Energy Storage in Salt

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ABSTRACT

Salt formations have been used extensively for hydrocarbon storage. A relatively new concept, compressed air energy storage (CAES), has extended the use of salt formations to power generation facilities by storing air in caverns. The CAES cavern may be utilized for fuel storage during seasons when cavern use for power generation is not required. Alternatively, additional salt caverns can be mined adjacent to the CAES cavern at the same time with resultant mining and equipment cost savings. With modifications, underground CAES plants with subsurface fuel storage have important military and civil defense applications.

INTRODUCTION

Domal and bedded salt has been used for hydrocarbon fuel storage throughout the world for many years because of its availability and desirable physical properties. Within the last decade, an increasing amount of attention has been focused on utilization of salt caverns for peaking electrical power generation facilities as well as peaking fuel storage facilities for generating plants.

Electric utilities have experienced a leveling of base-load growth over the last eight years. However, peak-load demand has generally risen owing to increased industrial power requirements and growing consumer preference for summertime air conditioning and wintertime electrical resistance heating. To avoid using high-cost premium fuel, some utilities have converted their base-load natural gas and oil fired plants to peak-load plants, with a resultant requirement for storage of peak-shaving fuel supplies.

Compressed air energy storage (CAES) plants sited in salt formations are a viable answer to both low-cost peak power generation and underground fuel storage facilities for peak shaving. Because typically peak electrical power demand fluctuates seasonally, with high summertime demand in southern latitudes and high wintertime demand in northern latitudes, the salt cavern created for containment of the compressed air could be used for hydrocarbon fuel storage during the season when peak electrical generation is not required.

A similar potential exists for salt caverns created adjacent to the compressed air cavern to be used for storage of the natural gas required to fuel the CAES plant. This concept would have the advantage of co-utilization of the CAES turbomachinery and piping for reducing physical plant cost.

Another potential use of CAES plants would be for "hardened" power generating capacity for military and civil defense applications. By placing the turbomachinery underground and creating underground fuel storage space, the only surface access required would be for air intake and exhaust lines and electric transmission lines.

THE COMPRESSED AIR ENERGY STORAGE CONCEPT

A compressed air energy storage plant utilizes off-peak electrical power from a nearby coal or nuclear fueled base-load power plant to run a reversible motor/generator which turns a compressor to charge an underground storage cavern with compressed air (Figure 1). When peak power is required, the compressed air, which is analogous to a turbocharger in an automobile engine, is drawn off, mixed with fuel oil or natural gas, and burned in a combustion turbine (Figure 2).

The combustion turbine turns the reversible motor/generator to generate electricity. Because the combustion turbine does not need to power a compressor during the power generation mode, approximately one-third as much fuel is required, compared with a conventional turbine of the same capacity (Schainker and Land, 1982).

There are two types of CAES plant concepts—constant pressure and constant volume. The constant pressure

