Compressed air energy storage

An evolving technology with relevance to industrial gases

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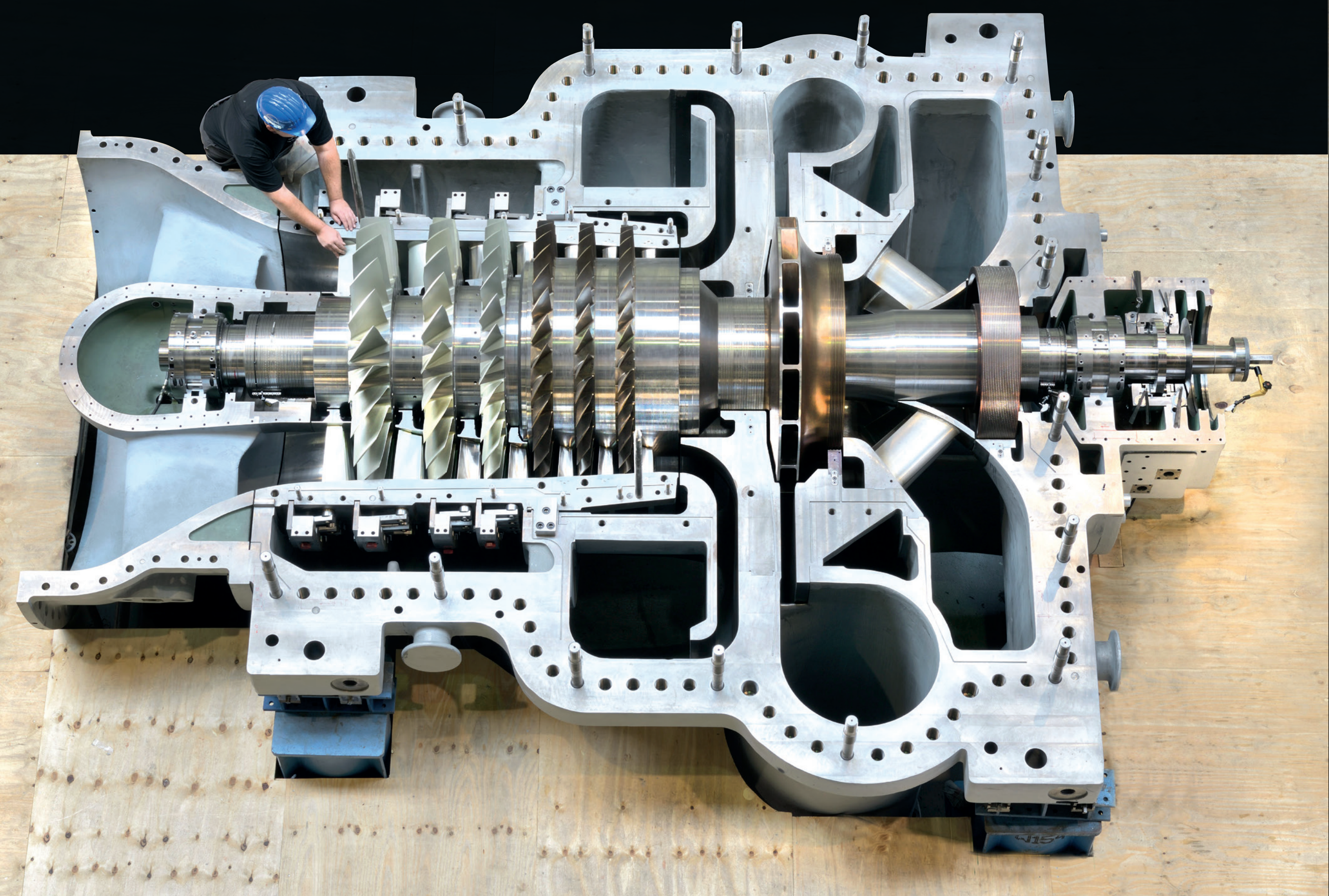


© MAN Energy Solutions | **Axial air compressor**

Power and energy storage will be essential complimentary technologies to a renewables-led world. At present, pumped hydro is the highest capacity power storage technology. Much has been said about the use of lithium ion batteries for power storage, but the timescale over which they can be depleted is between four and eight hours. This is not sufficient to support many requirements, such as continuous power delivery from a solar farm. Conversion of power to hydrogen for energy storage will become important for long duration energy storage.

