Adiabatic Liquid Piston Compressed Air Energy Storage - DTU Orbit (29/12/2018)

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This project investigates the potential of a Compressed Air Energy Storage system (CAES system). CAES systems are used to store mechanical energy in the form of compressed air. The systems use electricity to drive the compressor at times of low electricity demand with the purpose of converting the mechanical energy into electricity at times of high electricity demand.

Two such systems are currently in operation; one in Germany (Huntorf) and one in the USA (Macintosh, Alabama). In both cases, an underground cavern is used as a pressure vessel for the storage of the compressed air. Both systems are in the range of 100 MW electrical power output with several hours of production stored as compressed air. In this range, enormous volumes are required, which make underground caverns the only economical way to design the pressure vessel.

Both systems use axial turbine compressors to compress air when charging the system. The compression leads to a significant increase in temperature, and the heat generated is dumped into the ambient. This energy loss results in a low efficiency of the system, and when expanding the air, the expansion leads to a temperature drop reducing the mechanical output of the expansion turbines. To overcome this, fuel is burned to heat up the air prior to expansion. The fuel consumption causes a significant cost for the storage. Several suggestions have been made to store compression heat for later use during expansion and thereby avoid the use of fuel (so called Adiabatic CAES units), but no such units are in operation at present.

The CAES system investigated in this project uses a different approach to avoid compression heat loss. The system uses a pre-compressed pressure vessel full of air. A liquid is pumped into the bottom of the vessel when charging and the same liquid is withdrawn through a turbine when discharging. In this case, the liquid works effectively as a piston compressing the gas in the vessel, hence the name "Adiabatic Liquid Piston Compressed Air Energy Storage" (ALP-CAES). The compression ratio of the gas in the vessel (ratio between maximum and minimum pressure) is relatively low; typical values would be < 1.5, whereas the compression ratio in existing CAES systems can be higher than 100, because the air is compressed from atmospheric pressure to the storage pressure.

This investigation leads to the conclusion that:

• The mechanical/electrical efficiency of the ALP-CAES system is significantly higher than existing CAES systems due to a low or nearly absent compression heat loss. Furthermore, pumps/turbines, which use a liquid as a medium, are more efficient than air/gas compressors/turbines. In addition, the demand for fuel during expansion does not occur.

• The energy density of the ALP-CAES system is much lower than that of existing CAES systems (by a factor of 15-30) leading to a similar increase in investment in pressure vessel volume per stored MWh. Since the pressure vessel constitutes a relatively large fraction of the overall cost of a CAES system, an increase of 15-30 times renders the system economically unfeasible unless the operating conditions and the system design are very carefully selected to compensate the low energy density. Future electricity prices may increase to the extent that the efficiency benefit of ALP-CAES partly compensates the added investment.

• When comparing ALP-CAES to an adiabatic CAES system, where compression heat is stored in thermal oil, the ALP-CAES system is found only to be competitive under a very specific set of operating/design conditions, including very high operation pressure and the use of very large caverns.

• New systems are under development, which show an interesting trend in that they use near-isothermal compression and expansion of air (compression/expansion at almost constant temperature), eliminate compression heat loss and still maintain nearly the same level of energy density as existing CAES systems. This combination of features may make these systems superior to the ALP-CAES solution. The new systems are delivered by companies such as LightSail Energy and General Compression. Apparently, these new systems use piston compressors/expanders, at least for the prototypes. However, for large scale systems, piston mechanisms are not the most economical solution. In terms of large scale systems, turbo machinery is the only economical solution.

• Even adiabatic CAES systems seem to add more cost to the electricity than can be accepted in the Danish power system. This added cost is primarily due to the investment in turbine/generator, heat exchangers, and a large quantity of thermal oil. To improve the economy, it would be relevant to investigate the possibility of replacing the thermal oil by water, for example by injecting the water directly into the air flow between the different compression stages to get a direct heat exchange between water and air. This investigation would focus on direct heat exchange in combination with turbo machinery.

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