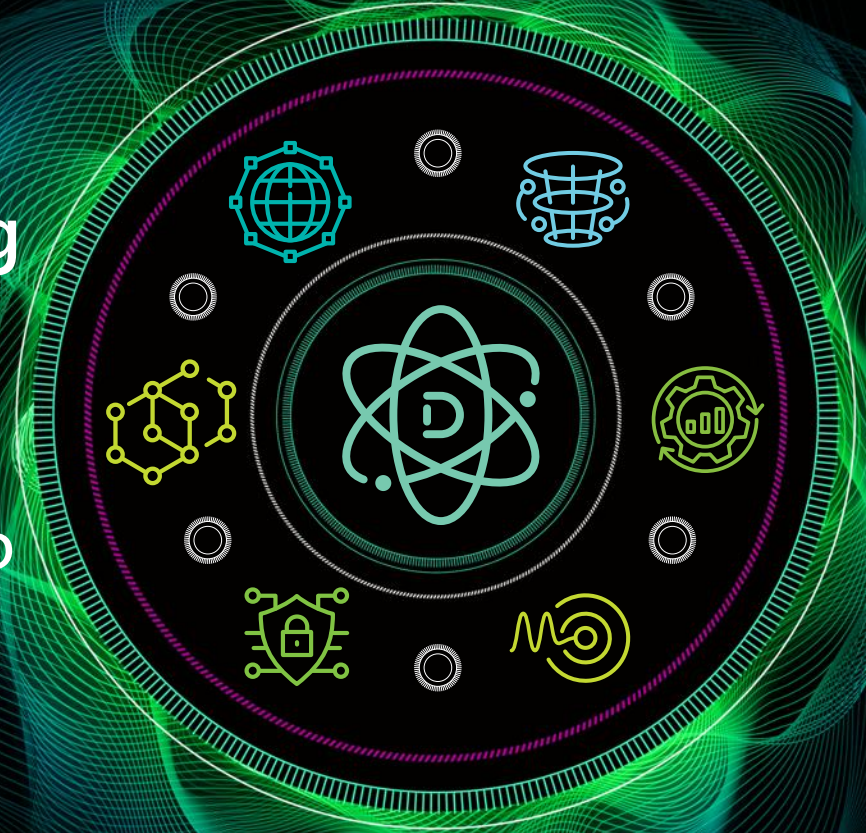
Quantum Computing Use Cases

Optimizing Supply–Demand Planning under Uncertainty with Quantum GAN × QAOA

The University of Electro-Communications and GRID



New Energy and Industrial Technology Development Organization (NEDO)

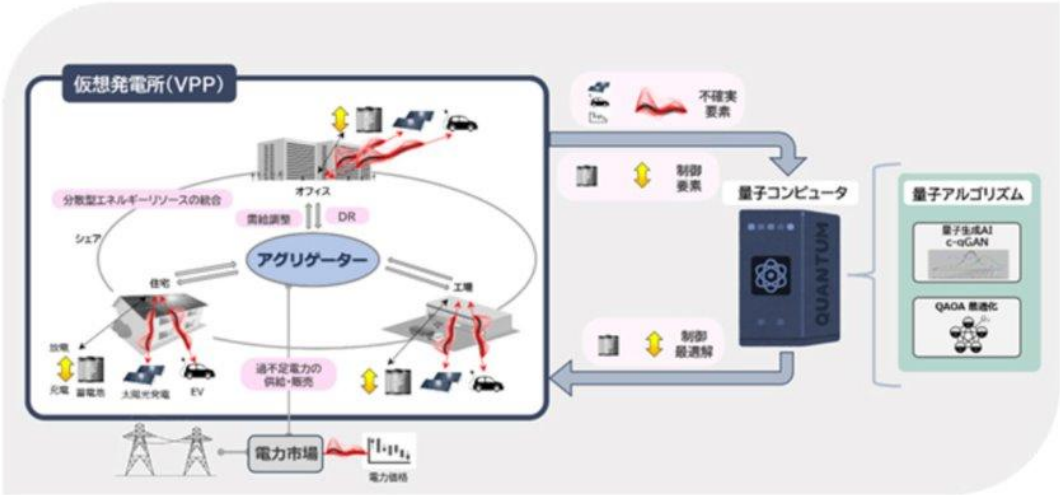
The University of Electro-Communications and GRID: Optimizing Supply–Demand Planning under Uncertainty with Quantum GAN × QAOA [2026/7] 1/4

