Fuel Saving Effects Using ESS for Shipboard Generators and Influence of Load Demand Variations

Tokyo University of Marine Science and Technology ◎Norichika Nagayama Hiroyasu Kifune

1. Introduction

Under multiple conditions in which onboard generators operate in parallel, the per-unit load factor of each generator tends to decrease and the efficiency also tends to deteriorate. This study addresses these issues by utilizing an energy storage system (ESS) in an onboard grid system. The ESS aims to control the load of generators indirectly, which improves the fuel efficiency of the generators. When the generator's load factor is low, the ESS is controlled to absorb power to raise the load factor and promote high-efficiency operation. When the power demand increases temporarily, an additional generator starts to supply electricity in ordinal situation. However, it is possible to avoid starting a generator by discharging power from the ESS, which prevents the generators from running under low-load conditions caused by parallel running. An original simulation was developed to estimate the performance of the ESS in terms of the fuel savings. This study addresses why fuel consumption can be reduced by the ESS.

2. Onboard grid with ESS

In the simulation, it was assumed that the ESS was installed in the AC power system of electric propulsion ship A, which had three 750 kW generators(Fig.1).

The ESS consists of an AFE converter, a chopper, and a battery bank connected in series to the AC bus. The AFE converter and chopper employ IGBTs with a rated voltage of 1700 V, and their rated output is 600 kW. The battery bank consists of numerous lithium-ion cells, the specifications of which are listed in Table 1. The entire battery capacity was approximately 280 kWh.

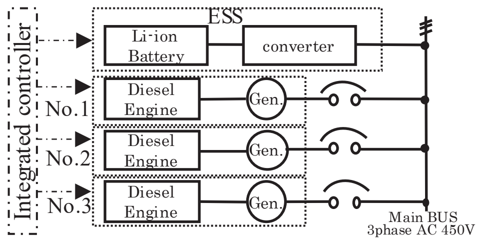

Fig.1 Onboard power system with ESS

Table.1 Specifications of lithium-ion cell

End-of-charge voltage [V/cell]	4.2
Nominal voltage [V/cell]	3.5
End-of-discharge voltage[V/cell]	2.8
C-rate	2
Current capacity [Ah/cell]	10
Internal impedance [Ω/cell]	0.01

3. Simulation Methods

The onboard power system including the ESS is monitored and controlled by an integrated controller. The ESS was charged and discharged so that the load factor of the running generators reach close to 80%. When the running generator and ESS cannot satisfy the power demand, an additional generator is started in an appropriate sequence. The characteristics of the fuel consumption of the generator were modeled based on the measured data of the main generator characteristics at Ship A. It calculates the fuel consumption according to the load factor. The power losses in the ESS and battery were calculated sequentially according to the SOC of the battery and the requested power on the converter. The energy dissipation of the entire power system was calculated every second according to the load conditions, which changed over time.

The electricity demand data measured by Ship A for 23 days were used in the simulation. The difference between the calculated results of the simulation and the observed data was sufficiently small to be within the accuracy guarantee of the fuel flow meter of Ship A. Therefore, it can be concluded that the simulation results were verified.

4. Simulation results and discussion

To evaluate the effectiveness of the ESS, fuel consumption was calculated by simulating the actual operation without the ESS. The fuel-saving effect of the ESS was set as the baseline (Fig. 2). The fuel consumption saving rate varies significantly from day to day.

Figure 3 shows the saving rate for the parallel running time of the generators. The time at which the generators were running in parallel during the actual operation was used as the base value. This shows how long the ESS prevents the generator from running. The fuel consumption saving rate depends on the saving rate of the parallel running time. In other words, the shorter the parallel running time of the generators using the ESS, the more fuel that can be saved.

To clarify this mechanism, the observed data in terms of the parallel running time were analyzed (see Fig.4). For instance, it shows that the generators operated in parallel for the entire day during navigation from 2nd to 4th of Feb. 2023. Parallel running time was classified into two states. One is in a state where the power demand is between 200 kW and 675 kW (Load Condition I), where 675 kW corresponds to a 90% load of a generator. Another state shows that the power demand was between 675 kW and 1275 kW (Load Condition II), where 1275 kW is the sum of the 90% load of the generator and the rated power of the converter in the ESS.

Comparing figures 3 and 4, the longer the time of load condition I, the greater is the reduction in the parallel running time of the generators. However, if the time of load condition I is short like 230202, the parallel running time cannot be decreased.

Looking closely at the data of 170208, the parallel running time in load condition I is approximately eight hours. However, the load factor of the generator reached condition II for several tens of minutes. Engineers may be concerned that the generator load may exceed 675 kW in this case. Therefore, they decided to run the two generators in parallel although one generator can supply sufficient electricity on most days. The ESS can supply electricity instantaneously when the power demand exceeds the set threshold value. Therefore, engineers may not be concerned with generator overload. If they let the integrated controller governs the operation of the generators and ESS automatically, the parallel running time can be reduced, as shown in Fig.3.

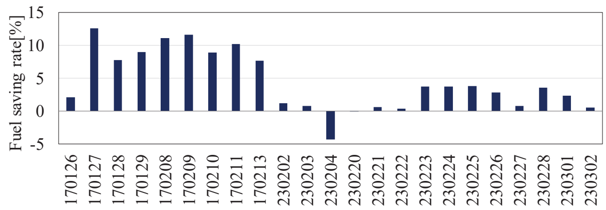

Fig.2 Fuel saving rate

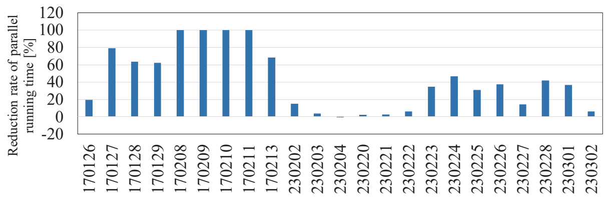

Fig.3 Reduction rate of parallel running time

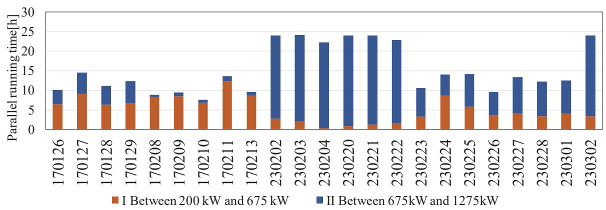

Fig.4 Parallel operation time of generators by electricity demand zone