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Optimal Power Management for Ship Propulsion Systems Using Differential Evolution Algorithms

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Abstrat: The electrification of maritime vessels, particularly their propulsion systems, is a highly active area of research. Utilizing shaft motors for parts of the ship's propulsion system emerges as a particularly promising approach. Traditionally, power dispatching on ships is conducted through simplified methods, unlike the complex optimal power dispatching methods used in mainland power systems. This study introduces an optimal power management algorithm incorporating differential evolution algorithms, ship technology, operational constraints, and environmental regulations set forth by the International Maritime Organization. By leveraging technical data from actual diesel engines, alternators, main generators, and auxiliary generators, various ship propulsion and power generation configurations were analyzed and compared. The findings demonstrate significant benefits, including reduced operating costs of the ship's power system, achieved through the implementation of the proposed algorithm.

Keywords: Marine power system ,greenhouse gas emissions,energy management scheme.

1. Introduction

Improving ship efficiency has always been a top priority in the shipping industry. As the ongoing global economic crisis is affecting all aspects of daily life-including transportation and trade-and environmental protection measures are being implemented more strictly, the demand for platforms to operate at lower costs is becoming more and more intense [1].

In the face of such a problem, some scholars have drawn continuous attention and related research. Some scholars continue to pay attention and carry out corresponding improvement research. Ameen M et al. Proposed a state-based energy management strategy, an equivalent fuel consumption minimization strategy (ECMS), power consumption maintenance charge (CDCS), and a classic proportional integral (PI) controller for hybrid fuel cell passenger ships. Four schemes, use different management schemes for different scenarios [2].Lisi Zhu et al. Proposed a fuzzy logic-based energy management strategy for fuel cell hybrid ships. The results show that the method used can meet the needs of ship loads, reduce fuel requirements, and optimize the performance of hybrid modules [3]. Michalopoulos et al. Adopted dynamic planning schemes and the scheme of adding shaft generators to manage the ship's power and power system, both of which can reduce the greenhouse gas emissions and reduce the ship's operating costs to varying degrees [4].

This article will study the economic distribution of ship generator load. Compared with the currently widely used method of proportional distribution, this issue will be handled in a way that reduces overall operating costs overall. To this end, the characteristic fuel consumption curves of generators and propellers will be considered, as well as technical and environmental constraints. Finally, by adjusting the cruising speed of the ship and deploying the optimal power generation scheduling to optimize the management of the propulsion load.

2. Ship Energy Management

2.1. Classic Power Management

In a classic ship configuration, the propulsion system consists of a prime mover (diesel engine, gas turbine, etc.) coupled to the propeller through a gearbox and shaft, a simple line diagram is shown in Figure 1.

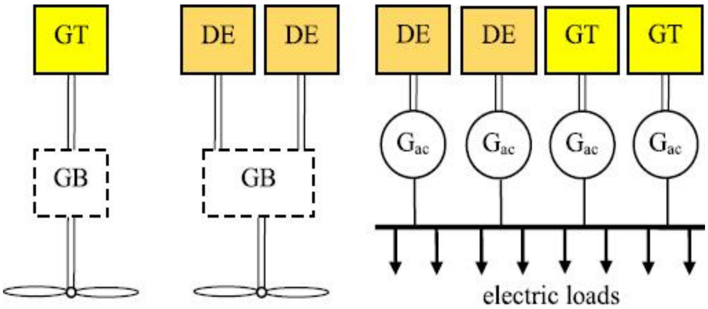

Fig 1. Generic line diagram of classic ship configuration (DE: diesel engine, GT: gas turbine, GB: gear box, and Gac: ac generator).

The optimized scheduling of the ship energy management system optimizes the scheduling of the ship's sailing speed, the start and stop status of the generator set, and the power distribution of the generator set when the system constraints are met.

The objective function is:

$$\min C = C_e + C_{pr} \tag{1}$$

In the formula: C is the total operating cost of the system; Ce is the total operating cost of the ship's power system; Cpr is the total operating cost of the ship's propulsion system, and the measurement unit of the operating cost is a monetary unit (m.u.).

2.2. ship power system

For the ship's power system, the total operating cost Ce is calculated according to formula (2).

$$C_e = \sum_{j=1}^{T}\sum_{i=1}^{N_E}\left\{P_{ij}\times\Delta T_j\times\left[t_{ij}\times\left(F_{c_i}\times S_{FC_i}\left(P_{ij}\right)+W_{Cij}\right)\right]+Q_{Cij}\right\} \tag{2}$$

In the formula: T is the total sailing time of the ship, the unit is h; N_E is the number of generators; ΔT_j is the j_{th} time period, the unit is h; P_{ij} is the power generated by the i_{th} generator in the ΔT_j time period, the unit is MW; t_{ij} is the coefficient, for the i_{th} generator, if it is running, it will take 1, otherwise it will take 0; f_{ci} is the cost of the unit fuel consumed by the generator, the unit is mu; s_{fci} is the specific fuel consumption of the generator, which is a curve; w_{cij} is the total maintenance cost of the diesel engine and generator started at ΔT_j time, in units of mu; q_{cij} is the startup cost of the diesel engine and generator started at ΔT_j time, in units of mu.