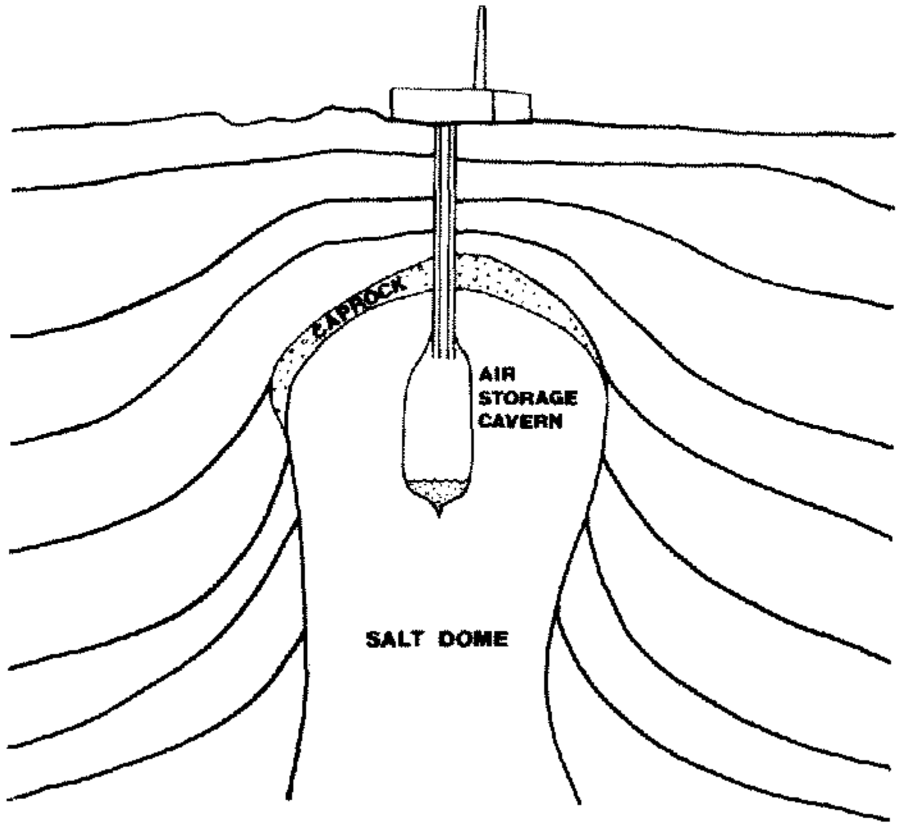

Figure 1. Cross-Sectional View of a Compressed Air Energy Storage Plant in a Salt Dome

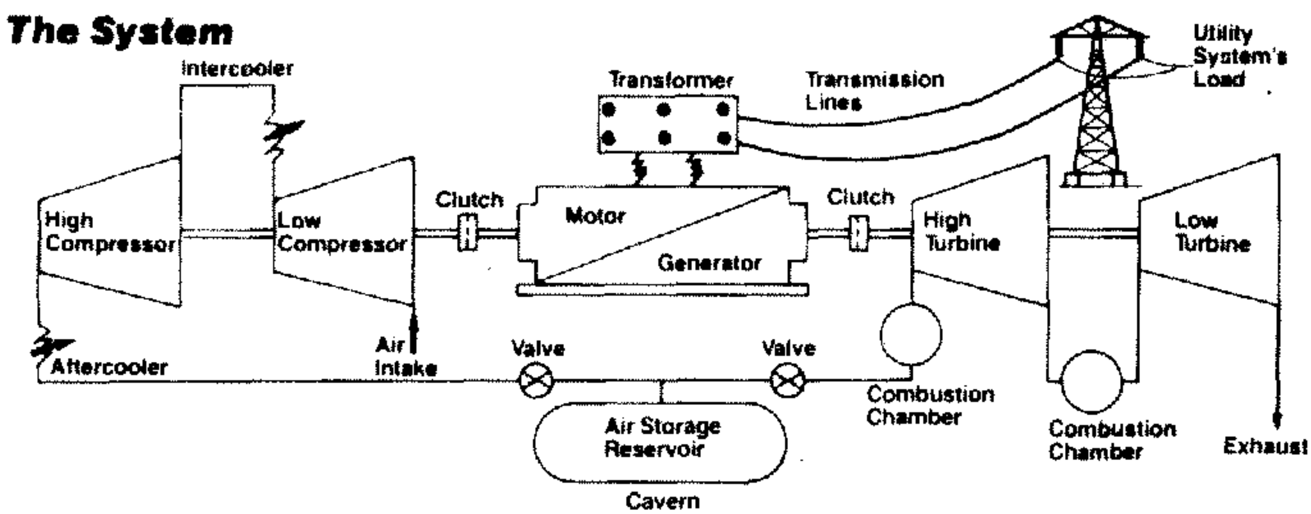

Figure 2. Component Schematic for a Compressed Air Energy Storage Facility

concept allows water from a surface reservoir to displace the volume of compressed air as it is withdrawn from the storage cavern (Figure 3). During the charging mode, the water in the cavern is forced back up into the surface reservoir. The water-compensated system was designed principally to reduce the volume of hard rock storage caverns to avoid high underground excavation costs.

The constant volume concept allows the air pressure in the cavern to decrease during the power generation mode (Figure 1). This concept is favored for CAES caverns in salt, since the relatively inexpensive solution-mining techniques employed for salt cavern construction do not warrant the expense of a compensated system.

