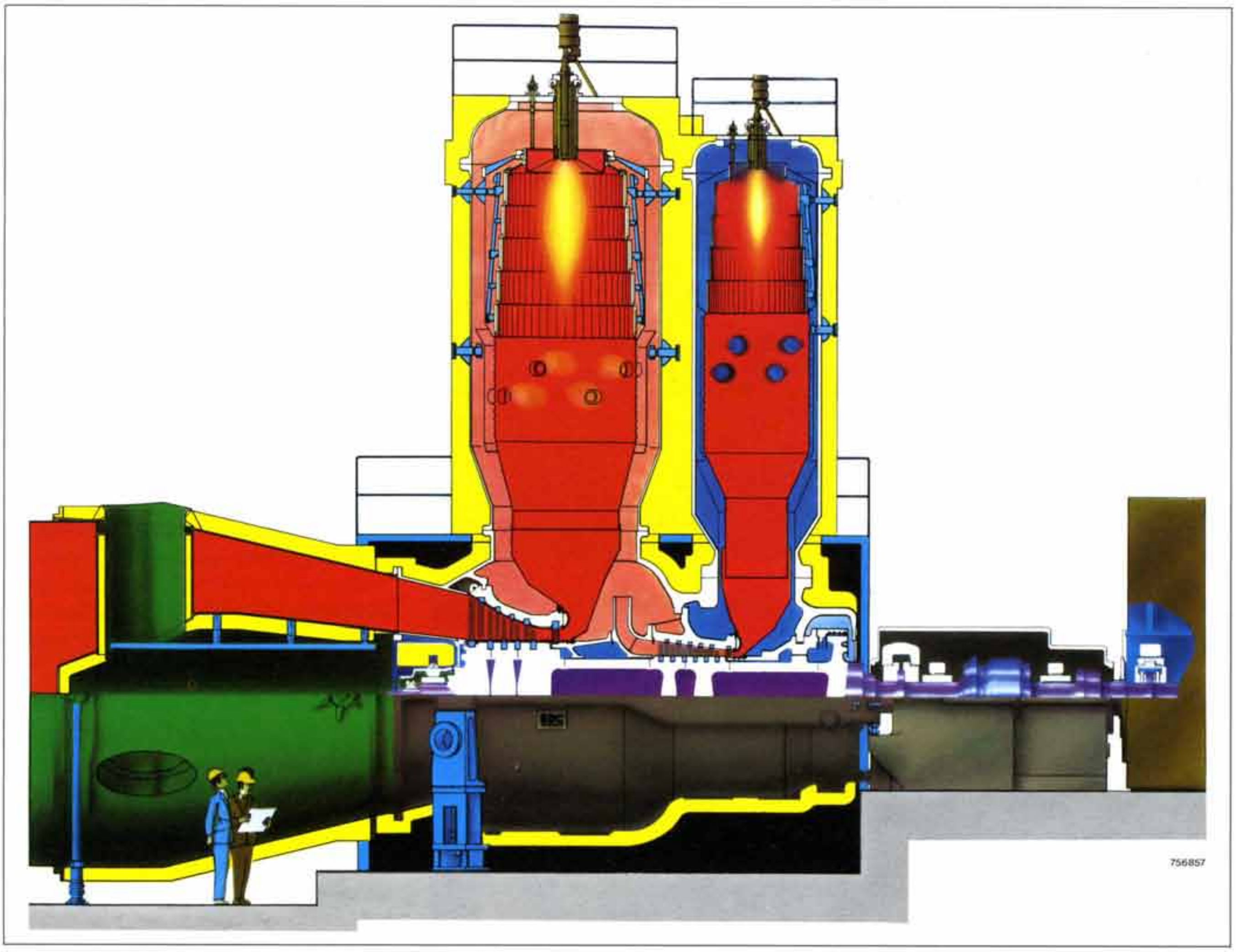
The Huntorf plant is designed for a daily peak power generation of 2 hours full load operation of the turbine. The compressors recharge the air storage caverns during 8 hours operation. It follows from this, that the compressors have only been designed for a quarter of the air consumption of the turbine, and the charging ratio is 1 : 4.