2.3. Ship Propulsion System

For the propulsion system, its operating cost Cpr can be expressed as:

$$C_{pr} = \sum_{j=1}^{T}\sum_{q=1}^{N_{pr}}\left\{t_{qj}\times P_{qj}\times\Delta T_j\times\left[t_{ij}\times\left(F_{cq}\times S_{FC_q}\left(P_{qj}\right)+W_{Cqj}\right)\right]+Q_{Cqj}\right\} \tag{3}$$

In the formula: N_{pr} is the number of diesel engines; t_{qj} is the coefficient, for the q_{th} diesel engine, if it is running, it is taken as 1, otherwise it is taken as 0; P_{qj} is the power output of the q_{th} diesel engine in ΔT_j time, the unit is MW; f_{cq} is The fuel cost of the q_{th} diesel engine at the time of ΔT_j, unit is MW; sfc_q is the specific fuel consumption of the q_{th} diesel engine, is a curve; w_{cqj} is the maintenance cost of the diesel engine and generator started at the time of ΔT_j, the unit is mu; q_{cqj} is the starting cost of the diesel engine and generator started at the time ΔT_j, and the unit is m.u.

3. Ship Related Parameters

Table 1. Ship power system model data

Ship parameters	GEN1	GEN2	GEN3	MOVER1	MOVER2
rated power /MW	4	4	4	17. 5	17. 5
Maximum power /MW	4	4	4	17. 5	17. 5
Minimum power /MW	1	1	1	4. 35	4. 35
CO^2 emissions/g	2. 7655	2. 5	2. 5	3. 2	3. 2
Minimum start and stop time /h	1/1	1/1	1/1	1/1	1/1
Switch consumption cost /m.u.	200/0	200/0	200/0	200/0	200/0
Fuel consumption /(m.u.•t^{-1})	500	500	500	450	450
Fuel mass per unit of power per hour /(kg•MW^{-1}•h^{-1})	$343.5-80.3P+12.5P^2$	$346.7-73.8P+11.12P^2$	$345.6-69.6P+10.44P^2$	$211.7-5.21P+0.2315P^2$	$210.7-4.47P+0.1988P^2$

Here, a route with a total length of 307.7442n mile is simulated, and 3 ports will stop in the middle of the route. During the voyage to these three ports, the actual number of passengers, actual cargo volume and load factor of the ship are shown in Table 2.

Table 2. Date for ship fullness

Starting and ending routes	Actual number of passengers	Actual cargo load / t	Load factor
Departure-Port 1	1515	400	38104
Port 1—Port 2	1255	375	35882
Port 2-Port 3	1319	402	38276
Port 3-destination	1331	405	38577

This article takes three different ways to calculate the operating cost. Case 1 is not optimized, case 2 is partially optimized for generators and propulsion components, case 3 is fully optimized for generators and propulsion components. And compares the various parameters as follows:

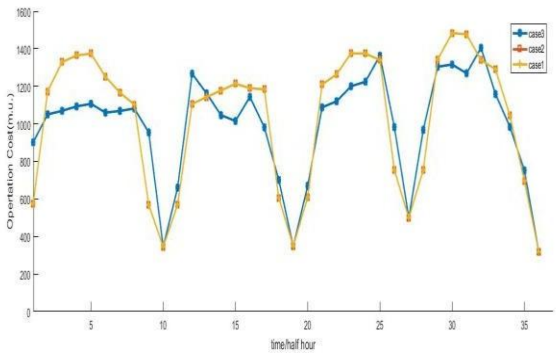

Fig 2. Operation Cost

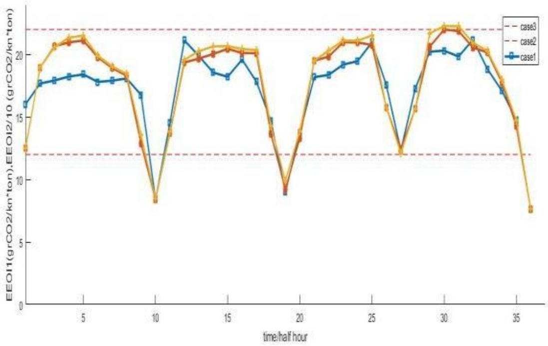

Fig 3. EEOI

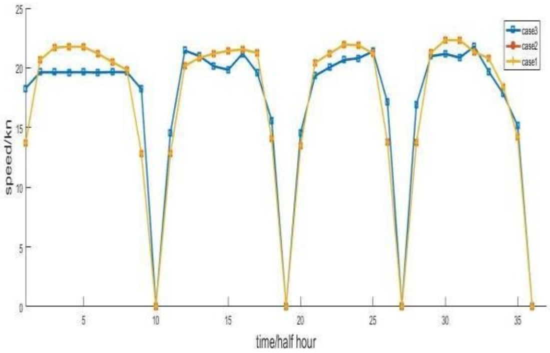

Fig 4. Ship speed

Case 1 is very similar to case 2. case 3 has a lower operating cost than the former, saving 2.88% of the cost. And the running speed is more stable than the previous ones, and it has better stability. At the same time, the co2 emitted by ships is lower than the upper limit of the eeoi standard, which meets the requirements of environmentally friendly emissions of greenhouse gases. Therefore, the parameters of case 3 are better.

4. Summary

This paper proposes an optimal power management method for complex ship power systems. Facts have proved that it will minimize operating costs and limit greenhouse gas emissions, while meeting the ship's power system technology and operating constraints, including energy and power balance, total travel distance, etc. Propulsion power adjustment is used to achieve efficiency optimization without the use of energy storage systems or any huge investments related to classic ship configurations. The proposed algorithm can be used to evaluate the integration of the shaft motor with any ship type and ship power plant configuration. It is completely parameterized and does not depend on any specific characteristics of the ship's main engine or generator.

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