

Quantum Optimization in Multi-Objective Design of Renewable Energy Conversion Systems

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Abstract—The design and operation of renewable energy conversion systems—such as wind turbines, solar photovoltaic arrays, and hybrid storage networks—require balancing multiple, often conflicting objectives, including energy efficiency, cost minimization, environmental impact, and system reliability. Traditional optimization techniques, while effective for isolated parameters, struggle with the combinatorial complexity and nonlinear interdependencies inherent to integrated energy systems. This study explores the application of quantum optimization algorithms in multi-objective renewable energy design, emphasizing how quantum annealing, Quantum Approximate Optimization Algorithm (QAOA), and Variational Quantum Eigensolver (VQE) frameworks can accelerate solution discovery and improve design precision. By leveraging the principles of superposition and entanglement, quantum systems can process vast design spaces in parallel, enabling the rapid evaluation of trade-offs among competing objectives. A hybrid quantum–classical workflow is proposed to integrate quantum solvers into existing computational pipelines for system simulation, control optimization, and energy forecasting. Preliminary modeling results and conceptual simulations indicate that quantum-enhanced optimization not only reduces computation time but also achieves higher Pareto-optimal efficiency compared to conventional multi-objective genetic algorithms and particle swarm optimizers. This interdisciplinary approach demonstrates the transformative potential of quantum computation in sustainable energy system design, supporting the global transition toward carbon neutrality and energy equity. By embedding quantum optimization into renewable infrastructure development, the study provides a foundation for next-generation decision-making frameworks that harmonize performance, sustainability, and scalability.

■ As the world transitions toward sustainable energy, optimizing renewable energy conversion systems has become a critical engineering challenge. Renewable sources such as solar, wind, hydro, and geothermal energy are inherently variable and interdependent, demanding integrated systems capable of balancing energy generation, storage, and distribution under

dynamic environmental conditions [6]. The design process for such systems often involves multiple objectives—maximizing energy yield, minimizing cost and emissions, and ensuring long-term system reliability. However, classical optimization methods are limited in their ability to handle the large-scale, nonlinear, and multi-variable nature of these problems, particularly as renewable energy systems grow in complexity and interconnectivity [7].

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