Resilient Entanglement (RE)

Research & Development

Experimental Quantum Computing to Solve Network DC Power Flow Problem

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Introduction, Climate Change

Energy-related greenhouse gas emissions are estimated to increase by 1.5 billion tons by the end of 2021 from 2.3 billion tons in 2020.

This is the second-largest increase in history and the largest annual rise since 2010, stated by The International Energy Agency (IEA).

The electric grid is the primary source of over 25% of these emissions. In the face of this warning, we must find and build a sustainable solution for our climate while considering the impacts of economic recovery from the Covid crisis.

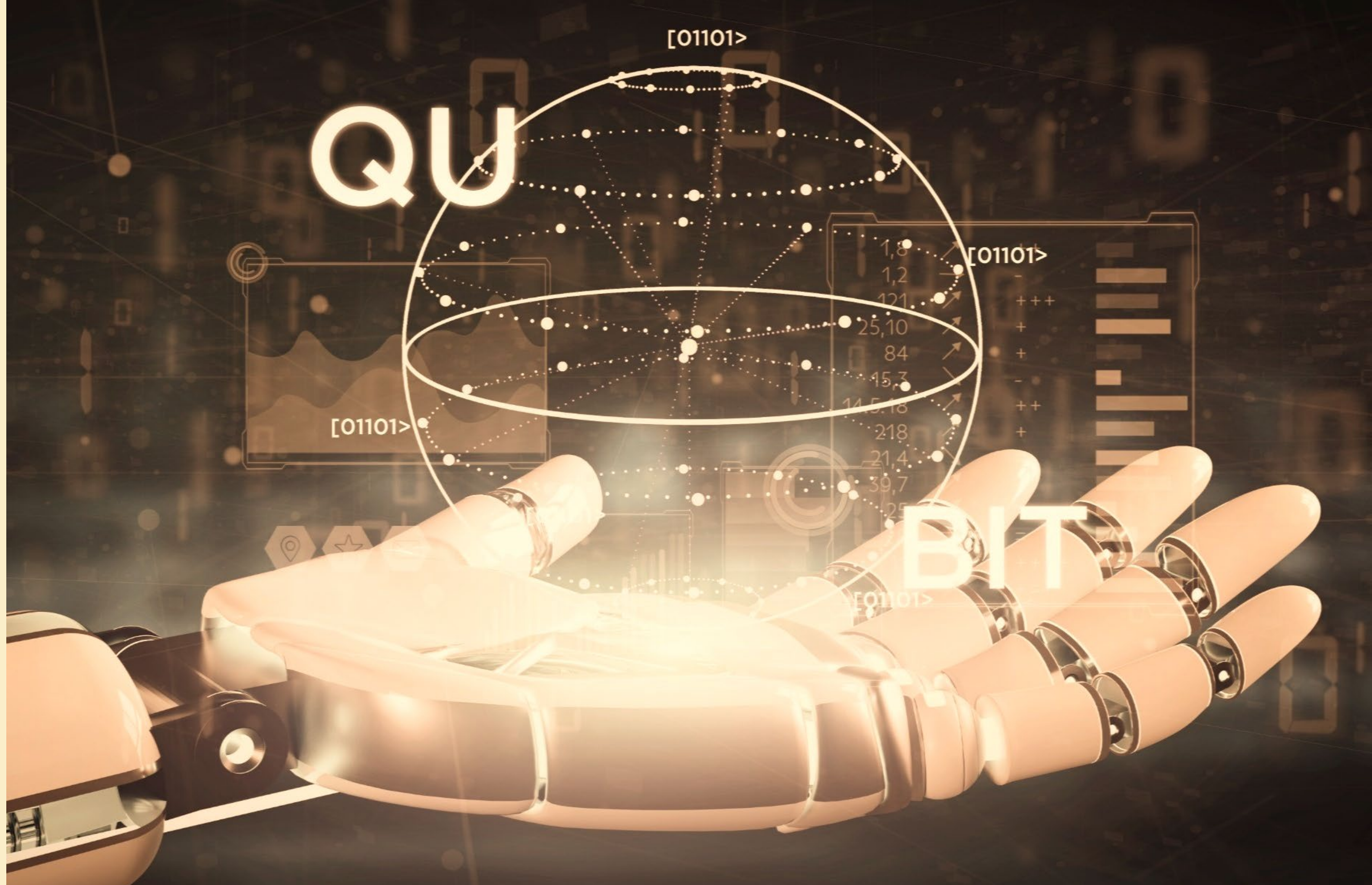
The world needs to provide energy without releasing any more greenhouse gases to avoid climate change, and its related natural disasters. If we do nothing, the picture of the world is one of absolute devastation.