A 220 MW water-compensated CAES plant with a

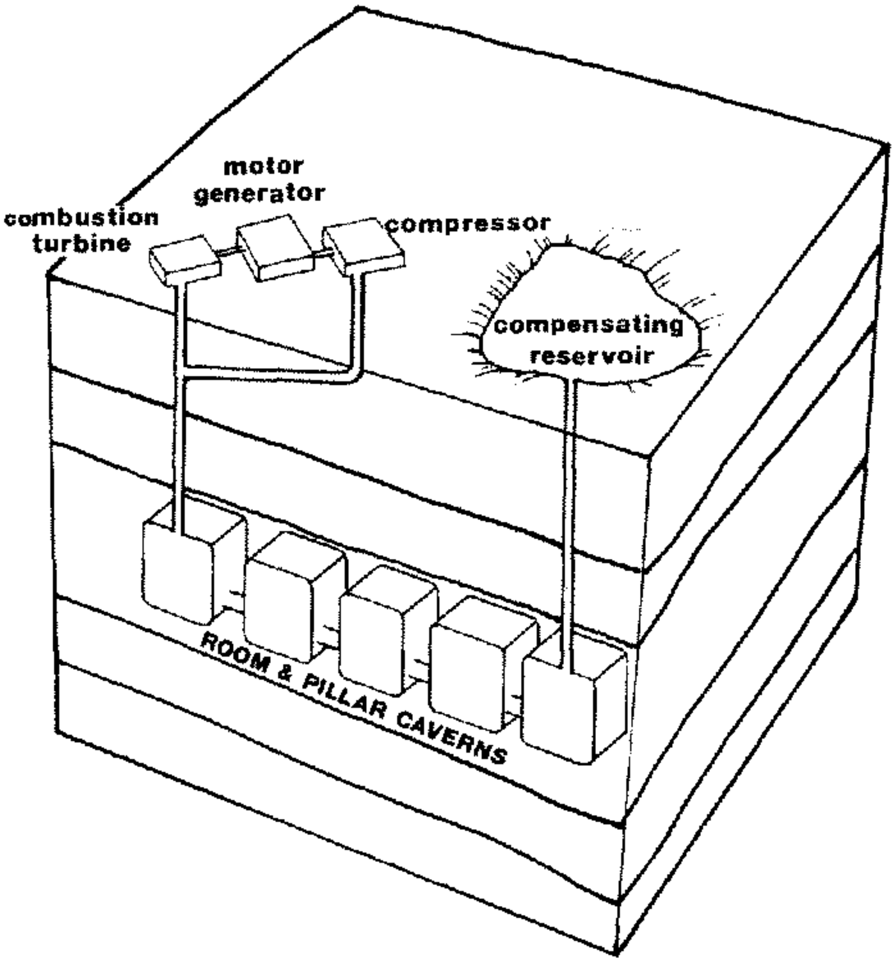

Figure 3. Block Diagram of a Water-Compensated Compressed Air Energy Storage Facility in Hard Rock

hard rock storage cavern would have a volume of 193,000 cubic yards compared with an uncompensated salt cavern volume of 521,000 cubic yards (Schainker and Land, 1982, page 8). However, Lang (1974, page 326), referred to a hydraulically compensated salt cavern. This cavern should probably use brine instead of fresh water to prevent salt dissolution (Figure 4).

The depth of the air storage cavern is dependent upon the air flow and storage pressures required. Cavern depths of 1000 to 3000 feet are under consideration. Cavern pressures would typically fluctuate between 50 and 75 atmospheres (735 to 1102 psi) in the uncompensated CAES plant (Schainker and Land, 1982, page 3). The length of the charging cycle is variable. A daily cycle with 8 to 10 hours of charging and a similar period of power generation has been proposed (EPRI, 1982).

Compressed air energy storage is not based on the concept of getting something for nothing. Approximately 0.7 kwh (6600 Btu) of electricity from a coal or nuclear base-load power plant which is used for charging the air storage cavern is combined with 4000 Btu of oil or natural gas fuel during the generation mode to produce 1 kwh of power output.