Validation

Industry	Energy
Process	transmission and distribution
Method	Combinatorial Optimization, AI
Category	Gate*

Background

- As the introduction of renewable energy is expanding globally, the instability of power supply due to weather dependence has become an issue, and **supply-demand balancing through VPPs (Virtual Power Plants) plays an important role in realizing efficient and stable power supply**
- **At the core of supply-demand balancing is the generator start-up and shut-down schedule**. Since base-load power sources such as large-scale thermal power plants require time to start up, decisions on whether to start them must be made before photovoltaic (PV) power generation becomes known, whereas peak-load power sources such as small-scale gas-fired thermal power plants can adjust their output after the PV generation level is realized
- **The framework for handling this "decision before observing uncertainty" and "adjustment after observation" is two-stage stochastic programming**, which is also common to logistics delivery route planning and financial portfolio allocation
- Last year, quantum GAN and QAOA were developed separately as elemental technologies. This year, **the project moved to a phase in which the two are integrated into a single quantum circuit and evaluated quantitatively**



Illustrative application of quantum technology in VPP supply-demand balancing

Reference: Taihei Kuroiwa et al., "Proposal of a QAOA-Based Two-Stage Stochastic Programming Method Incorporating a Quantum Probability Distribution Generation Circuit," 18th Quantum Software Research Workshop; T. Kuroiwa et al., "Quantum-Circuit Framework for Two-Stage Stochastic Programming via QAOA Integrated with a Quantum Generative Neural Network," arXiv:2512.22434 (2025) (https://arxiv.org/abs/2512.22434); The University of Electro-Communications, "[Report] Selected for the Cyber-Physical Development Project for Quantum-Classical Hybrid Technologies Publicly Solicited by the New Energy and Industrial Technology Development Organization (NEDO)"
(https://www.uec.ac.jp/news/announcement/2024/20240910_6472.html)
This result was obtained through a NEDO-commissioned project (JPNP23003)
*Gate（gate-based）: A computing approach in which operations are applied sequentially to qubits to perform calculations. Similar in concept to logic circuits in classical computers, it can address a wide range of problems.

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Issues to be solved and motivation

- Stochastic programming approximates uncertainty using a set of scenarios, but **improving accuracy requires a substantial increase in the number of scenarios, making computation time and memory practical bottlenecks**
- Classical decomposition methods for solving large-scale problems by dividing them also have limitations. The L-shaped method cannot be applied when the second stage includes discrete variables, and in the Progressive Hedging Algorithm, when the first stage includes discrete variables, **it is difficult to achieve convergence of non-anticipativity (that is, ensuring that first-stage decisions do not differ across scenarios)**
- Even when solving with a quantum computer, **directly converting a two-stage stochastic program into QUBO form would require 195 qubits under the conditions of this case, which is beyond the scale that current quantum hardware can handle**
- Accordingly, **the goal was to design a quantum circuit whose circuit size increases only gradually with the number of scenarios and that satisfies non-anticipativity without additional constraints**