The need to modernize traditional grid computing is our motivation to conduct R&D and support the industry in this emerging and critical field by accelerating the adaption of Quantum Computing in the energy sector.

Resilience & Sustainable

There is a significant push, driven primarily due to climate change concerns, to reduce the use of carbon-based fuels to slow the warming trend by increasing the capacity and generation of renewable energy sources.

This is simultaneous with the efforts in improving grid resilience against many climate change induced extreme events, such as hurricanes, floods, and wildfires, as there has been a surge in these events in terms of both intensity and the frequency of occurrence.



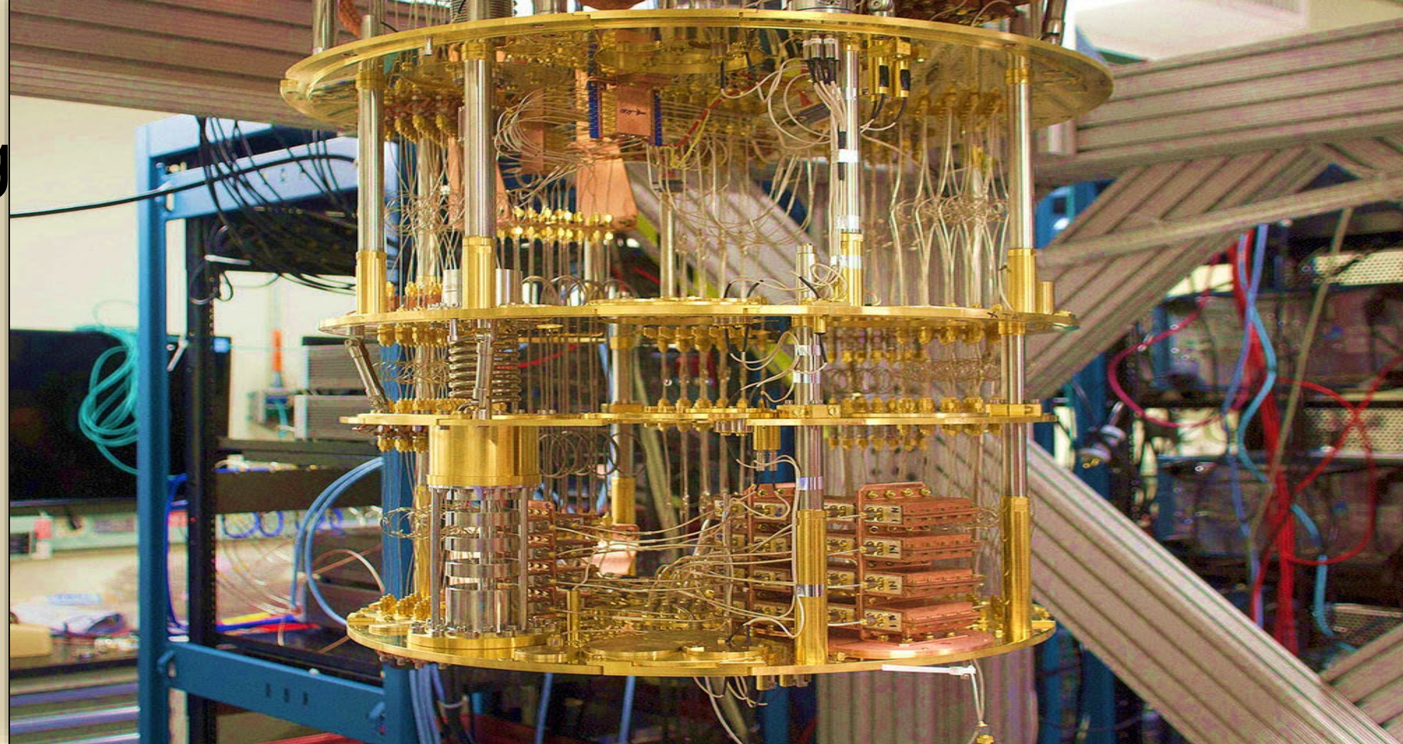
However, intermittent sustainable energy sources, electric vehicles, and smart loads will vastly change the behavior of the electric power grid and will result in new stochastics and dynamics to build the gird of the future.