In addition to the fact that it is relatively inexpensive to mine, salt has the added advantage of being self-healing due to plastic flow. Because air storage pressure lost to cavern leakage is an economic loss, owing to the cost of the electrical power required to replace it, salt has a considerable advantage over hard rock. Another advantage is that salt is available in areas such as the U.S. Gulf Coast, where the lack of topographic relief precludes development of other energy storage options such as pumped hydro.

THE HUNTORF CAES PLANT

The world's first CAES plant was commissioned in Huntorf, Federal Republic of Germany, in November, 1978. The owner is Nordwest Deutsche Kraftwerk AG (NWK) of Hamburg. The facility consists of two solution-

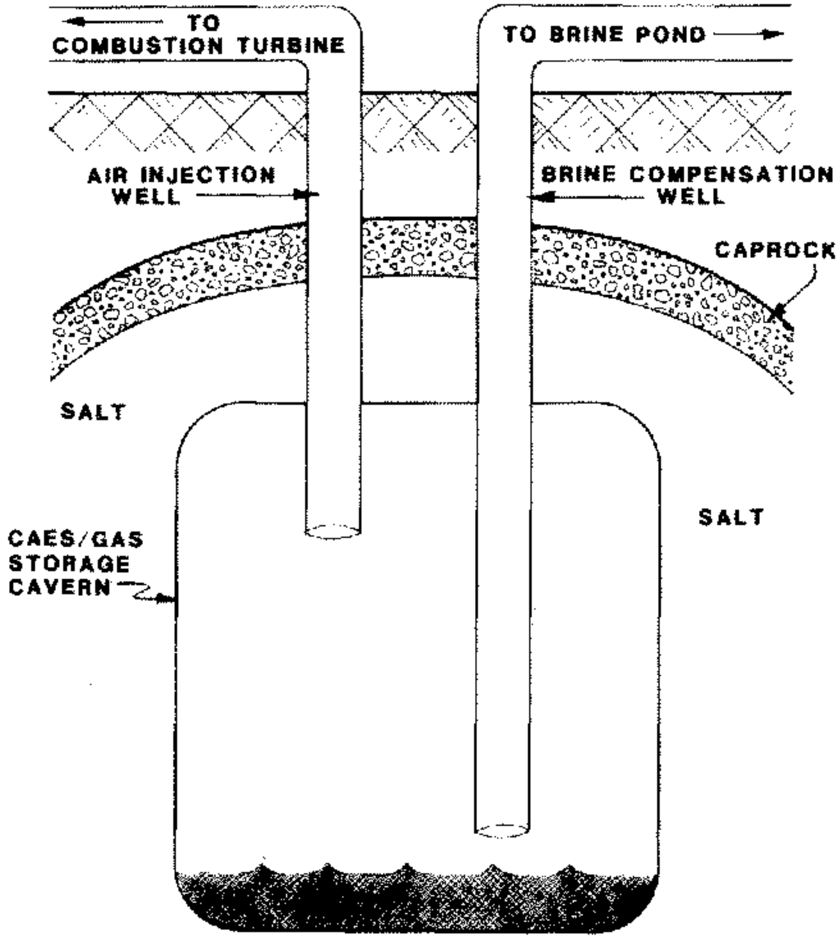

Figure 4. Cross-Sectional View of a Brine-Compensated Compressed Air Storage Cavern in Salt

mined air storage caverns in a salt dome and a daily cycle, 290 MW rated power plant. Each salt cavern has a volume of 591,800 cubic yards. The maximum air storage pressure is 68 atmospheres after 8 hours of charging and the plant provides two hours of power generation per day (Schainker and Land, 1982, page 7).

Natural gas is used to fuel the combustion turbine with a heat rate of 5500 Btu/kwh. The Huntorf plant starting reliability is 99 percent and the availability is 95 percent (Schainker and Land, 1982, page 7). The plant is fully automated and remote controlled. Start-up time was calculated to be 11 minutes under normal conditions and 6 minutes for emergency start (Mattick *et al*, 1975).