Liquid air energy storage (LAES) involves the compression and liquefaction of air for mid-term storage. The stored cryogen is pumped, vaporized and released through a turbine to generate power as required. Compressed air energy storage (CAES) works in a similar way to LAES, but instead of the air being converted to a liquid, it is contained in a large underground storage cavern. When the electricity grid needs a power top-up, the high pressure air is released through a turbine to generate power.

CAES was first implemented at scale in Germany more than 40 years ago. The Huntorf CAES facility was constructed west of Bremen in 1978. Since then, CAES has evolved to integrate thermal energy storage to eliminate natural gas usage in the system and improve the overall cycle efficiency. However, air compression and expansion are still fundamental to the process. With these technologies at its core, CAES has tremendous relevance for industrial gases operators and technology providers.

Huntorf CAES: An innovative gas-fired peaker

50 years ago, the introduction of pipeline natural gas supplies and LNG imports gave rise to the concept of gas-fired power generation to meet peaks in demand. In contrast to nuclear power or coal fired generation, gas fired power plants can start up from cold very quickly. In Europe, North America and Asia many open circuit and closed circuit gas-fired power plants were built to balance regional power grids.

The combustion turbine on a gas-fired power plant operates at a pressure of around 30 bar. About 65% of the energy produced by burning natural gas is used to compress the combustion air to the operating pressure. This issue seeded the idea of using stored compressed air to mix with natural gas to avoid the air-compression energy losses during power generation.

© Linde plc | **Six 3,200 tpd Linde ASUs at Shenhua Ningxia CTL in China.**

Huntorf power plant followed this design concept. The wide spread between power prices during peak and off-peak periods was deemed sufficient to justify investment in such technology. During periods of low demand on the grid, low-cost power is used to compress air into two underground salt caverns. When power generation is required and high prices can be achieved, the compressed air is released and blended with natural gas on the turbine to generate up to 321 MW of power. Start-up from cold to 50% generation capacity can be achieved within three minutes, with full capacity reached after seven minutes.

Underground geological salt formations in Northern Germany allow the creation of salt caverns. In addition to their application for CAES, they are used to store natural gas to balance seasonal supply and demand. Underground salt caverns are also being created to store hydrogen for a similar purpose.

The two Huntorf caverns are 140,000 and 170,000 cubic metres in capacity.