Optimizing such a stochastic and dynamic grid with sufficient reliability and efficiency is a vast challenge.

Importance of Quantum Computing

Data will be at the core of this transformation. Significant investments on the smart grid technology over the past two decades have resulted in advanced grid monitoring and measurement, resulting in the continual collection of myriads of data from various parts of the grid.

Traditional computing relies on large operating margins to ensure a secure and resilient grid operation. Today, these extensive operating margins cause an estimated $5-$15B in additional cost in energy delivery.



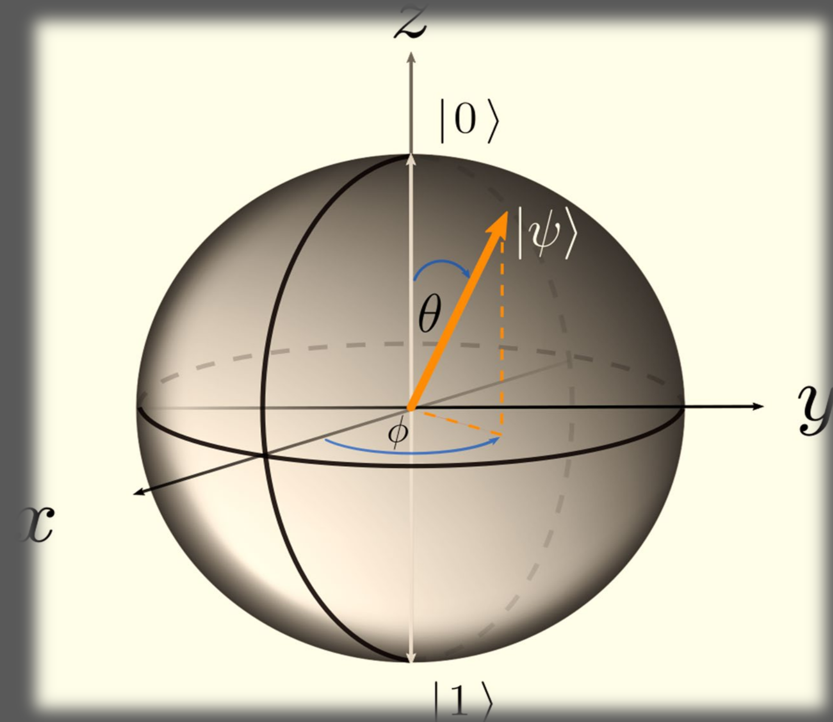
Through funding from the Colorado Office of Economic Development and International Trade (OEDIT), our team in the University of Denver, and Resilient Entanglement (RE), ComEd, have investigated possible solutions utilizing quantum models and quantum mechanical phenomena to address the critical challenges of the power sector.

The team focuses on the core of today's energy technology movement by developing a quantum solution to one of the most fundamental power system problems –DC power flow.

Quantum Computing Fundamental

A classical computer utilizes information by bits. A bit is a basic unit of data that represents a yes-no answer to a question, and mathematically is a binary number which can be either 0 or 1.

A quantum computer encodes the data by quantum bits or qubits. Like a regular bit, a qubit could be either 0 or 1, but unlike a regular bit, a qubit may also be simultaneously in both states.



A single qubit can be forced into a Superposition of the two states denoted by the addition of the state vectors:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

