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Influence of IQT on research in ICT, part 3

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***Abstract*—The advanced Quantum Information Technologies subject for Ph.D. students in Electronics Engineering and ICT consists of three parts. A few review lectures concentrate on topics which may be of interest for the students due to their fields of research done individually in their theses. The lectures indicate the diversity of the QIT field, resting on physics and applied mathematics, but possessing wide application range in quantum computing, communications and metrology. The individual IQT seminars prepared by Ph.D. students are as closely related to their real theses as possible. An important part of the seminar is a discussion among the students. The task was to enrich, possibly with a quantum layer, the current research efforts in ICT. And to imagine, what value such a quantum enrichment adds to the research. The result is sometimes astonishing, especially in such cases when quantum layer may be functionally deeply embedded. The final part was to write a short paragraph to a common paper related to individual quantum layer addition to the own research. The paper presents some results of such an experiment and is a continuation of previous papers of the same style.**

***Keywords*—ICT, QIT, biomedical engineering, electronics and communications engineering, sensors, quantum machine learning, quantum Internet, quantum computing, cybersecurity, quantum networks, quantum sensors**

I. Introduction

ADVANCED lecture for a group of diverse Ph.D. students is a demanding task. They are strongly concentrated on their individual research efforts. Timing of their Ph.D. study is demanding and they try to omit things which do not help them to go forward with the research. The subject on the Quantum Information Technology is designed in this way as not to slow down their work but to help and perhaps shed a new light on their research from a completely different yet very modern and promising perspective, the quantum one. The quantum perspective, especially when used against your serious personal research effort, is really very useful in the most of cases. Quantum integrated circuits are natural extensions of photonic integrated circuits. Quantum methods are used in simulations of large high energy experiments. Quantum simulators and annealers are used for research on molecular dynamics in material engineering and technology. IQT is used in a number of security solutions. A lot of photonic crystal technologies may be extended into quantum level. Quantum sensors include also a new generation of ionizing radiation devices and systems. Quantum dot dynamics is used in cancer diagnostics and therapy. IQT is used in automobiles and in aeronautics. Artificial Neural Network are extended successfully to quantum version. Power engineering start to adapt some quantum methods. IQT promise for faster and more precise genome sequencing and data analysis. Smart quantum antennas may enter into operation in G6 technology. Quantum batteries combine new materials and start to use quantum supercapacitors. IQT will be indispensable in banking and other security solutions.

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II. Post-Quantum Cryptography Integration in IoT Access System

A. Introduction

This study explores the potential future capabilities of securing Internet of Things (IoT) devices in response to the potential threats posed by QIT-enabled quantum computing advancements, with a focus on the application of Post-Quantum Cryptography (PQC) within the framework of an IoT Access System aimed at protecting access to a facility. IoT devices are built on an extensive network of small sensor networks, each specialized with different computing and networking capabilities to detect and interact with the environment. With the expansion of the network, it is crucial to integrate cybersecurity to its development lifecycle. Companies developing IoT devices prioritize rapid product launches over security measures, potentially overlooking security aspects as inadequate encryption, poor authentication mechanisms, scalability challenges, and susceptibility to diverse threats stemming from the growing number of interconnected devices [1]. These vulnerabilities will be amplified with advent of QIT, as traditional cryptography techniques may no longer be enough. By analyzing the proposed system, security measures, and exploring cryptographic approaches, this study aims to investigate how would quantum based solutions be applied to an IoT access to facilities system, in the face of quantum computing threats.

B. Overview and Design of the IoT Securing Access to Facilities System

The Securing Access to Facilities System is an IoT system designed to provide a robust and scalable solution for controlling physical access to facilities. The system ensures that access is granted only to authorized individuals while maintaining security against both network-based and physical threats. The system consists of two main components: an online system and an offline system, connected through a secure communication link. This link is the focus of this study, where PQC is proposed as advanced solutions to protect data exchanged between the two systems. These technologies aim to address vulnerabilities posed by the advent of quantum computing, ensuring that the communication link remains secure even in a post-quantum era.