Two air storage caverns having a total volume of 300 000 m^3 were created in a salt deposit by means of a leaching process. The volume, and thereby the plant costs, are not only dependent on the designed number of full load operating hours of the turbine, but also on the pressure and temperature of the air in the storage cavern.

Investigations into optimisation of the plant resulted in the plant having the best economic performance with storage pressures between 46 and 66 bar. At these pressures the relationship between useful work and pumping work is at an optimum. Above this pressure range the specific fuel consumption is lower but the size and investment costs for the equipment are considerably higher. Below 40 bar the storage volume and the turbine are larger and the manufacturing costs are higher.

Fig. 4 Cavern Head of the Huntorf Power Plant: The compressed air flows from the cavern heads of both air stores through a 300 m long pipeline to the power plant.

Fig. 5 290 MW Huntorf Air Storage Gas Turbine



Economics

The useful power produced by the Huntdorf plant is approx. three times larger than in conventional gas turbine power plants because of the different times at which compression of the combustion air and driving the turbine can take place. Normally, these two processes are simultaneous. A gas turbine of the traditional form requires approx. 60 % of the turbine power to drive the compressor. Only 40 % is converted to electrical power.
In Huntorf, the entire power of the turbine is utilized for electrical power generation.

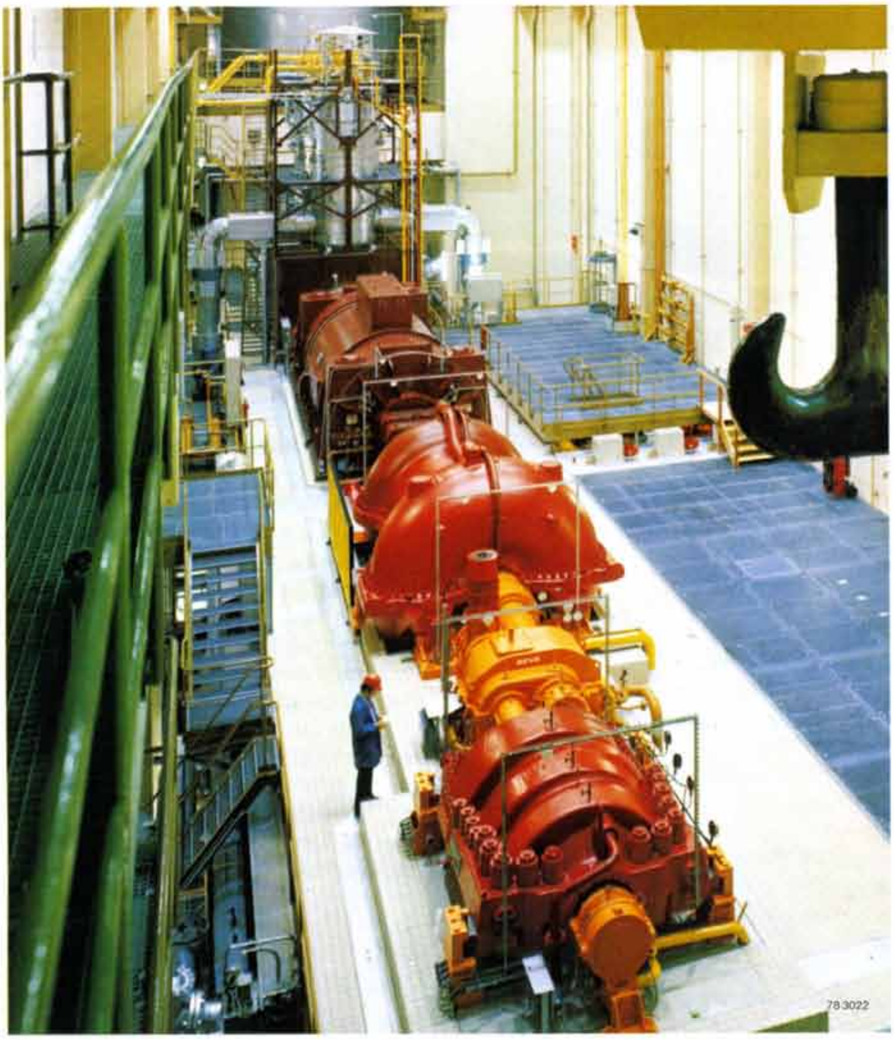
A further advantage of this method of operation is that the useful work of the plant is, according to the compressor and type of storage, 20 % to 45 % more than the pumping work applied. This is due to the introduction of the fuel, and thereby the heating of the air in the combustion chambers. Hydraulic pumped storage schemes must, in contrast, consume approx. 25 % more power than they later return in peak load generating periods.