where α and β are complex numbers

$$|\alpha|^2 + |\beta|^2 = 1$$

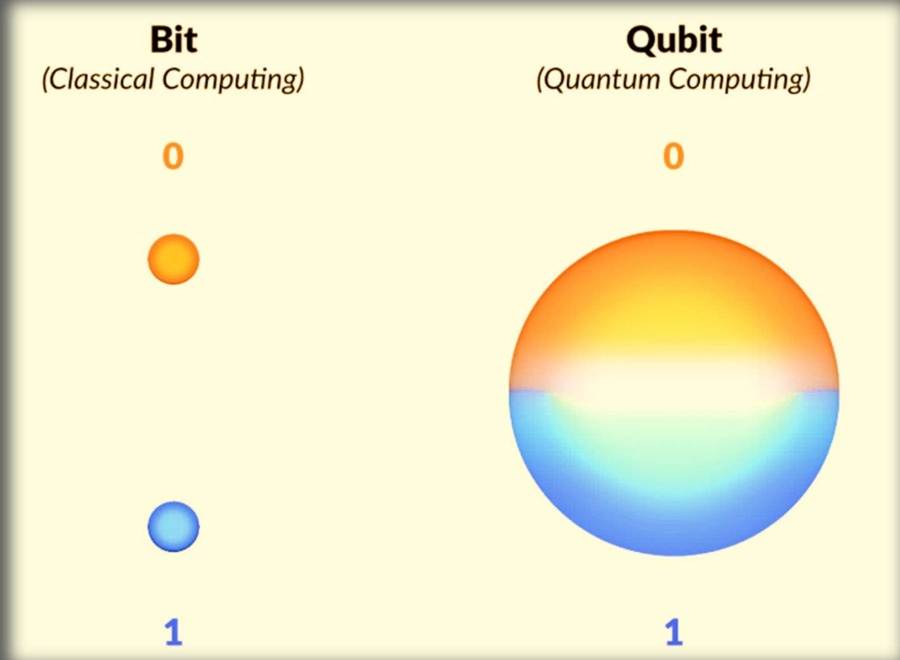
In general, an n qubit register can represent 2^n numbers simultaneously.

Quantum Computing Fundamental

There can be a strong correlation between quantum particles, to the point that two or more quantum particles can be inextricably linked in perfect unison, even if separated by great distances. This is called Entanglement.

The power of quantum computers comes from the superposition and the entanglement of states

Quantum computers rely on encoding information in fundamentally different ways than classical computers.



For N bits, there are 2N possible classical states. However, a classical computer can represent only one of these N-bit states at a time.

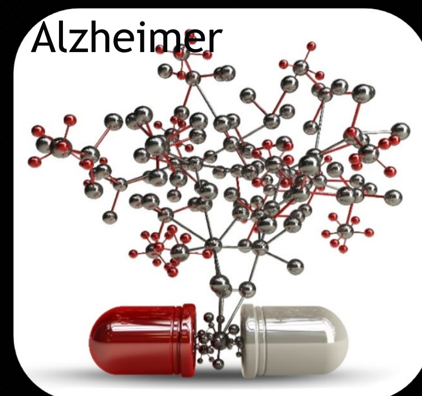
- Processing multiple N-bit states can either be performed sequentially in time or in parallel using additional copies of the hardware. This is classical parallelism.

In contrast, the qubits in a quantum computer can be set into a single superposition state that may simultaneously carry aspects of all 2N components.

Quantum Computing Fundamental

Quantum Applications

To create advanced private keys for encrypting messages to deter and prevent hacking



Quantum simulations could lead to treatment of Alzheimer’s disease, which affects millions of lives.(5.8 M/U.S.)

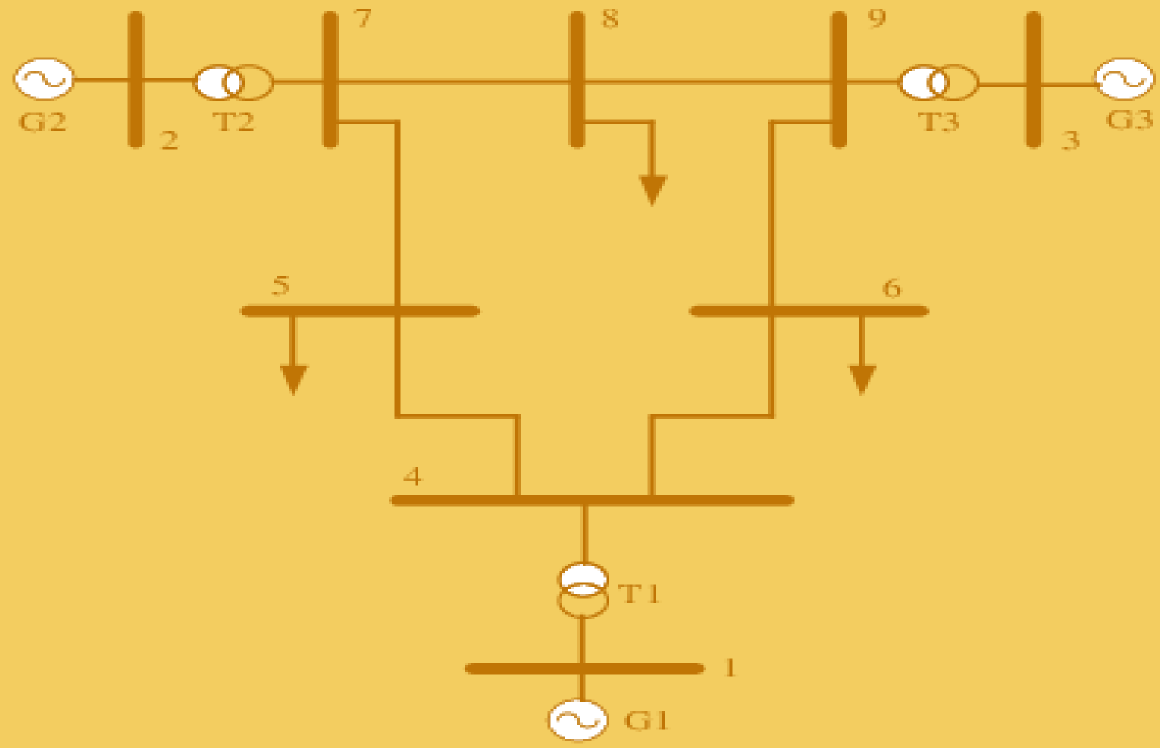
Teleportation of information without physically transmitting the information.