The architecture of the proposed Securing Access to Facilities System consists of two main subsystems: an online subsystem, an offline subsystem, and the secure communication link that connects them. The online subsystem handles user authentication and other network-dependent tasks. It verifies identities and integrates intrusion detection to monitor and respond to potential cyber threats. The offline subsystem is responsible for managing credential validation and controlling the physical lock mechanism. It operates in an isolated environment, and uses a secure microcontroller to generate dynamic access codes and validate user credentials locally to ensure protection against physical tampering and unauthorized access. The secure communication link separating the two subsystems minimizes the exposure of the offline subsystem to external threads and isolates it from the internet. The physical lock mechanism is considered a sensitive part of the system so the connection between it and the offline system is physically isolated in an airgap, which makes it more difficult for unauthorized software to access [2].

C. Post-Quantum Cryptography Application in the IoT Securing Access to Facilities System

PQC encompasses several cryptographic systems that are theorized to be resistant to attacks from future QIT attacks. This section will explore three key types: Code-Based Cryptosystems, Hash-Based Cryptosystems, and Lattice-Based Cryptosystems.

1) Code-Based Cryptosystems: The first code-based cryptosystem was introduced by Robert J. McEliece in 1978. It is primarily based on Algebraic Coding, which deals with the design and analysis of codes for error detection and correction in data transmission and storage. This cryptosystem leverages the structure and properties of error-correcting codes to ensure secure data encryption and transmission [3]. Code-based cryptosystems require high computational resources, making them not suitable for most IoT systems, which typically have limited resources. Additionally, since the prototype of the Securing Access to Facilities System uses the Raspberry Pi, which has limited resources, it would not be able to handle the computational demands of code-based cryptosystems.

2) Hash-Based Cryptosystems: Hash-based cryptosystems rely on the properties of cryptographic hash functions for secure digital signatures. They work by generating one-time or multi-time keys, which are used in conjunction with hash-based structures to efficiently authenticate and verify digital signatures. They provide strong security guarantees, but there are several challenges with their implementation in an IoT environment. One of the primary issues is state management, as hash-based systems require careful synchronization of keys, which can be complex and error-prone. Another concern is cloning threats, since private keys in hash-based systems are tied to specific uses, such as signing a particular message, the misuse of cloned private keys can lead to significant security vulnerabilities. Additionally, there are trade-offs regarding parameter specification, particularly between data size and performance. As the data size increases, the computational and storage overhead may become a limiting factor, affecting both efficiency and scalability [4]. Hash-Based Cryptosystems can be applied to Securing IoT systems with constrained resources, as demonstrated in [5], where the authors tested various hash functions, including SHA-2, Keccak (SHA-3 candidates), and PHOTON, on a Raspberry Pi 4 Model B. Access to Facilities System, and demonstrated that SHA-2 and Keccak-f variants demonstrated good performance, but noted that hash execution could be computationally expensive, and proposed a consortium blockchain model or layered IoT architecture where resource-constrained devices act as light nodes. Despite these challenges, hash-based cryptosystems offer a promising option for securing IoT systems, particularly for applications where digital signatures and authentication are critical. In the scope of the Securing Access to Facilities System, they can be applied, but they're not optimal because of resource constraints.

3) Lattice-Based Cryptosystems: Lattice-Based Cryptosystems are based on mathematical structures known as lattices, which are regular grids of points in multidimensional space. These cryptosystems rely on hard problems related to lattices, such as the shortest vector problem or the closest vector problem, which are considered difficult to solve even for quantum computers. Due to their underlying complexity, lattice-based cryptosystems offer a high level of security against quantum attacks. Additionally, the scalability, flexibility, and efficiency of lattice-based cryptosystems, makes them a good fit for securing IoT applications in the post-quantum era, where resource constraints are critical. Systems with low resources such as those using FPGAs, ASICs, and Raspberry Pi, can handle advanced Lattice-Based Cryptosystems effectively [6], which makes this type of PQC the best candidate for Securing Access to Facilities System.