The air-storage gas turbine power plant also has the advantage of having a considerably lower capital investment than that of the hydraulic pumped storage plant.

290 MW Gas Turbine

The Huntorf power plant incorporates a simple thermodynamic process and construction of the turbomachinery, whereby well-known and applied components are used.

The compressed air from the storage caverns flows with a reduced pressure of 42 bar into the high pressure combustion chamber of the turbine. This inlet pressure, for an air-storage gas turbine power plant, lies considerably higher than for conventional gas turbines, which work around 11 bar.



Extensive investigations concerning the possible designs of the turbine resulted in two especially economic ways of connecting the process:

- Since the well-proven BBC Type 13 gas turbine is used as low pressure section, an up-stream connection of a high pressure combustion chamber and high pressure turbine is necessary. In this way, 290 MW power output is achieved by almost 5800 kJ/kWh specific heat rate.
- If the air leaving the storage cavern is heated before it enters the high pressure combustion chamber, by means of an air preheater operating on low pressure turbine exhaust gases, then, for a comparable plant of 285 MW power output, the specific heat rate is 4600 kJ/kWh.

The Huntorf power plant operates without air preheater since the plant design was to be maintained as simple as possible.

Whereas a proven gas turbine model operating on a pressure drop of 11 bar to 1 bar was available, a high pressure turbine operating on a pressure drop of 42 bar to 11 bar had to be adapted for which there was no forerunner. Since the steam turbines work on an analogue principle, BBC designed the high pressure turbine on "steam turbine engineering" practice, i.e. the turbine inlet pressure is only 550 °C as opposed to 825 °C for the inlet temperature of the low pressure turbine. The gas inlet conditions for the high pressure turbine of 42 bar at 550 °C are a common feature of steam turbine construction. By means of this concept, both parts of the gas turbine plant could adopt proven techniques.

Fig. 6 Workshop assembly of the 290 MW gas turboset

Fig. 7 Turbine House of the Huntorf Power Plant

Compressors

The results of petromechanical investigations allowed the utilization of the air storage in Huntorf as a sliding pressure reservoir, which permits a maximum pressure gradient during turbine operation of 10 bar/h.

During 2 hours turbine operation at full load the pressure in the storage cavern falls around 20 bar.
During recharging the storage with the compressors, the pressure in the cavern and thereby the compressor pressure, rises during the 8-hour charging period by around 20 bar.

The compressor set comprises a LP axial compressor and an HP centrifugal compressor. To achieve the smallest possible power requirement for the compressors, which lies around 60 MW, intermediate coolers are arranged in the compression process. In addition, the air is cooled in an aftercooler down to 50 °C before entry into the cavern. This temperature corresponds to approx. the salt wall temperature of the cavern.
A gearbox converts the LP compressor speed from 3000 min^{-1} to 7622 min^{-1} for the HP compressor.

Generator/Motor

The entire gas turboset is designed as a single-shaft machine. A generator/motor, designed for two types of operation, is arranged between the compressors and the gas turboset. As a generator it has an apparent power of 341 MVA at a voltage of 21 kV. It serves as a motor to drive the turbine.

These two different modes of operation are made possible by an overriding clutch between the turbine and generator/motor on the one side and the generator/motor and compressor set at the other side.

