COMPRESSED AIR ENERGY STORAGE

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INTRODUCTION

Off-peak central station base-load power can be stored for peak use. This also applies to wind and solar power generation.

A compressed air storage system consists of three basic components: a motor, an air compressor and a turbine to retrieve the energy from the compressed air. In the energy storage stage, the motor drives the air compressor. In extracting the energy, the air is circulated through the turbine which drives the same motor which acts now as an alternator. This is the same situation as the pump-turbine and the motor-alternator in a pumped storage hydroelectric system.

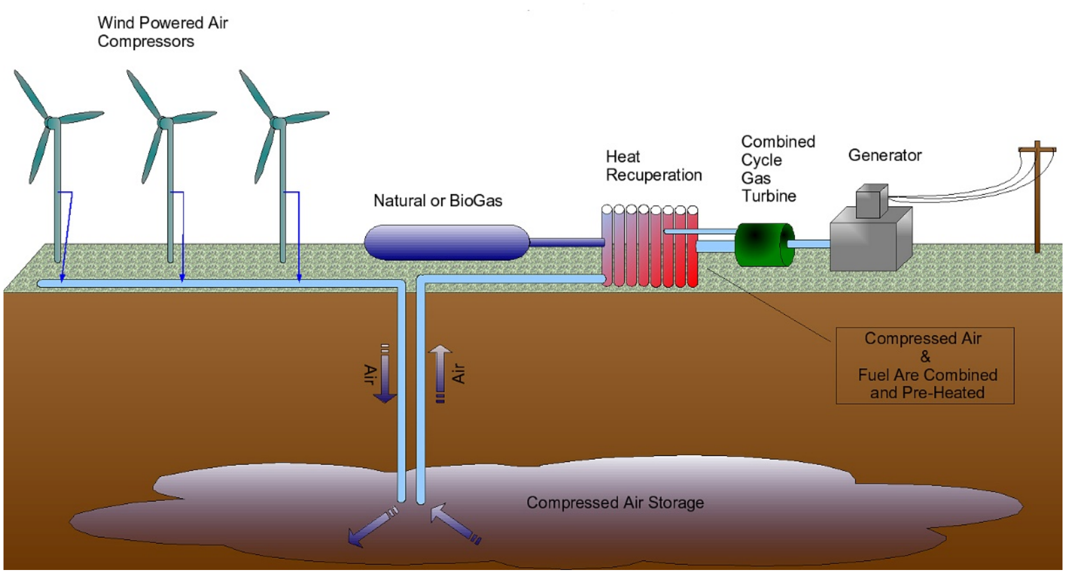

Figure 1. Compressed Air Energy Storage (CAES) system. Source: Sciam.

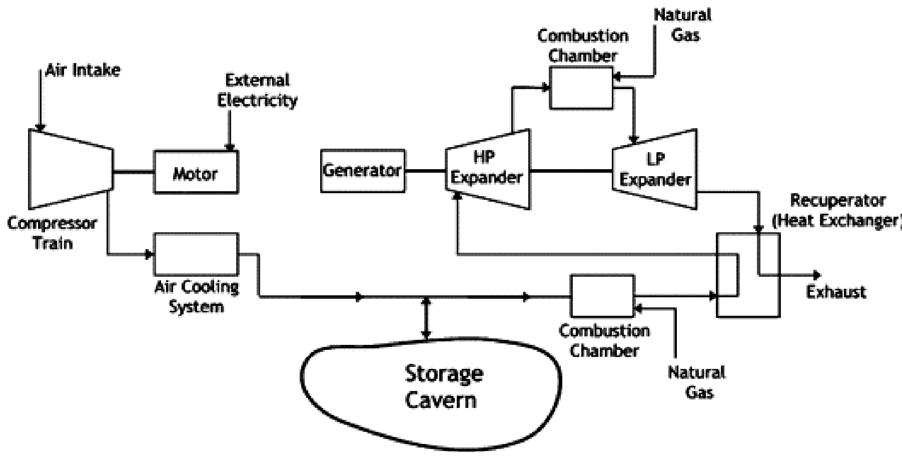

Figure 2. Schematic of Compressed Air Energy Storage (CAES) system. Source: Sciam.

Figure 3. A 290 MW Compressed Air Energy Storage (CAES) in conjunction with wind power at Huntorf, Germany [2].

