ECCOMAS Thematic Conference
Applied Quantum Methods in Computational Science and Engineering – AQMCSE 2025
October 8–10, 2025, Aachen, Germany

CAN ADIABATIC QUANTUM COMPUTING ADDRESS UNSOLVED CHALLENGES IN POWER SYSTEM PROBLEMS?

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Key Words: *Ising Machines, Quantum-Inspired Devices, Noisy Intermediate-Scale Quantum (NISQ) Era, Nonlinear Equations, State Estimation, Quadratic Unconstrained Binary Optimization (QUBO).*

ABSTRACT

The increasing complexity of modern power systems challenges conventional numerical solvers, especially for large-scale or ill-conditioned power systems. This work introduces a quantum-assisted framework that reformulates linear and nonlinear power system problems into binary optimization tasks suitable for adiabatic quantum computing. The framework uses iterative refinement and QUBO formulation to enable compatibility with Ising machines, including quantum and quantum-inspired devices. Experimental results using the D-Wave Advantage™ system (QA) and Fujitsu's Quantum-Inspired Integrated Optimization software (QIIO) platforms demonstrate successful parameter identification and power flow (PF) analysis with high accuracy. In addition, the framework exhibits promising scalability, solving systems with up to 1354 buses for PF analysis. These findings highlight the potential of quantum-classical hybridization for future power system applications.

1. Problem Description and Relevance

The growing integration of renewable energy resources and the increasing dynamics of power system operations introduce significant computational challenges. Classical numerical techniques, such as Newton-Raphson for power flow (PF) and least-squares methods for parameter identification, often face convergence issues or become computationally inefficient when applied to large-scale or ill-conditioned systems [1]. Recent developments in quantum computing, particularly adiabatic quantum computing (AQC), and quantum-inspired optimization suggest a promising alternative for tackling such high-dimensional problems [2, 3]. However, a key obstacle is that conventional power system formulations are not naturally suited for AQC solvers, which require discrete, combinatorial representations.

This work addresses this gap by proposing a quantum-assisted framework that reformulates nonlinear and linear power system problems into binary optimization models compatible with AQC. By doing so, we aim to assess whether adiabatic quantum computing can offer reliable and scalable solutions where traditional methods struggle, particularly in cases of ill-conditioned systems or large variable spaces.

2. Methodology

The proposed quantum-assisted framework reformulates power system problems as combinatorial optimization tasks compatible with adiabatic quantum computing. At its core, the method treats nonlinear or linear equations of the form $F(x) = 0$ as root-finding problems. These are transformed into binary optimization problems by discretizing continuous variables using a base value and a fixed increment, with binary variables determining directional updates.

To align with the quantum annealing paradigm, the residual function $F(x)$ is squared, resulting in a cost function that can be embedded into a Quadratic Unconstrained Binary Optimization (QUBO) model. When $F(x)$ is linear or mildly nonlinear, its squared form yields linear and quadratic terms suitable for direct mapping onto QUBO matrices. For higher-order nonlinearities, auxiliary variables and reduction techniques are used to preserve the quadratic structure.

An iterative refinement loop updates the base values and resolution (Δx), adaptively adjusting based on trends in previous bitstring solutions. This approach improves convergence while maintaining compatibility with quantum or quantum-inspired solvers. The optimization continues until the objective value falls below a pre-defined threshold ε, indicating a sufficiently accurate solution. The proposed framework is shown in Fig. 1.

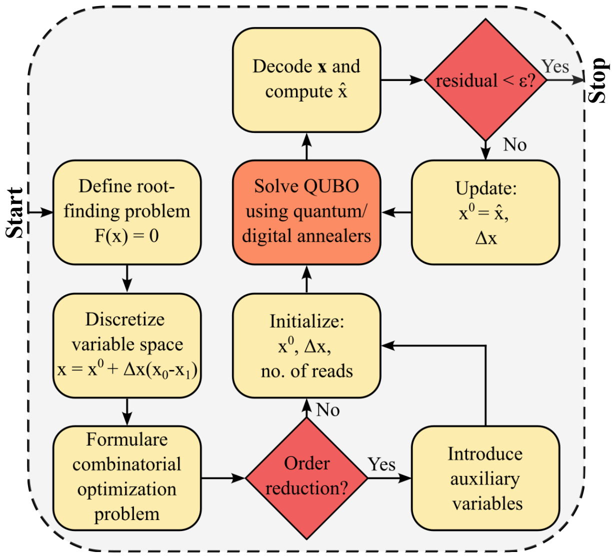

Figure 1: Schematic representation of the proposed framework for solving power system problems with Ising machines, i.e., quantum and digital annealers.

3. Practical Demonstration

To validate the proposed quantum-assisted framework for both linear and nonlinear problems, we perform experimental runs on real quantum hardware. Specifically, the D-Wave Advantage™ system (QA) is used to solve the reformulated QUBO problems corresponding to the parameter identification and PF analysis tasks. For the linear case, a 4-bus benchmark network is used to estimate the system admittance matrix, where the conductance and susceptance values are discretized and optimized. The quantum annealer successfully retrieves parameter values with a relative error below 3.9%, which demonstrates its applicability in real-world estimation problems.

For the nonlinear PF task, we apply the proposed quantum-assisted framework to compute bus voltage components that satisfy the active and reactive power balance equations. Discretized voltage variables are optimized using QA and Fujitsu's Quantum-Inspired Integrated Optimization software (QIIO). Accordingly, the maximum relative error obtained is below 0.3% for both QIIO and QA, which further demonstrates convergence toward physically meaningful operating points, hence confirming the feasibility of solving such nonlinear systems via adiabatic quantum computation.

4. Application Potential

To address realistic problem sizes, a hybrid approach combining quantum and classical computing resources is adopted. The quantum annealer handles discrete optimization over binary variables, while classical preprocessing and postprocessing stages manage tasks, such as variable encoding and solution decoding. This division of labor enables efficient use of quantum resources and mitigates current hardware limitations (e.g., [4]).

Complexity analysis indicates that the binary-encoded formulation grows polynomially with the number of buses and control variables. While standalone quantum hardware is currently limited in problem size due to constraints on qubit count and connectivity, quantum-inspired solvers, such as digital annealing, demonstrate significant capacity to manage mid- to large-scale cases. Specifically, QIIO has shown successful convergence on test systems up to 1354 buses, which highlights the viability of this approach at operational scales.

These results suggest that, through intelligent hybridization and algorithm design, quantum-assisted techniques can be extended to solve large-scale nonlinear power system problems with acceptable accuracy and runtime. As quantum hardware continues to evolve, this approach holds promise for deployment in future power system operation and planning tasks.

References

[1] J. Soares, T. Pinto, F. Lezama, and H. Morais, "Survey on complex optimization and simulation for the new power systems paradigm," *Complexity*, 2018.

[2] T. Morstyn, "Annealing-based quantum computing for combinatorial optimal power flow," *IEEE Transactions on Smart Grid*, 2022.

[3] F. Feng, Y. Zhou, and P. Zhang, "Quantum power flow," *IEEE Transactions on Power Systems*, 2021.

[4] Z. Kaseb, M. Möller, P. P. Vergara, and P. Palensky, "Power flow analysis using quantum and digital annealers: a discrete combinatorial optimization approach," *Scientific Reports*, 2024.