AI-accelerated physics-informed transient real-time digital-twin of SMR-based multi-domain submarine power distribution

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Small Modular Reactors (SMRs) have emerged as promising solutions for next-generation marine propulsion systems due to their enhanced efficiency, reduced maintenance requirements, and extended operational capabilities. However, traditional transient modeling methods for these systems often rely on conventional numerical integration techniques, which encounter significant challenges when dealing with nonlinear system dynamics, leading to considerable computational latency and extensive parameter tuning efforts. To address these limitations, this paper introduces an artificial intelligence (AI)-accelerated physics-informed real-time digital-twin (RTDT) for an SMR-based multi-domain submarine power distribution system. The proposed approach integrates physics-informed machine learning (PIML) methodologies, combining neural network models with explicit physical constraints. Leveraging the parallel computing capabilities of the Xilinx® UltraScale+ FPGA hardware platform, the proposed framework significantly reduces computational latency. The emulation results validate the effectiveness and efficiency of the proposed PIML-based RTDT, achieving mean percentage absolute errors (MPAEs) consistently below 1%, thus demonstrating superior performance compared to classical numerical methods.

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