Quantum computing is what the power system needs to manage the computing needs of the future

Problem Statement:

Solving a system of linear equations (SLE) is fundamental in many science and engineering problems.

Quantum computers are proven to provide an exponential speedup for SLE. The DC power flow analysis is an SLE that can be efficiently solved using a quantum computer.



We based our studies on the Harrow-Hassidim-Lloyd (HHL) quantum algorithm, which has a proven theoretical speedup over classical algorithms in solving a system of linear equations. Practical studies on a quantum computer were conducted using the WSCC 9-bus system.

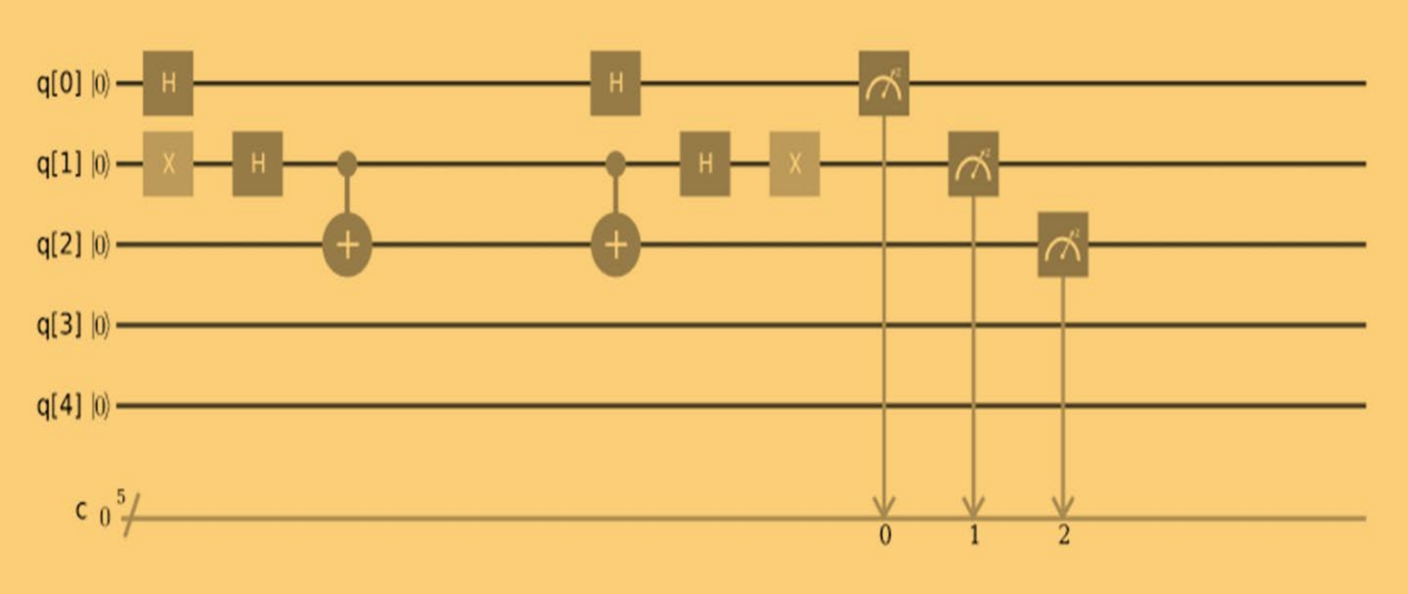
The results showed that a quantum computer could provide higher processing power and solve this fundamental grid problem up to 30 times faster than a classical computer for large-scale

Problem Statement:

Quantum algorithms:

A quantum algorithm comprises a sequence of single-qubit and two-qubit gates.

