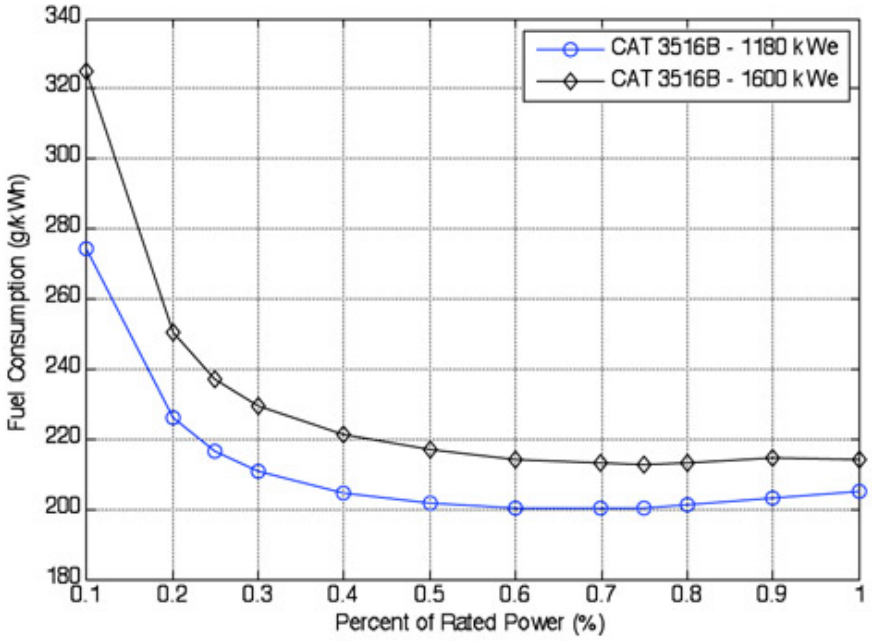
Evaluation of the Benefits of Large-Scale Energy Storage using Sodium-Sulfur Batteries for Marine Transportation

Introduction

This research assesses the potential for decreasing the fuel consumption of a large (100m) passenger vessel through the incorporation of an energy storage device. Ships of this scale typically use multiple diesel generator sets (gensets) to meet all propulsion and hotel power demands. Here, we use four Caterpillar units consisting of two 3516B gensets capable of producing 1180 kWe and two 3516B gensets rated at 1600 kWe. The fuel consumption data for these units is shown in Figure 1.



The base scenario varies genset load and turns units on and off to meet all ship power demands. A typical ship's duty cycle consists of 9 operational modes of varying duration and power demand, and is based on averages of annual data for such a vessel. The details of this load profile can be seen in Table 1. The indicated time distributions were applied on a monthly basis, such that each mode was visited for the indicated percent of time in a month, and that duty cycle was repeated 12 times annually. For the base scenario, an optimization routine was run for each mode, with the results also shown in Table 1. The total fuel consumed is 5195.2 m3/yr, where m3 is the volume of diesel fuel in cubic meters.

Table 1. Typical ship load duty cycle is based on averages from yearly operation.

Mode and Load Demand (kW)	Time In Mode	Total Fuel Used (m^3)	Genset % Full Load	GenSet Sizing (genset kW rating)
Mode 1 (365.4)	• 10%	• 80.2	• 31%	• 1x1180
Mode 2 (705.7)	• 10%	• 147.4	• 60%	• 1x1180
Mode 3 (1765.0)	• 1%	• 36.9	• 75%	• 2x1180
Mode 4 (5207.6)	• 4%	• 456.4	• 94%	• 2x1180 + 2x1600
Mode 5 (3107.6)	• 25%	• 1669.3	• 79%	• 2x1180 + 1x1600
Mode 6 (2086.4)	• 5%	• 221.0	• 88%	• 2x1180
Mode 7 (2743.4)	• 5%	• 294.2	• 69%	• 2x1180 + 1x1600
Mode 8 (3147.0)	• 15%	• 1014.7	• 80%	• 2x1180 + 1x1600
Mode 9 (2373.0)	• 25%	• 1275.1	• 60%	• 2x1180 + 1x1600

Next, a large-scale energy storage device was incorporated to manipulate power loads aimed at reducing fuel consumption, as in a hybrid-electric vehicle. A 1042 kW, 7,500 kWh sodium-sulfur battery pack was used, capable of fitting within the ship's allocated ballast. The system controller was designed to work on a rule-based strategy to maintain genset load percent at its peak level while keeping battery state-of-charge (SOC) near a specified target value. The result of the hybrid configuration simulation is an annual fuel consumption of 5102 m3/yr, which is a 2% savings over the base scenario of 5195 m3/yr.

Figure 2 illustrates the instantaneous fuel consumption rate for both the base model without energy storage, and this hybrid model with energy storage for the first 1,000 hours of the same duty cycle defined above. This illustrates the difference in fuel consumption tendencies created by the battery. The way the energy storage system works is to increase the diesel gensets' fuel consumption rate when it favorable yields more power per unit fuel and store it, or else decrease the total load on the generator sets, thereby decreasing consumption.