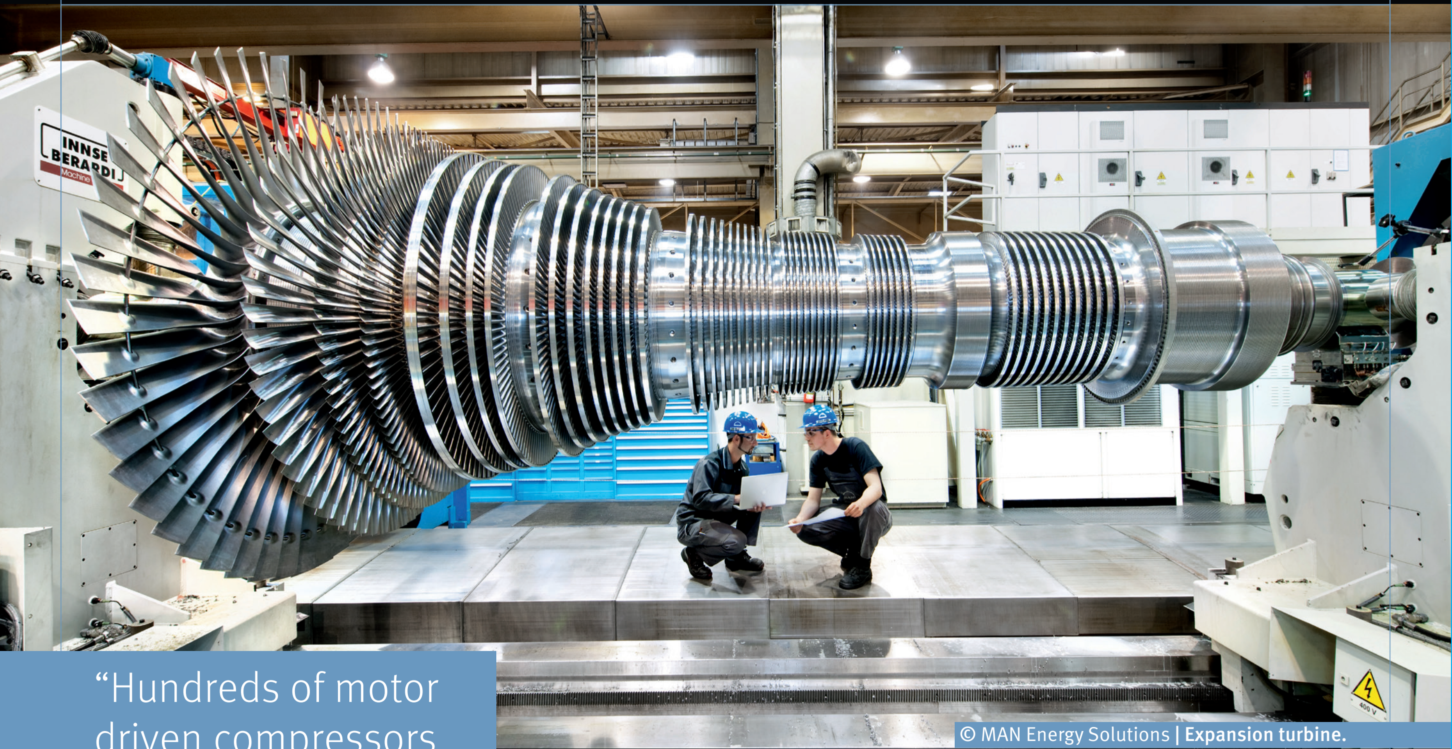
> "The combustion turbine on a gas-fired power plant operates at a pressure of around 30 bar"

The tops of the caverns are 650m below the surface of the earth. They are about 150m tall and up to 60m wide. To prevent geological shifts, they have a minimum operational pressure of 20 bar. However, the normal duty cycle is between 43 and 70 bar. The amount of air released during decompression can operate the turbine for about three hours.

The expansion turbines at Huntorf were manufactured by ABB. The high pressure turbine is like a steam expansion turbine in a thermal power plant and the low pressure unit is a typical gas-fired power generation turbine.

MW-scale air compression for CAES and ASUs

Air compression at Huntorf requires 60 MW of power to fill the caverns over a 12-hour period. The first phase of compression is achieved using an



© MAN Energy Solutions | **Expansion turbine.**

> "Hundreds of motor driven compressors manufactured by MAN ES operate on ASUs of up to 4,200 tonnes per day capacity"

axial compressor. After cooling the air, a second phase of compression takes place on a radial compressor. The air is again cooled prior to being introduced into the salt cavern. In this cycle, there is no attempt to recover the heat energy of compression.

The compressors at Huntorf were manufactured by MAN Energy Solutions (MAN ES). MAN ES is active in the construction of large air compressors for air separation units (ASUs). Their AIRTRAIN unit is driven by a steam expansion turbine and has been implemented on more than 80 installations worldwide.