Algorithms take an input state and, in a step-by-step manner, modify the weighting coefficients (probability amplitudes) until the quantum mechanical state evolves into an output state that encodes the answer to the problem.



QUANTUM CIRCUIT FOR CALCULATING THE LINE FLOW BY MEASURING THE READOUT REGISTER.

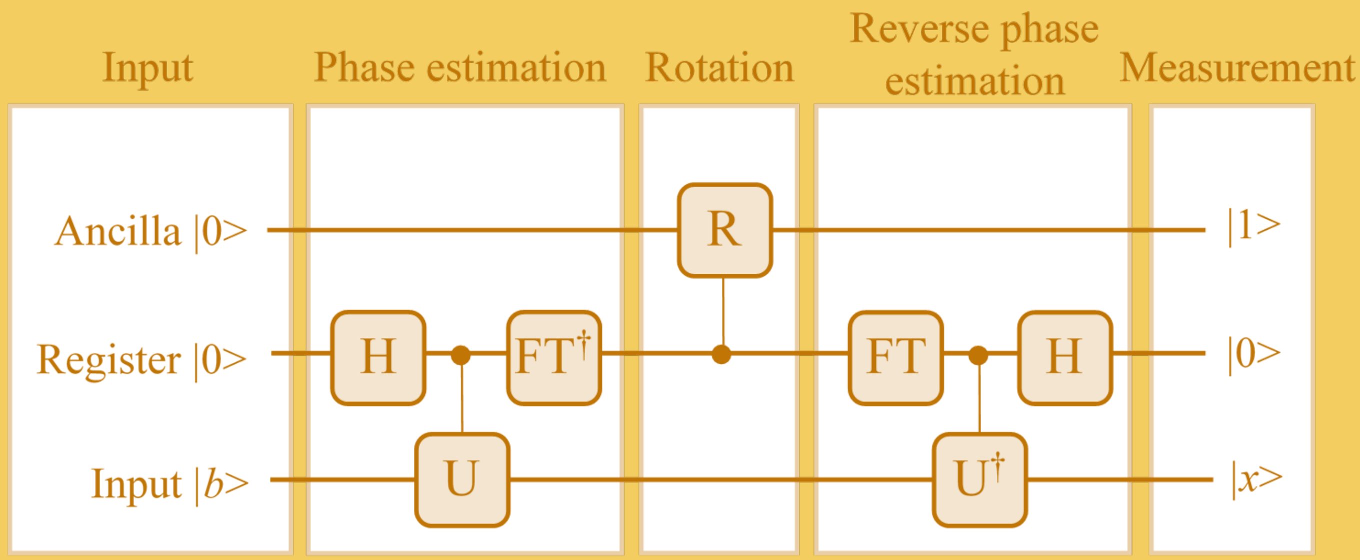
Since a projective quantum measurement will yield a single, classical state, it is imperative that the algorithm result in a final state that has a probability amplitude near unity such that -- with near unity probability -- the measurement will lead to the correct answer.

Numerical:

Table I demonstrates the results of the studied DC power flow problem. The obtained fidelity is 0:87. This high fidelity shows the promise in finding accurate solutions, despite the noise and the large size of the quantum circuit.

Table II shows the characteristics of the quantum circuit used to solve this problem. The depth is the maximum number of gates applied to a single qubit.

The width is the required number of qubits. The number of CNOTs is also provided as this number, along with the width, provide a sense of whether running the circuit on current practical hardware is feasible.



