Analysis of Different Permutation of Hybrid Concentrated Solar Power (CSP) & Pumped Thermal Energy Storage (PTES) System

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1. Introduction

A hybrid Concentrated Solar Power (CSP) plus Pumped Thermal Energy Storage (PTES) system design is being analyzed at the National Solar Thermal Test Facility (NSTTF), at Sandia National Laboratories. Two different system arrangements are being considered to determine the optimal pilot-scale demonstration configuration. The system is composed of three thermal storage subsystems: 1. A High Temperature Storage (HTS) with temperatures above 650°C, 2. A Medium Temperature Storage (MTS) with temperatures ranging from 25°C to 170°C, and 3. A Low Temperature Storage (LTS) system at 0°C. The energy stored in the HTS tanks is collected through a CSP particle receiver that allows for thermal storage at temperatures above 650°C. The heat energy stored in the MTS tank is obtained using a CO2 heat pump through a heat exchanger as shown in figure 1. Finally, the LTS will take advantage of the latent heat produced and adsorbed during the liquid-solid phase transition of water. Here coils with CO2 are submerged into the water tank for the CO2 to absorb or deposit heat depending on the operation phase. This investigation assesses cycle performance of two thermal energy storage (TES) configurations, specifically for the MTS and HTS, under varying operational modes. The assessment will be executed under steady operational conditions for each of the respective operational modes.

2. Configurations to Consider

The two permutations being considered for this investigation are shown in Figure 1.

Configuration A uses the HTS tank in direct contact with the supercritical CO2 (sCO2) engine system. Also, for this system the MTS tank is heated by the CO2 pump alone, reaching temperatures of approximately 150°C. Conversely, Configuration B implements the HTS tank at two different points within the system. Configuration B uses the CO2 pump and the CSP system connected to the HTS tank to heat up the MTS tank, increasing its temperature to 650°C. In this second permutation for the CSP/HTS configuration, the heat exchanger for the sCO2 engine bypasses the MTS tank.

3. Analysis

Both configurations occur in a two-phase manner, with the first being the charging phase and the latter being the discharging phase. During the charging phase, different thermal storage components are charged to desired temperatures. For the HTS and MTS heat is added, and for LTS heat is extracted (pumped into the MTS),
producing ice. Using the Engineering Equations Solver (EES) software, high-level thermodynamic, steady state analysis was performed to compare the theoretical, idealized performance of both systems during discharging.

3.1. Configuration A

Figure 2 shows the T-s and P-v diagrams for the sCO₂ engine with an output of 2kWe. A turbine with an isentropic efficiency of 88% was used to obtain the estimated mass flow rate for the engine, resulting in a mass flow rate of approximately 9.91 g/s of sCO₂. This value is bound to increase once frictional losses among other losses are introduced into the analysis. The overall thermal to electric efficiency was found to be 26.46% during discharge.

3.2 Configuration B

Figure 3 shows the T-s and P-v diagrams for the sCO₂ engine with an output of 2kWₑ. A turbine with an isentropic efficiency of 88% was used to obtain the estimated mass flow rate for the engine, resulting in a mass flow rate of about 10.11 g/s of sCO₂ for our idealized, simplistic thermodynamic analysis. Again, this value will increase due to frictional losses among other losses are introduced into the analysis. Configuration B exhibits an overall thermal to electric efficiency of 13.85% during discharge.

4. Conclusion

Cycle performance for two thermal energy storage (TES) configurations under varying operational modes was assessed. Even when both systems are operating at similar conditions, configuration A has a better thermal to electrical efficiency. However, configuration B offers the advantage of possible longer discharging periods as well as the capabilities of keeping the sCO₂ engine operating during the charging phase while configuration A only allows for energy production during the discharging phase.

References