D. Discussion

The study highlights the considerations for post-quantum readiness in IoT systems in the realm of PQC, and highlights the potential of lattice-based cryptosystems for securing resource-constrained devices. Future developments in IoT devices, and PQC algorithms might pave the way for robust and scalable IoT security solutions in the quantum era. The study overviewed a proposed IoT system designed to secure access to facilities and explored the integration of 3 types of PQC Cryptosystems into the system. Code-Based Cryptosystems, which require high computational resources, and are not suitable for most IoT systems. Hash-Based Cryptosystems, which rely on the properties of cryptographic hash functions for digital signatures, and are suitable for some IoT systems but face several challenges. These include the complexity and error-prone nature of state management for key synchronization, vulnerabilities to cloning threats arising from the misuse of private keys, and trade-offs between data size and performance. These trade-offs can significantly impact efficiency and scalability, particularly as computational and storage demands increase in resource-constrained IoT environments. Additionally, hash-based cryptosystems can be computationally expensive. While they could be applied to the proposed IoT system, they are not the most suitable option. Lattice-Based Cryptosystems, which are based on mathematical structures known as lattices, offer strong security against quantum attacks and are well-suited for resource-constrained IoT systems in the post-quantum era. Devices with limited resources, such as FPGAs, ASICs, and Raspberry Pi, can efficiently handle these systems, making them the best choice for securing the Access to Facilities IoT System.

III. Quantum Computing Applications for Enhancing Dam Safety and Infrastructure Monitoring

A. Introduction

Dams are essential infrastructure systems that need ongoing monitoring to maintain safety, structural integrity, and operational efficiency. Traditional methods for monitoring dam safety often struggle with large datasets, real-time analysis, and complex optimization challenges. Quantum computing, with its unique principles of superposition, entanglement, and quantum parallelism, could transform the management of dam safety. By improving data processing, sensor integration, and predictive analysis, quantum techniques can offer substantial advantages over classical approaches [7]. Dams are still at risk of failures, which can lead to severe consequences. For example, Africa has seen several catastrophic dam failures attributed to aging infrastructure and inadequate maintenance. In Sub-Saharan Africa, it's estimated that more than 70% of dams are vulnerable due to insufficient monitoring systems and the impacts of climate change [8]. Likewise, Poland experienced the devastating Silesian floods in 1997, which resulted in extensive damage estimated at $3.5 billion USD and claimed over 50 lives [9]. These events highlight the need for advanced real-time dam monitoring systems to mitigate risks. Incorporating advanced computational tools like quantum computing can address dam safety challenges and prevent future disasters [10].

B. Quantum Optimization for Dam Safety Parameters

A significant challenge in dam safety is optimizing factors like stress distribution, predicting water levels, and ensuring structural stability. Traditional optimization methods frequently face difficulties in non-convex, high-dimensional spaces that are susceptible to local minima. Quantum algorithms, including the Quantum Approximate Optimization Algorithm (QAOA) and Quantum Annealing, provide a powerful alternative by effectively navigating the solution space [11].

1) QAOA for Structural Monitoring: The QAOA algorithm, when applied to near-term quantum devices, has the potential to optimize control parameters for dam systems. For example, stress measurements gathered from sensors can be converted into a Quadratic Unconstrained Binary Optimization (QUBO) problem. where represents stress distribution variables, are weights corresponding to sensor outputs, and indicates interactions between stress regions. By solving this QUBO formulation with QAOA, we can minimize errors in safety predictions and improve structural reliability [11].

C. Quantum Machine Learning for Sensor Data Processing

Dams are equipped with thousands of sensors that monitor a range of parameters, such as vibrations, water pressure, temperature, and material stress. The vast amount and complexity of this sensor data pose challenges for identifying hazards and detecting anomalies in real time. Quantum Machine Learning (QML), particularly through Quantum Neural Networks (QNNs) and Quantum Support Vector Machines (QSVMs), has the potential to enhance the efficiency and accuracy of data processing. [12].