HHL algorithm process

TABLE I
Quantum Simulation Results

	Results
Fidelity	**0.872159**
Probability	0.537650
Classical Solution	[0.1157, 0.0948, -0.0713, 0.1316, -0.0644, 0.0118, -0.0514, 0.0220]
Quantum Solution	[0.1125, 0.0599, -0.0299, -0.0826 -0.0458, 0.0047, -0.0858, -0.0040]]

TABLE II
Characteristics of The Quantum Circuit

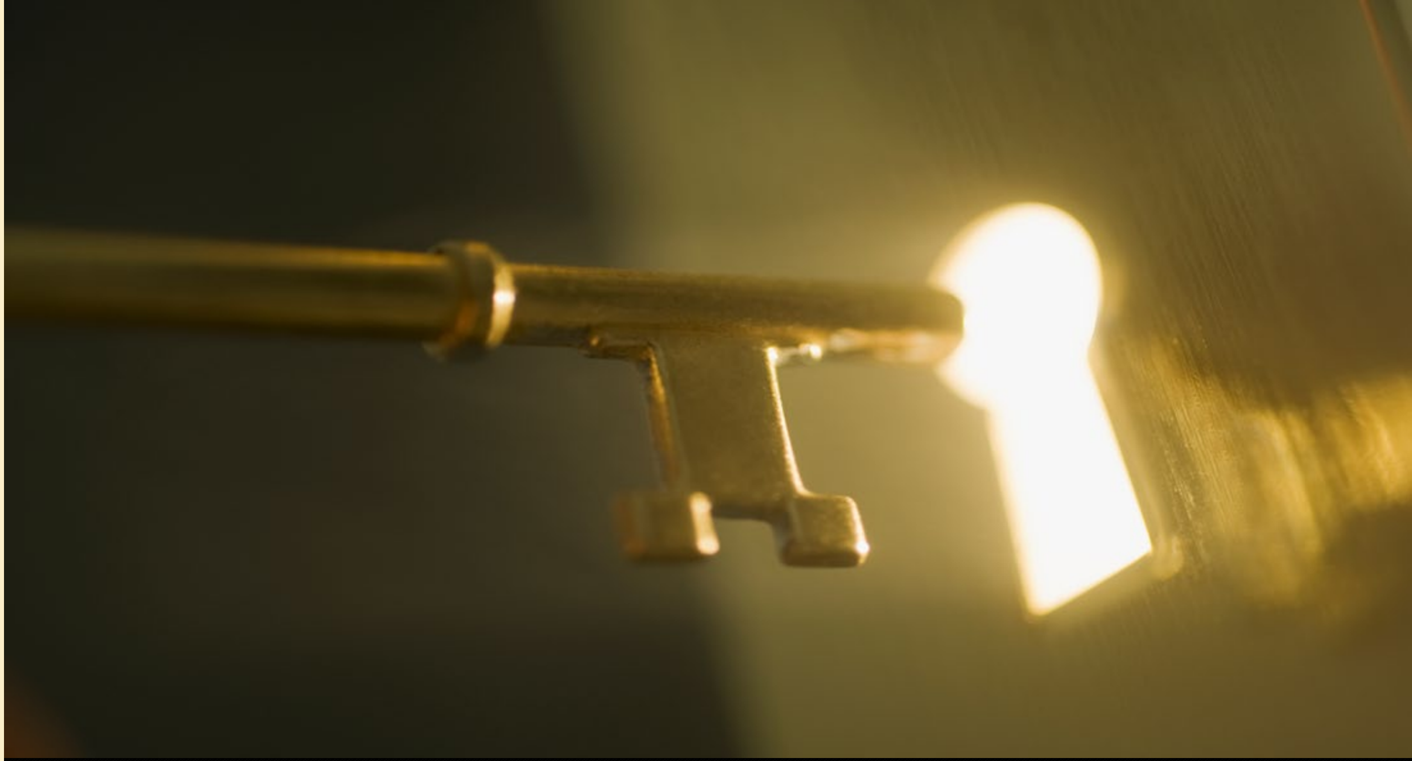
	Results
Circuit Width	9
Circuit Depth	129
CNOT Gates	70

Conclusion

This paper presented an experimental quantum computing solution to the widely-used DC power flow problem.

The results showed that a quantum computer could provide higher processing power and solve this fundamental grid problem much faster than a classical computer.

It was further shown that this conclusion holds true even for cases that quantum hardware adds delays to computations.



even for cases that quantum hardware adds delays to computations.

As the next step, our mission is to develop and offer a SOFTWARE-as-a-SERVICE SaaS product called Quantum-Power-Flow software to support the deployment of renewable energy generation and responsive demand strategies.

We also expect this successful experimental study to enable broader research and applications of quantum computing to power grids in the near future.

Thanks

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