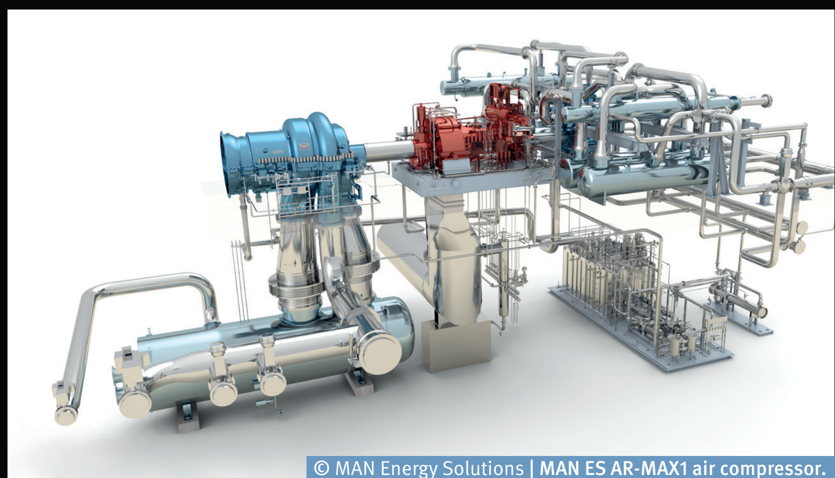
Hundreds of motor driven compressors manufactured by MAN ES operate on ASUs of up to 4,200 tonnes per day capacity. In addition to main air compressors and booster air compressors, these machines are used for nitrogen and oxygen compression to supply tonnes of industrial gases by pipeline from ASUs to customers.

As an example, MAN ES supplied the air compressors to six Linde ASUs at Shenhua Ningxia Coal Industry Group's coal to liquids (CTL) facility in the Ningxia Hui autonomous region of Northwest China. Each of the ASUs supplies around 3,200 tonnes per day (tpd) of oxygen for coal gasification to produce syngas to the CTL process.

The 11 units delivered in the above case were AIRMAX M trains, each consisting of a six-stage MAX1 axial/centrifugal main air compressor of type AR115-06M and a six-stage RG056-6 geared booster air compressor. Both compressors are driven by a centrally mounted MST080 condensing steam turbine. The total equipment supply scope of MAN ES had a value of €125m.

Energy efficiency and AA-CAES

The future of CAES lies in energy efficient power storage to support



© MAN Energy Solutions | **MAN ES AR-MAX1 air compressor.**

variable renewable power generation and grid balancing. To increase the round-trip efficiency of CAES, various modifications have been made by innovators such as Hydrostor. One such development is to capture the heat of compression in a thermal energy storage (TES) unit. This heat is then given back to the air as it expands across the power generation turbine to avoid excessive cooling of the air. The innovative combination of TES and CAES is known as advanced, adiabatic CAES, or AA-CAES.

An expansion turbine on an ASU is designed to produce cold energy to support the cryogenic air separation process and produce liquid products from the ASU. On the other hand, expansion of air as it is released from the CAES storage is not intended to create cryogenic temperatures.

A further enhancement in some AA-CAES systems is that the pressure of air in the underground storage remains constant. This is achieved by the air displacing water in the underground cavern to an above-ground reservoir. In this mode of operation, the underground gas cavern must be mined into rock. The use of a salt cavern for such an application would not be appropriate.

Hydrostor is planning to develop several AA-CAES facilities worldwide. One in Cheshire, in the UK. will use a salt cavern for compressed air storage and the pressure of the stored air will rise and fall through the cycles of operation. Another project planned for Kern County; California will use a rock cavern for the compressed air storage. In this project, water will be used to operate the cavern at a constant pressure.

“Another project planned for Kern County; California will use a rock cavern for the compressed air storage...”

Synergies

The heat derived from air compression on industrial gases ASUs is wasted. It is lost to the ambient air using evaporative cooling towers. Lessons from AA-CAES could see this heat stored on the ASU site. Heat is required on many tonnage supply scheme ASU sites to revaporize cryogenic liquid gases during periods of peak pipeline demand. Most sites generate steam for this purpose, meaning additional fuels cost and CO_2 emissions. Alternatively, the stored heat may be of value to neighbouring operators if the ASU is in an industrial cluster.

An additional idea is to use CAES principles to minimise the power cost to the industrial gases operator. In many geographies where ASUs operate, there is a wide spread in power costs between peak and off-peak rates. Storing high pressure air onsite in above-ground compressed air containers, or underground caverns could enable low-cost power to be consumed during off-peak periods and the energy from the compressed air could be used either to generate power or directly to drive the ASU compressor during periods when the power price spikes.

The fundamental equipment items and thermodynamics of CAES are very close to warm-end ASU operations. Multiple synergies are likely to exist between these technologies in the future. gw

Kern County California.