1) Quantum Neural Networks for Anomaly Detection: QNNs can analyze multivariate sensor data and detect anomalies more quickly than traditional methods. Quantum circuits used in QNNs utilize parameterized quantum circuits (PQCs) to transform sensor data into quantum states, allowing for the encoding of high-dimensional data: The quantum circuit is represented with adjustable parameters. By training Quantum Neural Networks (QNNs) on past sensor data, we can more accurately predict potential hazards [12].

D. Quantum Digital Twins for Real-Time Monitoring

The idea of Digital Twins has become popular for simulating physical systems in real time. When combined with quantum computing, Quantum Digital Twins (QDTs) provide improved abilities to simulate how dams behave under different environmental and operational scenarios. QDTs can analyze real-time data, forecast structural changes, and optimize control strategies with unmatched speed [13]. Use Case: The idea of Digital Twins has become popular for simulating physical systems in real time. When combined with quantum computing, Quantum Digital Twins (QDTs) provide improved abilities to simulate how dams behave under different environmental and operational scenarios. QDTs can analyze real-time data, forecast structural changes, and optimize control strategies with unmatched speed: Predicting the structural integrity of dams involves using quantum algorithms, where Quantum Differential Equations (QDTs) are employed to solve Ordinary Differential Equations (ODEs) that describe the dynamics of the dam. For instance, these dynamics can be represented through a quantum Hamiltonian. [13].

E. Conclusion

Quantum computing has the potential to revolutionize dam safety management by tackling issues related to optimization, processing sensor data, and enabling real-time monitoring. Techniques like QAOA, QML methods such as QNNs, and Quantum Digital Twins offer valuable tools for precise hazard detection, effective data analysis, and predictive modeling. Given the serious consequences of dam failures, exemplified by the fact that 70% of dams in Africa are at risk and the

Silesian floods of 1997 in Poland, which resulted in damages exceeding $3.5 billion USD, the use of quantum techniques is essential for risk mitigation. As quantum hardware and algorithms continue to advance, their application will become even more critical in ensuring the safety and durability of vital dam infrastructure [14].

IV. Combination of Weather IoT and Quantum Computing: Prospects

With the rapid development of information technology, weather forecasting and climate prediction have entered a new stage. Traditional weather forecasting relies on large-scale meteorological data collection and high-performance computing, but with the surge in data volume and the increasing demand for computing, how to efficiently process massive amounts of meteorological data has become an urgent problem to be solved. In recent years, the combination of Weather IoT and quantum computing has been considered an important development direction in the field of future weather forecasting. This article will explore the prospects, potential of the combination of Weather IoT and quantum computing. [15]

A. Weather IoT: A new era of meteorological data collection

Weather IoT refers to a system that collects, transmits and analyzes meteorological data in real time around the world through various sensors, devices and network technologies. [16]These sensors can include detectors of various meteorological parameters such as temperature, humidity, wind speed, and air pressure, which are widely distributed in different environments, such as cities, rural areas, mountainous areas, and oceans. Through these sensors, the Weather IoT can provide extremely accurate and high-frequency real-time meteorological data [17].

The advantages of the Internet of Things lie in the high frequency, wide coverage and real-time nature of data, which make the Weather IoT have great potential in meteorological monitoring, climate forecasting, and disaster warning. For example, in the face of natural disasters such as typhoons and heavy rains, the Weather IoT can provide timely and accurate warning information to help relevant departments do a good job in disaster prevention and mitigation.

However, with the popularization of IoT devices and the explosive growth of data volume, how to effectively store, process, analyze and mine these massive data has become a huge challenge. Traditional computing methods and hardware often have difficulty coping with such a large data scale, especially in real-time prediction and rapid response.