SALT DOME CO-UTILIZATION

Efficient operation of a CAES plant requires that either fuel oil or natural gas be mixed with the air withdrawn from the cavern to power the combustion turbine. Because solution-mined salt caverns are commonly used for hydrocarbon storage, it makes sense to consider co-utilization of the CAES cavern or additional caverns in the salt formation for fuel storage.

In the case where an electric utility's peak-load demand met by a CAES plant is seasonal, e.g., only in summer, the CAES salt cavern could be used for natural gas storage to meet peak shaving load demands during the winter heating season. This case may be just the reverse in other climates or where industrial demand fluctuates during different seasons.

An adjacent salt cavern, created to store natural gas to fuel the CAES plant, or created to store natural gas for other purposes, could also be mined at essentially the same time that the CAES cavern is being mined (Figure 5). The fixed costs of mobilizing solutioning equipment and the costs of installing freshwater wells and brine injection wells would be shared among two or more storage caverns.

Whether the CAES cavern has a dual use on a seasonal basis, or whether a separate natural gas storage cavern is created adjacent to it, the turbomachinery already in place for the CAES plant can be used to compress the

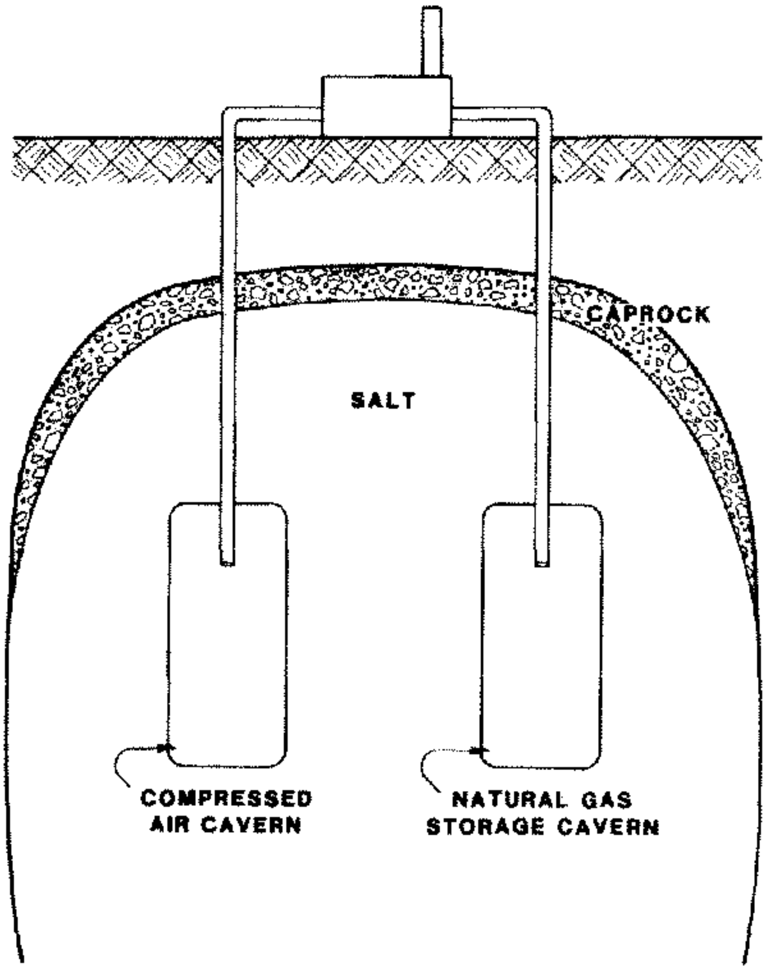

Figure 5. Cross-Sectional View of the Co-Utilization of a Salt Dome for Compressed Air and Natural Gas Storage

natural gas. This would result in substantial saving on capital equipment for the natural gas storage facility.

DEFENSE-RELATED ENERGY STORAGE

Dependable supplies of energy are vital to national defense. To assure these supplies, military bases must have reliable backup energy resources that have minimal vulnerability to overt attack, natural disasters and acts of sabotage. If the basic CAES plant design was modified so that the turbomachinery presently designed to be on the surface was constructed underground, the facility's vulnerability would be substantially reduced (Figure 6).

