

Quantum Computing for Smart Grids

Shaping the Future of Energy Distribution

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The Scalability Problem

Smart grids have emerged as one of the key technologies paving the way towards the goal of achieving net-zero emissions by 2050, playing a vital role in accommodating the fluctuating nature of renewable energy generation¹. However, while promising in terms of energy management and efficiency, smart grids face significant challenges when it comes to scalability². The complexity of integrating various components and technologies into a cohesive system is an ever-growing problem as the size of these networks increases. Smart grids rely on a vast network of sensors, communication infrastructure, data management systems, and control mechanisms, but coordinating and synchronizing these elements at a large scale can be highly intricate and time-consuming. Moreover, the sheer volume of data generated by smart grids poses a significant challenge by itself³. As the number of connected devices and energy prosumers increases, the amount of data to be processed and analyzed grows exponentially, requiring robust computational resources and efficient data management techniques.

Failing to address scalability issues in smart grids can have far-reaching consequences, being the strain on existing infrastructure one of the most immediate. If the grid cannot efficiently handle the growing demand and data load, it may result in network congestion, reduced performance, and even failures or outages. This could lead to service disruptions, affecting not only the reliability of the energy supply but also critical services dependent on electricity, such as healthcare and transportation. Additionally, scalability issues can hinder the integration of renewable energy sources, since smart grids play a vital role in accommodating the fluctuating nature of renewable energy generation. Without a scalable smart grid infrastructure, the effective integration and management of renewable energy resources become challenging, impeding the transition to a sustainable energy future. Ultimately, the consequences of not developing scalable smart grids could undermine the potential benefits of this technology and hinder the optimization of energy systems.

¹ <https://www.iea.org/reports/smart-grids>

² Ma, S., et al. *Scalability for Smart Infrastructure System in Smart Grid: A Survey*. *Wireless Personal Communications: An International Journal*, Volume 99, Issue 1, 1 March 2018 <https://doi.org/10.1007/s11277-017-5045-y>

³ Tu, C., et al. *Big data issues in smart grid – A review*. *Renewable and Sustainable Energy Reviews* 79:1099-1107, DOI:10.1016/j.rser.2017.05.134

Quantum computing holds potential to address these scalability issues by offering enhanced computational power and capabilities. While this technology is still in its early stages of development, its development offers promising solutions to the complex challenges of scaling up smart grid infrastructures. From grid management to enhanced security, quantum computing emerges as a potential game changer in the development of smart grid technologies.

Use Cases

Quantum computing can enable more efficient optimization algorithms, allowing for the optimal scheduling and dispatch of electricity generation, load balancing, and resource allocation. Applications such as PMU placement⁴, unit commitment⁵ or facility location-allocation⁶, are among the first expected to be addressed by quantum devices. As this technology evolves, it will also be able to solve more complex issues in power flow⁷ and transient analysis⁸, minimizing energy waste and enhancing system performance.

Due to the growing amounts of data produced by sensors in smart grids, finding a way to enhance classical machine learning methods is imperative to be able to make predictions in close to real time. Quantum machine learning algorithms have the potential to handle and analyze vast amounts of data generated by smart grids⁹, enhancing data processing, pattern recognition, and anomaly detection, which would enable faster and more accurate decision-making. This can lead to more effective fault detection¹⁰, more precise electricity load¹¹ and price¹² forecasting and improved grid stability¹³, ultimately enhancing the scalability and reliability of the grid.

Quantum computing can also contribute to strengthening the security of smart grids. Quantum encryption techniques, such as quantum key distribution¹⁴ or quantum direct communication¹⁵, provide a highly secure method for transmitting sensitive data over communication networks. As smart grids rely on secure and reliable data transmission, quantum encryption can help mitigate cybersecurity threats and protect critical grid infrastructure.

⁴ Jones, E.B., et al. *On the computational viability of quantum optimization for PMU placement*. IEEE Power & Energy Society General Meeting (PESGM), pp. 1–5. IEEE, Piscataway (2020)

⁵ Nikmehr, N., et al. *Quantum distributed unit commitment*. IEEE Trans. Power Syst. 37(5), 3592–3603 (2022)

⁶ Ajagekar, A., You, F. *Quantum computing for energy systems optimization: Challenges and opportunities*. Energy 179, 76–89 (2019)

⁷ Feng, F., Zhou, Y., Zhang, P. *IEEE. Quantum power flow*. IEEE Trans. Power Syst. 36(4), 3810–3812 (2021)

⁸ Zhou, Y., Feng, F., Zhang, P. *Quantum electromagnetic transients program*. IEEE Trans. Power Syst. (2021)

⁹ <https://isg-one.com/articles/quantum-computing-and-the-future-of-big-data>

¹⁰ Uehara, G., et al. *Quantum neural network parameter estimation for photovoltaic fault detection*. 12th International Conference on Information, Intelligence, Systems & Applications (IISA), pp. 1–7. IEEE, Piscataway (2021)