B. Quantum computing: the potential to solve large-scale data processing

As a new computing paradigm, quantum computing uses the principles of quantum mechanics (such as superposition state, entangled state, etc.) for data processing. Compared with traditional classical computers, it has extremely powerful parallel processing capabilities. Quantum computing can achieve exponential acceleration on certain specific problems, especially in processing large-scale data, complex optimization and probability calculations. which has significant advantages. [18]

In weather forecasting, quantum computing can help speed up the calculation process of weather models. Weather prediction involves a large number of physical equations and complex calculations, especially large-scale numerical simulations. Traditional calculation methods need to process a large number of meteorological variables and complex partial differential equations. [19]The calculation process is usually very time-consuming and has extremely high requirements on computing resources. Quantum computing can make use of the superposition state and parallel processing capabilities of quantum bits (qubits). In theory, it can complete more computing tasks in a shorter time and greatly improve prediction efficiency.

In addition, quantum computing also has huge potential in optimization and machine learning. In the weather IoT system, data processing requires not only computing power, but also efficient pattern recognition and data mining. Quantum computing can perform complex optimization and pattern recognition tasks on large-scale data sets, helping to extract useful information hidden in huge meteorological data, thereby improving the accuracy and precision of forecasts.

C. Prospects of combining weather IoT with quantum computing

Combining weather IoT with quantum computing has the potential to fundamentally change the way weather is predicted. Specifically, the weather IoT system combined with quantum computing can play a role in the following aspects:

Improve data processing efficiency: Quantum computing can process data from sensors around the world in a very short time and update meteorological forecast models in real time. Compared with traditional methods, quantum computing can perform large-scale data analysis and model calculations more quickly.

Enhance prediction accuracy: The accuracy of weather forecast models can be improved by optimizing the processing of massive data by quantum computing. Quantum algorithms can capture complex nonlinear relationships in weather changes, thereby improving the ability to predict meteorological changes.

Optimize resource allocation and decision support: Quantum computing's advantages in optimization can help meteorological departments better dispatch and allocate resources, such as the layout of weather observation equipment and emergency response strategies. This not only improves resource utilization efficiency, but also optimizes disaster response decisions. [20]

Coping with complex climate change issues: Climate change is a highly complex system involving the interaction of multiple factors. Quantum computing can provide more effective solutions than traditional methods when dealing with such complex systems, helping scientists better understand and predict climate change.

V. Carbon nanotubes in Quantum devices

Carbon nanotubes have been of interest to researchers for years due to their unique properties. However, it is crucial to understand the relationship between a carbon nanotube's structure and its electrical parameters to be able to fully exploit their potential in many devices as composites, transistors, printed electronics or quantum technology [21] [22] [23] [24].

A. Carbon nanotubes structure

Carbon nanotube can describe as a layer of graphene rolled into a tube and their electrical properties depend on the type of their chirality (geometric arrangement of carbon atoms in the nanotube wall). There are 3 groups of chirality: armchair (semimetals) and zig-zag and intermediate (semiconductors) [25]. Nanotubes are also divided according to the number of their layers. We distinguish between single-walled SWCNTs (Single Walled Carbon Nanotubes) and multi-walled MWCNTs (Multi Walled carbon nanotubes). Nanotubes that have only one layer show better electrical properties. In the case of carbon nanotubes, we can also talk about ballistic transport So far, the state of literature knowledge as to the factors affecting the structure of carbon nanotubes is insufficient to gain complete control over their chirality. At this point, the carbon nanotubes obtained have random and varied chirality, only some of which are semi-metallic. The process of obtaining nanotubes with a specific chirality is inefficient at this point. In order to obtain nanotubes with a specific chirality, several syntheses and then a selection process are required. The described procedure is highly expensive and not cost-effective for industrial applications.

B. CNTs synthesis

One promising method for obtaining carbon nanotubes is the FC-CVD (Floating catalyst chemical vapor deposition) method, in which a catalyst is introduced into a reactor using carrier gas [26]. This process shows great potential as far as obtaining SWCNTs is concerned due to the ability to control many parameters such as Temperature, reaction time, gas flow, catalyst and carbon source dosage rate, etc.

