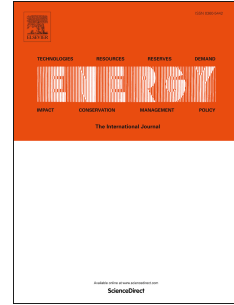


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Optimal Sizing of Hybrid Energy Storage Subsystems in PV/Diesel Ship Power System Using Frequency Analysis

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5 **Abstract**—Owing to the increasing concerns about the release of pollution by traditional ships, the
 6 use of the renewable energy in ships' power systems is attracting much attention. However, an
 7 improperly designed renewable generation system and energy storage system (ESS) will increase
 8 costs and greenhouse gas emissions. This paper proposes a mathematical model of a photovoltaic (PV)
 9 power generation system for a ship, taking into account the effects of ship rolling. A PV system on
 10 the shipboard, unlike one on land, has to confront dramatic power fluctuations that are caused by
 11 the motions of the ship and bad weather, so hybrid ESSs play a significant role in a ship's power
 12 system. In this work, the discrete Fourier transform (DFT) is employed to decompose the required
 13 balancing power into various time-varying periodic components, which are utilized to calculate the
 14 maximum required power of the hybrid energy storage systems. A cost analysis is performed using
 15 particle swarm optimization (PSO) algorithm to optimize the size and capacity of various types of
 16 energy storage systems. Simulation results reveal the efficiency of the optimal allocation of the ESSs.

17 **Index Terms**—Hybrid energy storage system, photovoltaic generation, ship rolling, discrete
 18 Fourier transform, particle swarm optimization.

Nomenclature

Acronyms

| | |
|------|-------------------------------------|
| CRF | capital recovery factor |
| DFT | discrete Fourier transform |
| ESS | energy storage system |
| FFT | fast Fourier transform |
| GA | genetic algorithm |
| HESS | hybrid energy storage system |
| IMO | international maritime organization |
| PSO | particle swarm optimization |
| PV | photovoltaic |

Variables

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