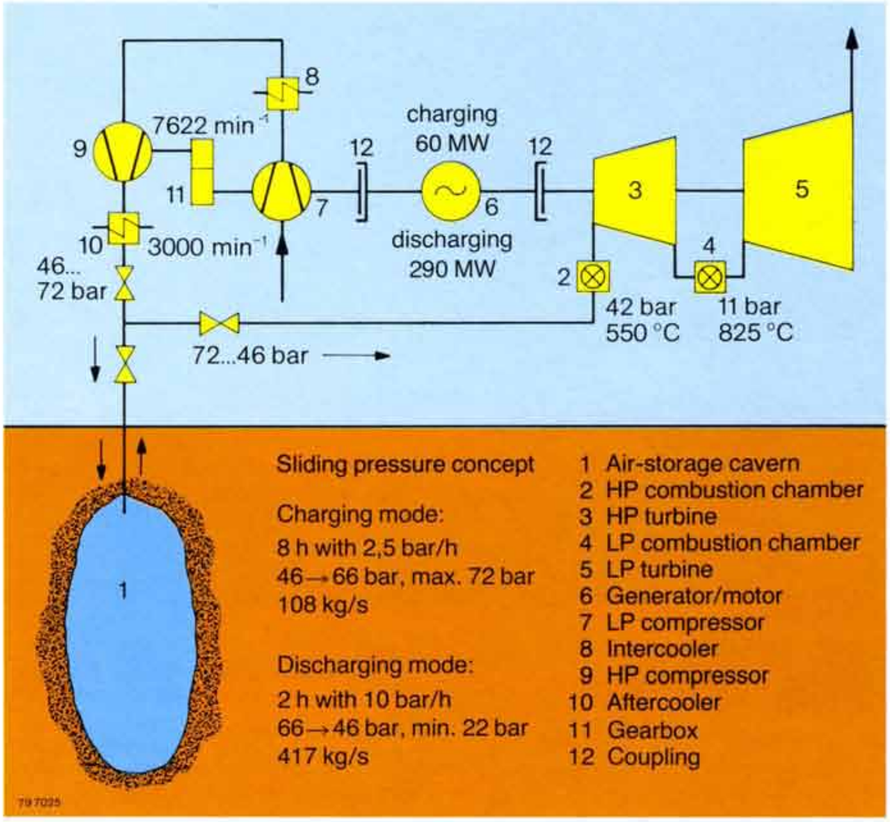


Fig. 8 Schematic with operating data of the air-storage power plant

Fuel

Natural gas serves to warm the air coming from the storage cavern in the two combustion chambers. Reducing stations expand the air to both combustion chambers down to the required pressure of approx. 50 bar and 15 bar. Alternatively fuel oil may be used as fuel.

Process Control

The Huntorf power plant is designed for fully automatic remote control operation; it can therefore run without operating personnel.
Remote supervision of the plant is carried out at the NWK-Power Station Farge, near Bremen. Selection may also be made from Farge for the remote control by means of the NWK load dispatching station situated 150 km away at Hamburg-Harburg.
Considerable differences exist between controlling an air-storage gas turbine and a conventional gas turbine. Load control on a conventional machine is carried out by adjustment of the fuel quantity. Whereby the air flow remains almost constant. This results in a relatively high heat consumption at partial loads.

In contrast to this, the air-storage gas turbine has the air flow adjusted according to the power requirement, and the inlet temperature of the high pressure turbine as well as the exhaust temperature of the low pressure turbine are controlled to a constant value. Partial load heat consumption is therefore considerably better, which leads to the air-storage gas turbine being economically suited for load control applications.