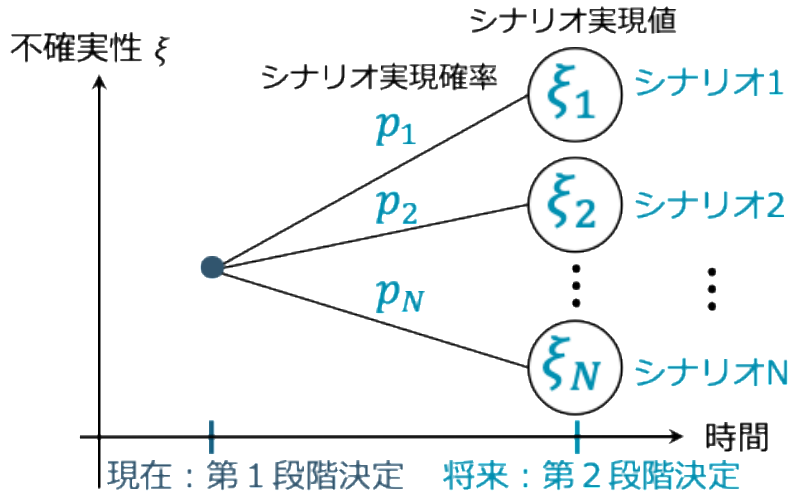


Illustration of two-stage stochastic programming

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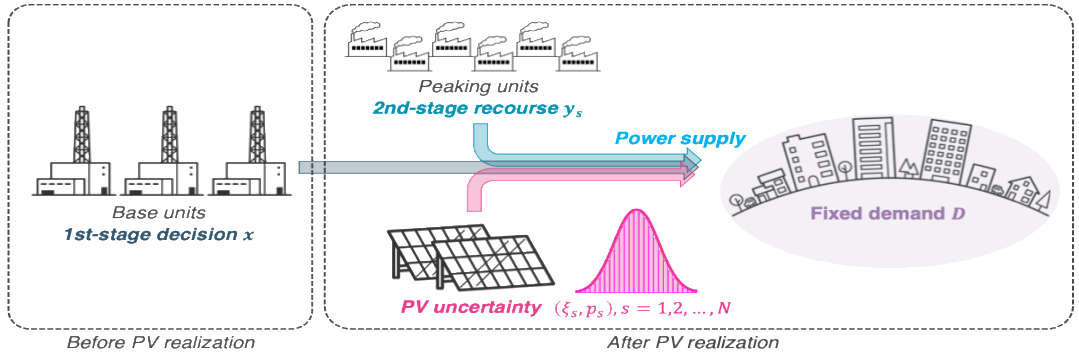
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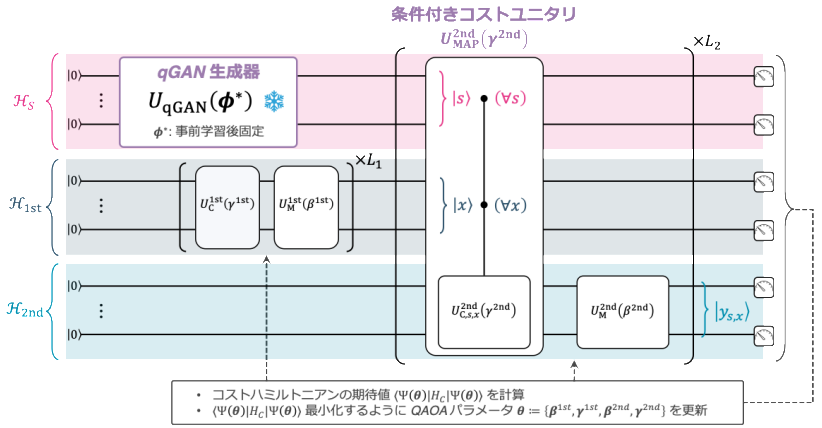
Problem formulation for quantum computer

- **The target problem was a stochastic unit commitment problem**, in which the start-up and shut-down schedule of generators is determined at minimum cost under uncertainty in photovoltaic (PV) power generation
  - ✓ **The start-up decisions for three base-load units, corresponding to large-scale thermal power plants** that require time to start up, are made in the first stage before the PV generation level becomes known
  - ✓ **The output levels of six peak-load units**, corresponding to small gas-fired thermal power plants that can start up quickly, **are adjusted in the second stage after the PV generation level is realized**
  - ✓ PV generation **was discretized into 32 scenarios following a beta distribution**
  - ✓ **The objective is to minimize the sum of the expected start-up cost, the expected generation cost, and penalties for violations of supply-demand constraints**



Generator unit commitment planning under PV uncertainty

- The proposed method consists of the following three elements:
  - ✓ **A quantum GAN is used to learn the distribution of PV generation**, and **the scenario distribution itself is retained as a quantum state** by amplitude encoding it into a 5-qubit superposition state
  - ✓ Instead of duplicating second-stage variables for each scenario, **a quantum mapping gate is used to reflect scenario information in the second-stage cost**
  - ✓ **By separating the mixers for the first and second stages, non-anticipativity is guaranteed by the circuit structure, eliminating the need for additional penalty terms**
- As a result, the problem considered in this case, which would require 195 qubits under a conventional QUBO formulation (3 first-stage binary variables + 6 second-stage binary variables × 32 scenarios), can be represented using a total of 14 qubits: 5 for scenarios, 3 for the first stage, and 6 for the second stage.