¹¹ Zhang, Z., Hong, W.C. *Electric load forecasting by complete ensemble empirical mode decomposition adaptive noise and support vector regression with quantum-based dragonfly algorithm*. Nonlinear Dyn. 98(2), 1107–1136 (2019)

¹² Zhang, X., et al. *Electricity price forecasting method based on quantum immune optimization bp neural network algorithm*. 6th Asia Conference on Power and Electrical Engineering (ACPEE), pp. 310–314. IEEE, Piscataway (2021)

¹³ Zhou, Y., Zhang, P. *Quantum machine learning for power system stability assessment.*, arXiv:210404855 (2021)

¹⁴ Li, Y., Zhang, P., Huang, R. *Lightweight quantum encryption for secure transmission of power data in smart grid*. IEEE Access 7, 36285–36293 (2019)

¹⁵ Jiang, Z., et al. *Quantum internet for resilient electric grids*. Int. Trans. Electr. Energy Syst. 31(6), e12911 (2021)

Conclusions and Economic Impact

2022 witnessed an unprecedented economic effort in energy transition technologies, with a record USD 1.3 trillion invested, including USD 0.5 trillion in renewable energies¹⁶. While still far from the annual amount of investment needed to achieve net-zero by 2050, current trends indicate a sustained capital mobilization towards sustainable development goals¹⁷. However, the scaling of smart grid infrastructure is key to accommodate new developments in this domain. Although quantifying the exact economic cost of scalability issues in smart grids can be challenging, mostly due to the dynamic nature of the energy sector and the specific circumstances of each situation, their potential financial impact is undeniable. Inadequate scalability in smart grids can lead to inefficiencies in energy distribution and management, which can result in higher operational costs for utility companies, which may need to invest in additional infrastructure or manpower to meet the increasing demand and data load. These additional costs can ultimately be passed on to consumers in the form of higher electricity prices. Moreover, these issues can hinder the integration of renewable energy sources, which are crucial for achieving sustainability goals. If smart grids cannot effectively handle the variability of renewable energy generation, it may result in curtailment of excess energy or the need for backup fossil fuel-based power plants. These inefficiencies can increase the overall cost of electricity generation and hinder the transition to cleaner energy sources.

Scalability issues can also impact the reliability of the energy supply, and service disruptions and outages caused by the strain on the grid can have significant economic consequences. Businesses reliant on uninterrupted power, such as manufacturing industries, data centers, and healthcare facilities, may suffer financial losses due to production disruptions, data loss, or compromised patient care. Additionally, the lack of scalability in smart grids can impede the development and deployment of innovative energy technologies and services. Startups and businesses in the energy sector may face barriers in scaling up their operations, limiting their potential for growth and economic impact.

While it is challenging to provide precise figures for the economic costs, addressing scalability issues in smart grids is essential to minimize these potential economic impacts, improve efficiency, and foster the integration of renewable energy sources. The introduction of quantum technologies in the domain of smart grids could be an enormous boost for this technology, ultimately leading to a more sustainable and cost-effective energy system.

¹⁶ IRENA (2023), *World Energy Transitions Outlook 2023: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi.

¹⁷ <https://www.irena.org/Energy-Transition/Finance-and-investment/Investment>

About the Authors

Daniel García Guijo is a Technical Project Manager in Multiverse Computing. Daniel holds a BSc in Physics at the University of Oviedo, final project on fluid simulations using Deep Convolutional Neural Networks. Daniel has participated in key projects in the energy, life sciences and manufacturing sectors in Multiverse specializing in quantum and quantum-inspired machine learning, and contributes decisively to Multiverse's efforts in sustainability.

Gianni Del Bimbo's current role in Multiverse is Chief Operations Officer. Gianni is a quantum physicist, holding a MSc in Condensed Matter Physics from the Ludwig Maximilian University (LMU) of Munich and a BSc in Physics and Astrophysics from the University of Florence. In Gianni's own words: "At Multiverse, I started as a quantum machine learning specialist and later worked as head of quantum engineering managing teams and leading client projects in finance, energy, manufacturing and chemistry. As COO, I'm now responsible for designing, implementing and overseeing day-to-day operations to drive the company's strategy. I'm also responsible for designing and building the company's ESG plan".

Esperanza Cuenca Gómez is Head of Strategy and Outreach at Multiverse Computing. She is a digital transformation enthusiast with more than 12 years of experience in consumer finance and banking, and more than 5 years in strategy and operations consulting. Quantum mechanics has always fascinated Esperanza, so she decided to study and research in quantum computing and communications. As an engineer, Esperanza sees applied science and engineering as ways to build new technologies, solve problems, and contribute to society. Esperanza is a member of Bankinter Foundation for Innovation FIBK Voices, an ecosystem of experts who are international referents and give the Foundation their vision on how innovation is revolutionizing areas such as science, technology, entrepreneurship or education. Esperanza also serves as Head of Change Navigation at the Quantum Strategy Institute.