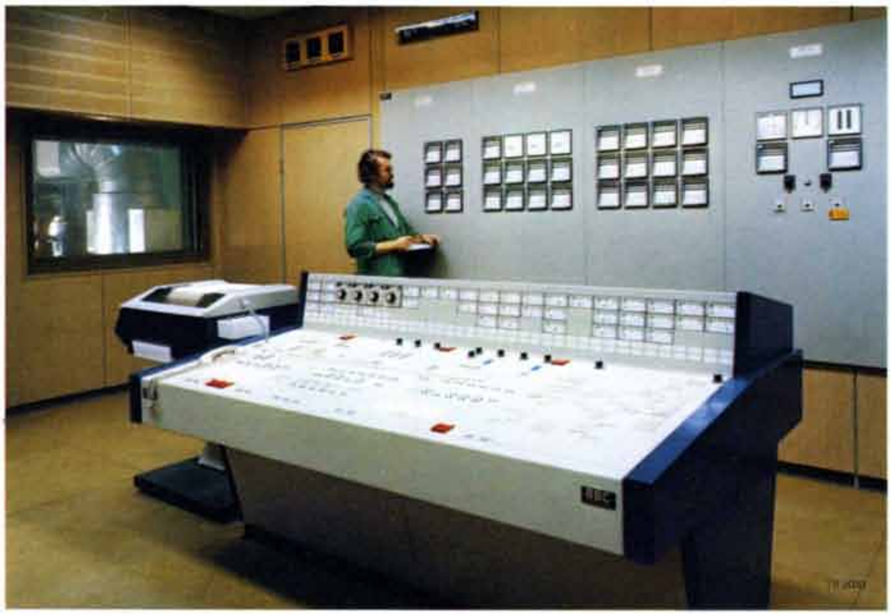


Fig. 9 Control room of the Huntorf Power Plant, which is designed for fully automatic remote control operation.

Fig. 10 Model of the Huntorf Power Plant showing the air-storage caverns in the salt deposit.

Start-up Behaviour, Operating Modes

When the turbine inlet valves are opened for start-up of the plant, then the turbine with generator coupled by an overriding clutch, are accelerated by the air coming from the storage cavern, with simultaneous ignition of the high pressure combustion chamber. When the synchronous speed is reached then the generator is synchronised, the low pressure combustion chamber is ignited, and the turbine loaded.

The complete start-up process requires, in the normal case, 11 min from standstill to full load; emergency start takes only 6 min. Synchronous speed is reached already after 2 min. A starting motor, as is usual with conventional gas turbines, is not necessary since the storage cavern always has enough air to run up the turbine.

The compressors can be run up with the turbine from standstill to synchronous speed in approx. 6 min. They are run up with the turbine and the air which is still available in the storage cavern until the synchronous speed is attained. After synchronising the generator, it then operates as a motor to drive the compressors and the turbine can be run down, whereby the coupling between the turbine and the generator opens.

The plant concept at Huntorf allows the following additional operating modes:

Emergency Operation

If, during compressor operation, a sudden peak load is required, then the turbine can be immediately run up, coupled, and loaded. The compressor hereby remains connected, the blow-off valves are opened and the air discharged to atmosphere. Approximately 90 % of the normal electrical power is then available. The emergency start-up times are quoted above.

Emergency Discharge

If further energy is required during discharging the storage cavern, then, in exceptional cases, it may be discharged to a pressure of 22 bar. A compressor start is still possible with this pressure.

