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Optimizing Hybrid Energy Storage Management for Advanced Reactor-Powered Maritime Vessels via Hierarchical Multi-Agent Reinforcement Learning

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ABSTRACT:

The maritime industry is facing increasing pressure to reduce greenhouse gas emissions and improve energy efficiency. All-electric ships have emerged as a promising solution to meet these challenges. These ships rely on electric power generated by a prime mover, which can be powered by various sources such as batteries, fuel cells, small modular reactors (SMRs), or microreactors. Among these options, SMRs/microreactors are a promising candidate as they can provide a reliable and long-lasting source of energy for all-electric ships.

The overall objective of this Phase II project is to develop optimal operation and planning strategies for SMR/microreactor-based maritime vessels equipped with a hybrid energy storage system by utilizing multi-agent deep reinforcement learning over graph for hierarchical control. The novelty of the proposed approach lies in: (i) developing multi-agent reinforcement learning for managing the hybrid energy storage system onboard a reactor-based vessel, capable of performing multi-timescale operation along with multi-fidelity models and varying levels of abstraction (including interactions among agents and layers, as well as the complex relationships between local and global information), (ii) optimizing the operation of both the hybrid energy storage system and the reactor-based shipboard power system, and (iii) planning the optimal capacity for HES system components as well as essential reactor-based vessel components under uncertainties, such as the reactor and propulsion system. To realize these novel contributions, we have outlined a research plan with the following three major research tasks.

- Task 1: Reactor, Battery, and Thermal Energy Storage Systems Sizing: This task aims to optimize the sizing and dispatching of SMRs/microreactors, batteries, and thermal energy storage systems while accounting for uncertainties in voyage or other working conditions based on the type of vessel, by leveraging a joint stochastic optimization scheme.
- Task 2: Hierarchical Control of Reactor, Battery, and Thermal Energy Storage Systems: This task is to study a hierarchical control strategy for the optimal operation of different resources deployed onboard, integrated with multi-agent reinforcement learning and graph-based state representation for hybrid energy systems and shipboard power systems.
- Task 3: Hardware-in-The-Loop Test: This task will evaluate the proposed hierarchical control strategy for HES within all-electric ships using a Hardware-in-The-Loop system.