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The compressed air can be stored in storage tanks, in underground caverns or in aquifers. Few fresh water aquifers exist below a depth of 2,000 feet. At that depth aquifers are saline and unusable for fresh water supplies. In the case of the caverns, a surface lake and a water piston are needed to recover the flow work:

$$Flow\ Work = \int PdV \tag{1}$$

This flow work is not recovered in the case of the use of an inflexible tank. In the use of an aquifer, the water in the interstitial spaces of the porous medium acts as the piston, and no surface area would need to be used.

PROCESS EFFICIENCY AND ECONOMICS

If used in conjunction with wind power production. The efficiency of the compressed air process can be defined as:

$$\eta_{CS} = \frac{W_{turbine}}{W_{compressor}} \tag{2}$$

A recovery efficiency of 67 percent is reported to be attainable. A capital investment of about $200/kW of installed capacity is needed.

Both compressed air storage and pumped storage hydroelectric storage systems require substantial land use and are limited to suitable sites that may be situated away from the load centers requiring an additional investment in the electrical power transmission facilities. Depending on whether High Voltage Direct Current (HVDC) or HVAC are used a power transmission efficiency can be added as:

$$\eta'_{CS} = \eta_{transmission} \frac{W_{turbine}}{W_{compressor}} \tag{3}$$

A further efficiency can be added depending on the end use of the produced electricity whether it is for heating, lighting, refrigeration or air conditioning:

$$\eta''_{CS} = \eta_{transmission} \eta_{end\ use} \frac{W_{turbine}}{W_{compressor}} \tag{4}$$

It is advantageous to use a high value of the pressure ratio:

$$\gamma = \frac{P_C}{P_A} = \frac{\text{Compressed air pressure}}{\text{Atmospheric air pressure}} \tag{5}$$

A value of 40 for the pressure ratio is contemplated.

If a separate turbine and a compressor are used for a surface tank, underground cavern or an aquifer, two choices present themselves:

a) The air can be extracted from storage and run through the turbine without heating. The performance in this case is the same as in pumped storage hydroelectric at about 67 percent.

b) A small amount of any fuel such as natural gas can be burned to heat the air before it enter and expands through the turbine. The output of the system can double in this case for 4,000 BTU/kW.hr. An *apparent* efficiency of 2 x 67 = 134 percent is attained at the expense of some energy input as heat.

COMPARISON TO OTHER ENERGY STORAGE SYSTEMS

In pumped hydroelectric, batteries, and flywheel energy storage, once full storage is attained, no more can be stored. This depends on the original investment in the storage capacity. Pumped hydroelectric, in fact, can be stored only overnight because of its cost.

Underground storage of compressed air possesses a unique flexibility in being a compressible fluid. If 2-3 days of power production is stored at 600 psi, it can be extended to 7 days by increasing the pressure to 650 psi. The compressed air would push the water in the aquifer closer to its dome and one gets the piston action by the air being more compressed. Because air is a compressible fluid, more energy can be stored into it by increasing the pressure or by pushing back more of the interstitial water in the aquifer pores.

DISCUSSION

Utilities have adopted gas turbine systems for peak operation. The main advantage is their rapid installation. They cost $110-115/kw of installed capacity. They are large spendthrifts of fossil fuel energy and depend on the cost of natural gas. Their heat rates are about 17,000 BTU/lb. About ¾ of the energy of the turbine is used in the compressor. Thus a 1 kW gas turbine system is in fact a 4 kW turbine composed of a 1 kW alternator and a 3 kW compressor.

Compressed air storage has the reheat capability, a low capital cost among energy storage systems, and an environmental advantage of not using a surface area.

Underground compressed air storage can be beneficially contemplated for a wind park in the range of 50-100 MW of capacity for providing peak power capability in competition with gas turbine systems. The lower 50 MW limit accounts for the need for well drilling and associated machinery and infrastructure.

It can be used for offshore wind power installations several miles off the continental shelf. Air can be stored underground. A membrane at large depth or a bag at shallow depth lying at some water depth can also be used. The water pressure would push the air back to a turbine at the water surface.

EXERCISE

1. A compressed air storage system is used in conjunction with a wind turbine. For each 3 kW.hr of energy stored, 2 kW.hrs are extracted. Calculate the efficiency of the system.

REFERENCES

1. George C. Szego, "Energy Storage by Compressed Air," Wind Energy Conversion Systems, NSF/RA/N-73-006, pp.152-154, December 1973.

2. Andrew Lee, “Energy Storage Takes on the Variability Conundrum,” Renewable Energy World Magazine, September 28, 2010.