Phase Shifter Operation

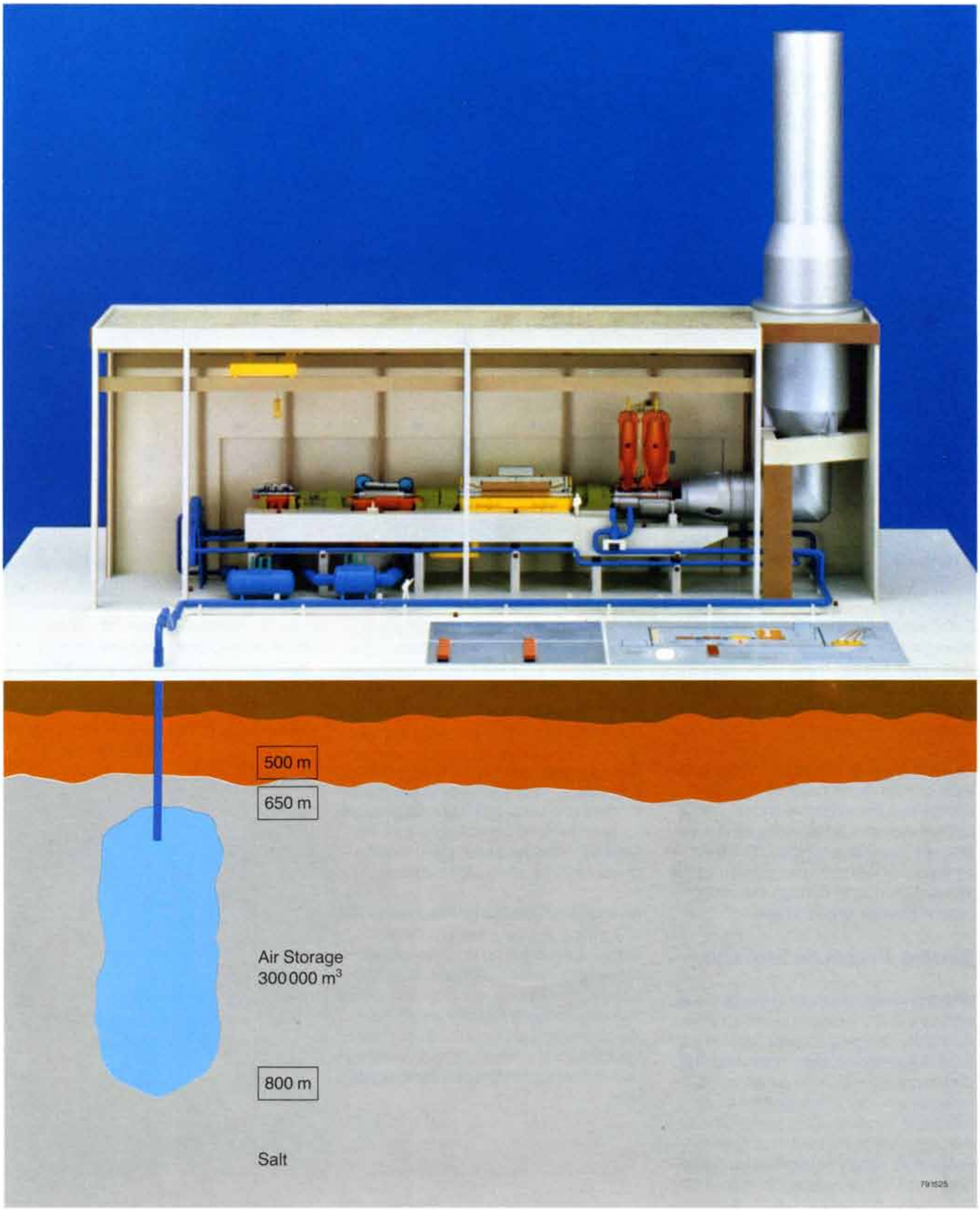
It is possible at all times to take the generator/motor out of power generation, or from standstill, for use as a phase shifter.

Black Start

The plant can be used to build up a partial grid system, and for isolated operation, following a collapse of the power supply grid (blackout).

Commissioning

The commissioning of this prototype plant was carried out in the period from 1977 to 1978. Following proof of the guarantee data and fully automatic power generation, as well as charging operation, the commissioning was completed at the end of 1978. After 14 days of trials the plant was handed over to the utility. During these trials, and with an unmanned power plant, the plant reached a start-up reliability of 97 % and an availability of 96 %.