C. Quantum Technologies

Carbon nanotubes with controlled chirality can be successfully used in quantum technologies. Due to their size, they can be used to excite single photons. CNTs can play a key role in many applications, for instance in quantum devices as chips [27]. Single walled carbon nanotube can be placed between electrodes and be a part of quantum circuits. Work is already underway today on quantum computers using carbon nanotubes as a the fundamental building block of their processor. [28] SWCNTx can be also used in Secure communication. They are crucial in quantum key distribution protocols where single photons are used securely encode information. They can be also used in optical fibers because CNT can emit photons in range of wavelengths which is used in telecommunications and also in FET transistors where photon emission is the source of light [29] [30].

VI. QIT in Biodetection

The integration of Quantum Information Technology (QIT) with photonic crystal (PhC)-based biosensing introduces groundbreaking opportunities for advanced biodetection. In our research, the enhancement of PhC performance through precise surface structuring and the application of nanocoatings aligns with the principles of QIT to address limitations in classical sensing methods. Photonic crystals, with their unique ability to confine and manipulate light at sub-wavelength scales, provide an exceptional platform for leveraging quantum phenomena such as superposition, entanglement, and quantum interference. These properties enable ultra-sensitive and highly selective detection of biological interactions, critical for applications in medical diagnostics, environmental monitoring, and biochemical research [31] [32].

Key to this integration is the role of surface structuring, which allows for precise control over light propagation within the photonic crystal lattice. By engineering the photonic bandgap and enhancing light-matter interaction, structured PhCs improve sensitivity to changes in the refractive index caused by biomolecular binding events. Nanocoatings further enhance this effect by optimizing the refractive index contrast at the sensing interface, facilitating higher signal amplification. When combined with QIT techniques such as quantum state discrimination and quantum-enhanced interferometry, these biosensors can exceed the classical limits of detection. For instance, quantum metrology enables the measurement of refractive index variations with sub-nanometer precision, making it possible to detect minute biomolecular concentrations that would otherwise go unnoticed using traditional methods [31] [33].

Beyond improved sensitivity, the incorporation of QIT principles opens doors to a broader range of applications. Quantum networks, which use entangled photons for secure communication, could integrate with PhC biosensors to enable real-time, encrypted biodetection data transmission. Such systems could play a pivotal role in fields requiring high data integrity, such as telemedicine and secure laboratory diagnostics. For example, a PhC-based biosensor integrated into a quantum key distribution (QKD) network would not only provide highly accurate detection but also ensure that the transmitted data is protected from eavesdropping [34].

These advancements position photonic crystal biosensors as a bridge between the classical and quantum realms, demonstrating their potential to solve practical challenges while contributing to the theoretical foundations of QIT. This convergence highlights the value of interdisciplinary research, where innovations in material structuring and quantum physics combine to push the boundaries of what is possible in biodetection. As such, our work not only advances the state-of-the-art in biosensing but also contributes to the growing field of quantum-enhanced technologies, reinforcing the critical role of QIT in shaping the future of scientific discovery and application.

VII. Quantum technologies in power system

A. Introduction

The electric power system faces numerous challenges as the energy transition continues. The increasing share of uncontrollable RES sources and dynamic loads in the form of high-power consumers (e.g., e-mobility chargers) or prosumers (entities connected to the grid that both consume and produce electricity), combined with the widespread use of electronics and power electronics (computers, inverters, etc.), is resulting in operational problems in a system that has previously operated in a more predictable manner. In the past, large system power plants produced energy that was transmitted through high-voltage lines to consumers, and the flow could be simplistically treated as unidirectional. Today, in contrast, energy flows between different types of sources depending on the weather, the momentary level of consumption, or, for example, the settings of building automation [35]. However, at all times, the energy in the system must be balanced. This leads to a number of operational problems, some of the most significant of which are voltage fluctuations, increasing levels of higher harmonics, or forced reduction of green energy generation as the only available solution to maintain system balance.