Quantum circuit configuration of the proposed method

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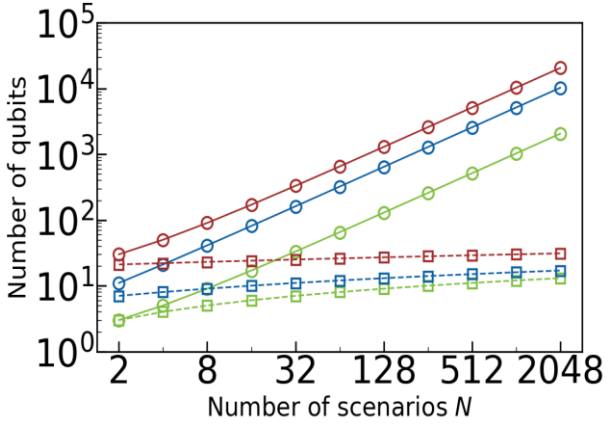
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Expected business benefits

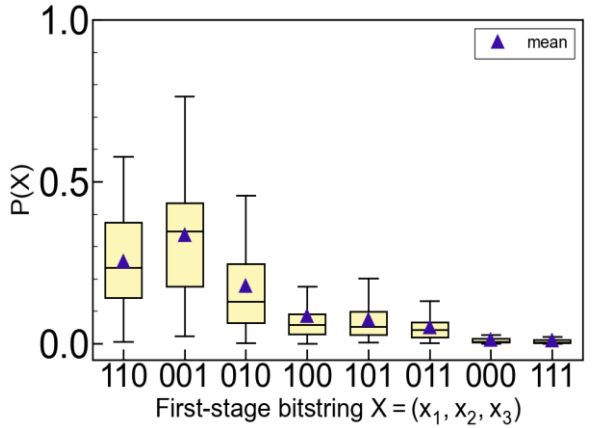
- For the same problem and the same number of scenarios, **a two-stage stochastic program that would require 195 qubits when converted into QUBO form for standard QAOA or quantum annealing (QA) was implemented using 14 qubits**. Because the increase with respect to the number of scenarios can be kept logarithmic, **this opens a path for handling such problems on currently available quantum computers**
- It **was confirmed that the evaluation metric for non-anticipativity remained sufficiently small throughout all optimization iterations**, yielding a single start-up schedule that does not depend on the scenario. Since **no additional penalty term is required, there is also no need to tune penalty coefficients**
- The quality of the solution was evaluated using VSS (the value of the stochastic solution, a metric that measures how much the expected cost can be reduced compared with a solution obtained by replacing uncertainty with its expected value). **The proposed method assigned high probability to globally optimal and near-optimal solutions with low expected cost, and VSS tended to improve as the number of layers in the first-stage unitary increased**

Expected business benefits

- **As the number of scenarios increases, the increase in gate count and circuit depth remains moderate**
- Two-stage stochastic programming is a common framework across delivery route planning (logistics), portfolio allocation (finance), and supply-demand planning (energy), making it possible to **extend the same circuit design horizontally across these application areas**
- Going forward, the work will address extensions to multidimensional and time-series scenarios involving demand uncertainty and multiple periods, reduction of the cost of scenario-state preparation, and validation under real-hardware noise. At the current problem scale, classical solvers are faster than the quantum-circuit simulations used in this evaluation. A runtime comparison with real quantum hardware has not yet been conducted, and the next challenge is to demonstrate scaling advantages as the number of scenarios increases.



Comparison of the required number of qubits



Distribution of first-stage solutions produced by the proposed method

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More use cases are available on our website. We invite you to explore them.
https://www.quantum-computing-use-cases.nedo.go.jp/english/

More Use Cases

New Energy and Industrial Technology Development Organization (NEDO)
AI and Robotics Department (e-mail: quantum_ai@ml.nedo.go.jp)

This collection of use cases was obtained as a result of the work commissioned by the New Energy and Industrial Technology Development Organization (NEDO) "Cyber-Physical Development Business of Quantum/Classical Hybrid Technology/Study of Use Case of Quantum Technology" and the “Post-5G Information and Communications System Infrastructure Reinforcement R & D Project (Quantum Industrialization)/Comprehensive Study for Promoting the Industrialization of Quantum Computers”.