500 m
650 m
Air Storage
300 000 m³
800 m
Salt
791525

4. Air Storages

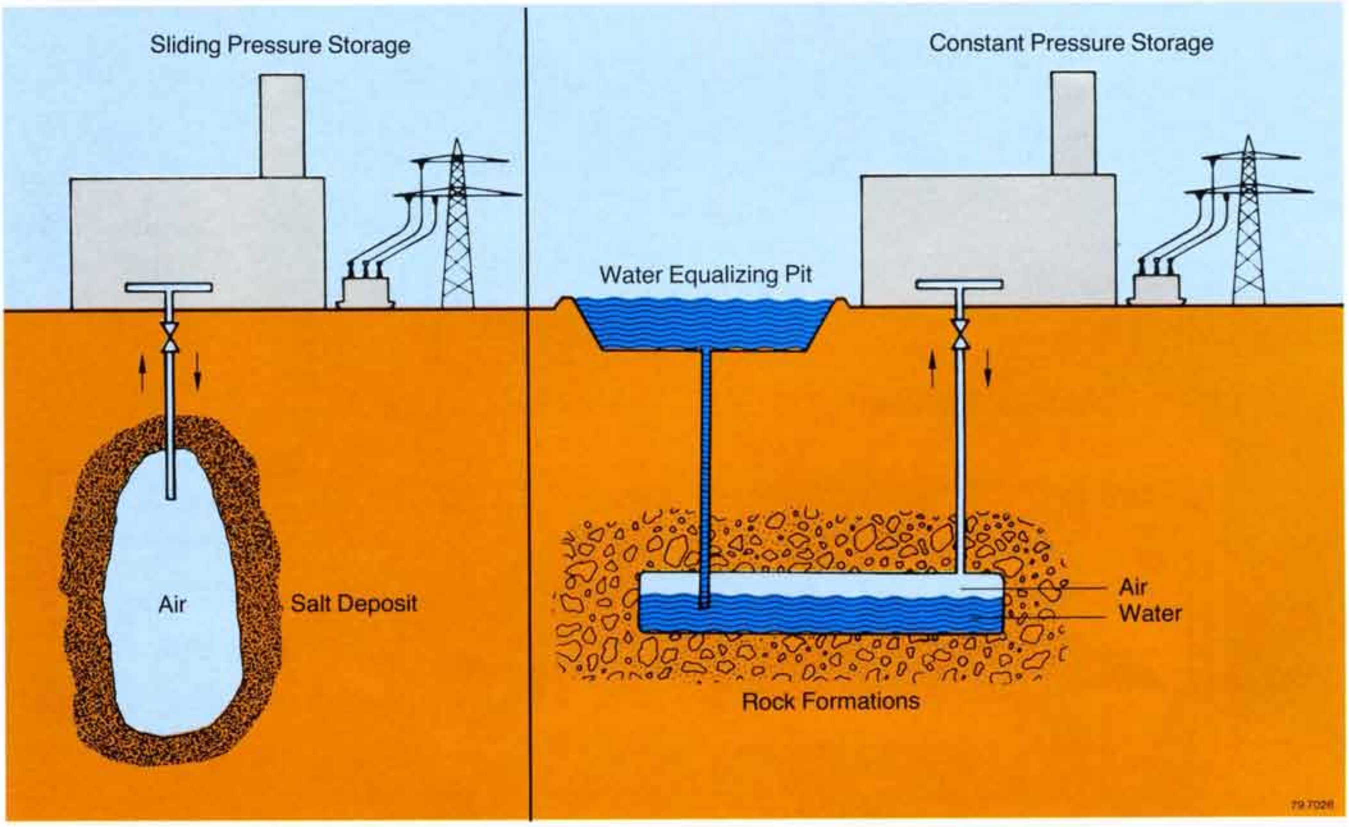


Fig. 11 Schematic presentation of the economically viable types of air storage systems: Sliding Pressure Storage and Constant Pressure Storage.

Since air storages are a new concept in power station engineering, the technical features of the two types of storages in economic use today – sliding pressure and constant pressure storage – will be described.

For both types of storage, naturally available or man-made caverns may be used. From the technical and economic point of view stores below the earth's surface are especially suitable. The latter construction has been propagated in previous years mainly through the underground storage of oil and gas.

Sliding Pressure Storage

With the sliding pressure concept the air pressure in the storage cavern changes during the charging and discharging process. If the turbine were driven with this sliding pressure then its power would be reduced with discharging of the store. Since this situation is not acceptable for the utility due to the load characteristics in its supply network, then the turbine is run with a constant inlet pressure of 42 bar to produce a constant power independent of the state of charge. For this purpose the available pressure in the store is throttled down to the turbine inlet pressure, accepting the resulting throttling losses as inevitable.