This concept is applicable not only to power supplies for military bases but also to civil defense. A network of strategically located "hardened" CAES plants would substantially reduce the vulnerability of present power grids to destruction or interruption due to acts of war and sabotage.

The geologic setting most conducive to this type of facility would probably be bedded salt overlain by hard rock. The salt would be used for solution-mined caverns to store the compressed air and turbine fuel while the hard rock near the surface would be conventionally mined for the power house.

Because military installations may not require 220 MW per day CAES plants, smaller amounts of power could be produced over longer periods of time. The integrity of the salt would prevent the escape of air so that lesser amounts of power could be generated for weeks or months without losing the air charge in the caverns. If for some reason fuel supplies were interrupted, the compressed air alone could be used to power the turbine to generate power, although at a reduced efficiency. Also, the fast response of a CAES plant for an emergency start-up, approximately 6 minutes (Mattick, *et al*, 1975, page 4), makes it especially attractive for military and civil defense applications.

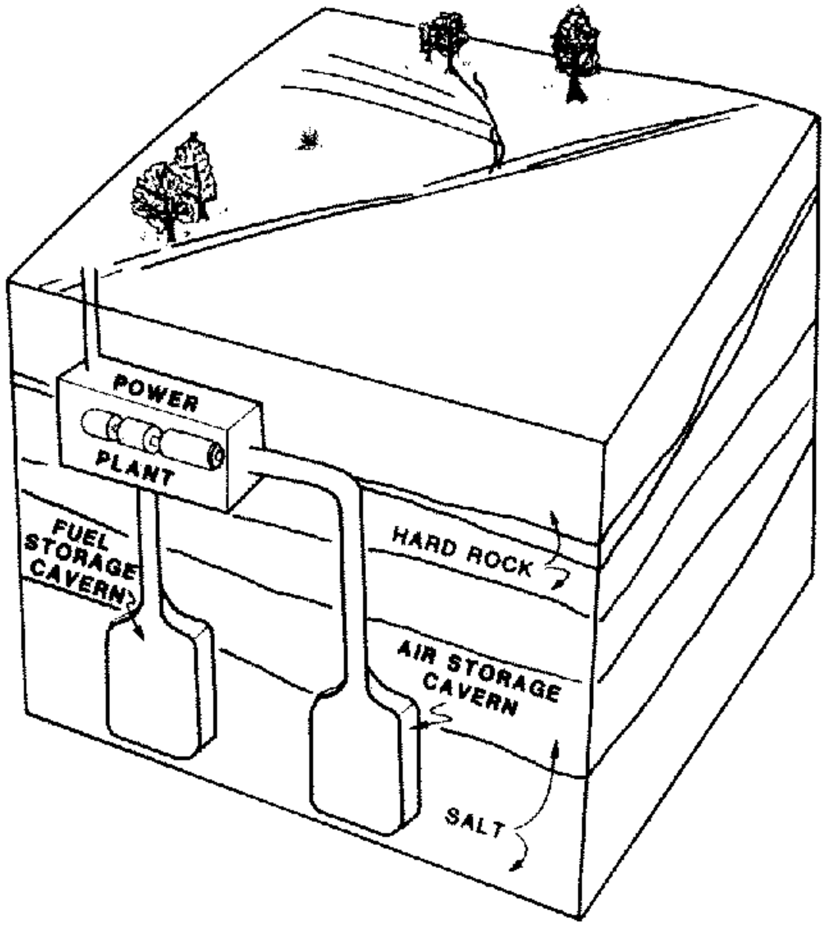

Figure 6. Block Diagram of a Compressed Air Energy Storage Plant Modified for Military or Civil Defense Purposes

CONCLUSIONS

Salt, with its desirable geographic distribution and physical properties, is a favorable geologic medium for siting CAES plants. The successful operating experience with the Huntorf CAES plant in a German salt dome helps establish the viability of this energy storage concept. Co-utilization of salt caverns or salt formations for CAES and fuel storage has significant economic benefits. CAES plants, combined with fuel storage in salt caverns, have important military and civil defense applications.

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