Optimization of PV-hybrid electric propulsion system with environment uncertainty

Jianyun Zhu, Li Chen*

State Key Laboratory of Ocean Engineering, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiao Tong University, Shanghai, China

ABSTRACT

Solar radiation resource is abundant in open water and can help reduce fuel consumption and emission of ships if used reasonably. In this paper, a PV-hybrid electric propulsion system (PV-HEPS) is proposed as well as an optimization method for the system pursuing minimum fuel consumption and greenhouse gas (GHG) emission considering the use of shore power. Firstly, the PV-HEPS is modeled. Then, Monte Carlo method and NSGA-II algorithm are introduced to handle the multi-objective optimization problem considering the uncertainty in global solar irradiance, temperature and water speed. The proposed probabilistic simulation-based optimization approach is applied to a tourist ship cruising on the Huangpu River. Simulation results show that the system optimized by the proposed method provides benefits on average fuel consumption and GHG emission compared with a traditional propulsion system.

KEY WORDS: Multi-objective optimization; PV-hybrid electric propulsion system; environmental uncertainty; Monte Carlo method.

NOMENCLATURE

- \( k \): function of hull form geometry
- \( AMEP \): available mean effective pressure
- \( B \): breadth
- \( BMEP \): brake mean effective pressure
- \( B_{\text{low}} \): upper bound of SOC
- \( B_{\text{up}} \): lower bound of SOC
- \( G \): solar irradiance
- \( G_0 \): standard solar irradiance
- \( I_{\text{bat}} \): current of the battery cell
- \( I_{\text{bat}, \text{max}} \): maximum current of discharge
- \( I_{\text{bat}, \text{min}} \): maximum current of charge
- \( I_{\text{ele}} \): average lifecycle GHG intensity of shore electricity
- \( I_{\text{luc}} \): lifecycle average GHG emission of diesel fuel
- \( I_{\text{sc0}} \): short-circuit current of the PV module under standard solar irradiance
- \( K \): Boltzmann constant
- \( K_T \): thrust coefficient of the propeller
- \( K_{T_i} \): thrust factors of the propeller
- \( K_Q \): torque coefficient of the propeller
- \( K_{Q_i} \): torque factors of the propeller
- \( m_{f_{\text{year}}} \): annual fuel consumption
- \( m_{\text{GHG}} \): annual GHG emission
- \( m_{\text{su}} \): fuel consumption of DG per startup
- \( n \): ideality factor of the PV module (1 < n < 2)
- \( n_{\text{bat}} \): number of battery modules in the ESS
- \( n_p \): propeller speed
- \( n_{\text{su}} \): number of the DG startup times
- \( \text{SOC} \): state of charge
- \( T \): temperature
- \( T_0 \): standard temperature
- \( T_p \): effective thrust of one propeller
- \( t_{\text{t}} \): thrust deduction coefficient
- \( N_p \): number of propellers
- \( P_{\text{bat}} \): terminal power of the battery cell
- \( P_{\text{DGrate}} \): rated power of DGs
- \( P_{\text{ESS}} \): power of the ESS
- \( P_{\text{ESSmax}} \): max discharge power of the ESS
- \( P_{\text{ESMin}} \): max charge power of the ESS
- \( P_{\text{PV}} \): output power of single PV module
- \( P_{\text{PVsys}} \): output of the PV system
- \( P_{\text{req}} \): total power demand
- \( Q_{\text{bat}} \): battery capacity
- \( q \): magnitude of the electron charge
- \( R_{\text{bat}} \): internal resistance

\( j=0,1,2 \)

\( q_{ij} \): Willans factors

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