For a terminal power of 290 MW and a pressure of 42 bar before the turbine, a storage volume of 130 000 m^3 is required for each full load operating hour of the turbine, under the assumption that the pressure in the store slides 20 bar.

An economic solution for the construction of a sliding pressure storage cavern today, is the leaching process applied to an underground salt deposit. Manufactured stores above-ground are technically and economically too expensive. Also, the plastic and yet very solid structure of the salt rock is extremly suited for storage caverns, which are practically absolutely tight.

Two concentrically arranged pipes are installed in a bore hole down to the depth of the salt deposit. Pumps force fresh water down through the inner pipe. The fresh water dissolves the salt to form a saturated solution. The brine formed flows up through the outer pipe.

An echo sounder checks the cavern contour during the leaching process. The control of the cavern form is made by using buffer gas which is specifically lighter than the brine, and is neutral with respect to the brine. Changes in the height of the brine level allow a range to be determined at which the water can dissolve no more salt.

Test borings in the area around Huntorf confirmed the suitability of the salt deposits for the installation of plant for the air-storage project. No measures are necessary in preventing air leakage. The salt deposit at Huntorf lies at a level of 500 m below the ground. The two stores were leached in the salt deposit each having a volume of 150000 m^3. Each cavern is in the form of an erect cylinder with a diameter of approx. 40 m and a height of approx. 150 m. Since, for geological reasons, a salt layer of at least 100 m thick is required above the caverns, and the salt deposit at Huntorf commences at 500 m, then both caverns lie at a depth from approx. 650 m to 800 m. Pipes connect both parallel-operating air storages with the power station.

Constant Pressure Storage

This type of storage is not used at Huntorf. It is suitable for air-storage gas turbine power plants which are built in areas where there is no possibility to construct a salt cavern.

A constant pressure storage can be constructed in underground rock formations whereby a 500 m deep and approx. 6 m diameter hole is sunk into the ground. At a depth of 500 m a horizontal tunnel is then constructed with a tunneling machine for a diameter of approx. 5.5 m which is then used later for the storage. A water equalizing pit above ground then maintains the pressure constant in the store.

The required volume for a constant pressure storage is considerably smaller, since almost the entire air contained in the storage may be used for the production of useful work. Also, the throttling losses and change in conditions of the air, which occur in sliding pressure systems, are not present. A volume of 30000 m^3 is required for each full-load operating hour of a 290 MW turbine, i.e. approx. only one quarter of the volume which is required for a sliding pressure store.

In view of this fact, the higher construction costs per cubic meter storage volume of a constant pressure storage are almost compensated for, and the installed costs per kilowatt are approx. the same as for a sliding pressure storage.

5. Technical Data

Gas Turbine	
Rating	290 MW
Speed	3000 min^{-1}
Air consumption	417 kg/s
Inlet conditions HP Turbine	42 bar/550 °C (823 K)
Inlet conditions LP Turbine	11 bar/825 °C (1098 K)
Specific heat rate	5800 kJ/kWh
Fuel	Natural gas
Generator/Motor	
Apparent power	341 MVA
Frequency	50 Hz
Voltage	21 kV
Speed	3000 min^{-1}
Cooling	Hydrogen/Water
Compressors	
Number of compressors	2
Total driving power	60 MW
Construction of LP compressor	axial
Speed	3000 min^{-1}
Construction of HP compressor	centrifugal
Speed	7622 min^{-1}
Intake conditions	10 °C/1.013 bar
Air flow	108 kg/s
Conditions after compressor	46 to max. 72 bar/50 °C
Number of intercoolers	3
Number of aftercoolers	1
Air Storage	
Type of storage	Sliding pressure
Volume	2 x 150 000 m^3
Pressure range	20 bar
Pressure gradient during discharge	10 bar/h

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