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Nearly Reversible Heat Engines for Thermal Storage of Excess Electric Power

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Abstract (Summary)

Efficient and affordable energy storage technologies would enable greater use of electricity generation with low operating but high capital cost. Such generating plants must maximize their utilization to spread capital cost over as much output as possible. Without affordable storage capacity their penetration into the market is limited to base load. Intermittent solar and wind power, which at times are simply not available, suffer even more than baseline power plants from the lack of affordable storage technologies. With the exception of pumped hydro-storage, energy storage is too expensive, suffering from low energy density in storage and low round-trip efficiency. Low grade thermal storage with temperature differences of up to about 100°C could achieve storage densities far in excess of that in most pumped storage facilities while avoiding the costs associated with high temperature operations. Roundtrip efficiency, defined as the ratio of the electric output from a heat engine driven by stored thermal energy to the electric input used to drive a heat pump to store the thermal energy, can approach 100% as the heat pump and the heat engine both approach Carnot efficiency. This theoretical limit is independent of the temperature difference between the heat reservoirs. Roundtrip efficiencies of at least 70 to 80% are necessary for energy storage to be economically competitive with higher priced electricity sources. This high round trip efficiency implies that both the heat engine and the heat pump would have to operate at 85 to 90% of the efficiency of a reversible engine. The most promising practical engines for such high efficiency are based on the Stirling cycle. This paper discusses a variation of the Stirling cycle aimed at large, slow units optimized for high efficiency far in excess of the Curzon-Ahlborn efficiency, which results from maximizing the power of the engine. This tradeoff in favor of efficiency over power output demands extreme simplicity in design, as the size of the engine is far larger than that of conventional engines optimized for power throughput. The goal of the paper is to show that low-grade thermal energy storage could provide a viable alternative to regionally limited pumped hydro-storage as long as the design challenges explained in the paper can be overcome. Given the current lack of cost-effective, scalable energy storage systems, thermal storage technology could have a profound impact on future energy infrastructures.