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Compressed-air-energy storage (CAES) is a way to store energy for later use using compressed air. At a utility scale, energy generated during periods of low demand can be released during peak load periods.[1]

One ongoing challenge in large-scale design is the management of thermal energy, since the compression of air leads to an unwanted temperature increase that not only reduces operational efficiency but can also lead to damage. The main difference between various architectures lies in thermal engineering. On the other hand, small-scale systems have long been used for propulsion of mine locomotives. Contrasted with traditional batteries, systems can store energy for longer periods of time and have less upkeep.

Compression of air creates heat; the air is warmer after compression. Expansion removes heat. If no extra heat is added, the air will be much colder after expansion. If the heat generated during compression can be stored and used during expansion, then the efficiency of the storage improves considerably.[4] There are several ways in which a CAES system can deal with heat. Air storage can be adiabatic, diabatic, isothermal, or near-isothermal.

Packed beds have been proposed as thermal storage units for adiabatic systems. A study [7] numerically simulated an adiabatic compressed air energy storage system using packed bed thermal energy storage. The efficiency of the simulated system under continuous operation was calculated to be between 70.5% and 71%.

Advancements in adiabatic CAES involve the development of high-efficiency thermal energy storage systems that capture and reuse the heat generated during compression. This innovation has led to system efficiencies exceeding 70%, significantly higher than traditional Diabatic systems.

The McIntosh, Alabama, CAES plant requires 2.5 MJ of electricity and 1.2 MJ lower heating value (LHV) of gas for each MJ of energy output, corresponding to an energy recovery efficiency of about 27%.[8] A General Electric 7FA 2x1 combined cycle plant, one of the most efficient natural gas plants in operation, uses 1.85 MJ (LHV) of gas per MJ generated,[9] a 54% thermal efficiency.

To improve the efficiency of Diabetic CAES systems, modern designs incorporate heat recovery units that capture waste heat during compression, thereby reducing energy losses and enhancing overall performance.

Hybrid Compressed Air Energy Storage (H-CAES) systems integrate renewable energy sources, such as wind or solar power, with traditional CAES technology. This integration allows for the storage of excess renewable energy generated during periods of low demand, which can be released during peak demand to enhance grid stability and reduce reliance on fossil fuels. For instance, the Apex CAES Plant in Texas combines wind energy with CAES to provide a consistent energy output, addressing the intermittency of renewable energy sources.

Compression can be done with electrically-powered turbo-compressors and expansion with turbo-expanders[16] or air engines driving electrical generators to produce electricity.

This storage system uses a chamber with specific boundaries to store large amounts of air. This means from a thermodynamic point of view that this system is a constant-volume and variable-pressure system. This causes some operational problems for the compressors and turbines, so the pressure variations have to be kept below a certain limit, as do the stresses induced on the storage vessels.[17]

The storage vessel is often a cavern created by solution mining (salt is dissolved in water for extraction)[18] or by using an abandoned mine; use of porous and permeable rock formations (rocks that have interconnected holes, through which liquid or air can pass), such as those in which reservoirs of natural gas are found, has also been studied.[19]

In some cases, an above-ground pipeline was tested as a storage system, giving some good results. Obviously, the cost of the system is higher, but it can be placed wherever the designer chooses, whereas an underground system needs some particular geologic formations (salt domes, aquifers, depleted gas fields, etc.).[17]