Solutions are being sought to support the operation of the power system under new circumstances, and one of promising directions may be the use of solid-state transformers (so-called SSTs) [36]. The concept is based on the replacement of classic medium voltage transformers with devices built from power transistors. The result is a device that is cheaper (uses less copper and iron), smaller (higher operating frequencies result in a reduced size) and has similar efficiency (this was difficult to achieve until recently, but the latest power transistor solutions make it possible to achieve competitive performance). In addition, this device can be intelligently controlled (either remotely or with a customized algorithm, including AI solutions), which will result in active compensation of interference between the medium- and low-voltage network and adaptation of operation to dynamic changes in the system. This task cannot be performed by existing transformers, which are controlled remotely only for high voltages and manually for lower voltages, and regulation is limited only to adjusting voltage levels on both sides of the device.

The potential of Quantum Information Technologies (QIT) in the area of SST application in the power system is presented below.

B. Cybersecurity

SST transformers should be actively controlled to realize their full potential. By changing the signals that control the power transistors, it is possible to actively shape the current-voltage waveforms, which has the effect of reducing the occurrence of higher harmonics and maintaining the desired voltage values in the grid. As a result, this leads to the possibility of better energy management in the grid, as higher harmonics introduce additional losses, and the possibility of introducing generated energy (e.g. from RES) into the grid is limited when voltage levels are too high. Regardless of whether the SSTs will operate independently or be controlled remotely, it is necessary to ensure a secure and reliable communication protocol with the device. These devices - due to their potential multiplicity in the system, their key role in its correct operation, and their exposure to third parties - absolutely must be protected from tampering, as potential hacking and disruption of their operation would have very serious consequences for at least regional part of the power system. Quantum cryptography can provide the desirable solution. It provides unconditional security (it is impossible for an attacker to intercept or modify the quantum information being transmitted without altering it in a detectable way), privacy (only the intended recipients can read the information (with the use of so-called Quantum Key Distribution)), and allows detection of attempts to breach the security of the system (any attempt to intercept or measure the quantum states used in quantum key distribution will inevitably disturb them). It ensures that the information exchanged with SSTs (software updates, instructions, and measurement data) is secure and true, and that any attempt to compromise the communication system will be detected [37].

C. Control

As mentioned above, SSTs are controllable devices that are supposed to adjust their operating parameters to the current state of the power system. As a rule, the faster they are able to respond to various disturbances and changes (e.g., the Sun coming out from behind the clouds and increasing PV generation, the launch of an electric car charger, etc.), the better for the system and its stability. Electronic power devices that interface with the electrical grid are most often controlled using closed-loop PID controllers, and the key parameters of these systems are their settings. The use of quantum algorithms, such as QPDRL (Quantum Process Deep Reinforcement Learning), allows obtaining controllers with better performance characteristics [38].

D. Sensing

The SST transformers discussed in this chapter are advanced power electronic devices, built with many semiconductor components, such as power transistors and diodes. Considering that after successful implementation the demand for these devices would be very high (in Poland alone there are currently more than 200 000 classic MV / LV transformers), it is necessary to take care of the quality of key semiconductor components' manufacturing. Defects in their structure can result in overheating and malfunctioning of the devices, which in the long run can lead to costly failure not only of the SST transformer but also of the connected devices, which may fail to react in time to the occurrence of a short-circuit current, for example. In this area, quantum technologies also have a promising solution. The company Quantum Diamonds proposes to use synthetic diamonds to detect defects in the crystal structure of manufactured semiconductor components. A synthetic diamond containing nitrogen vacancy centers (which have a spin) when illuminated with a green laser emits a red light as a result of excited spins – the light is later captured by a camera. The intensity of the light depends on the strength of the magnetic fields the diamond is exposed to. Because magnetic fields are generated by current flows in the chip, the nature of those current flows can be inferred from the data collected from the light since resulting in the estimation of semiconductor's structure quality [39].

E. Computations (simulations and forecasting)

Quantum algorithms can help with solving complex optimization problems since quantum physics boils down to an energy minimization problem - everything tends to reach a minimum-energy state (any object slides down slopes). So-called quantum annealing simply uses quantum physics to find low-energy states of a problem, and therefore the optimal or near-optimal combination of elements. Solutions utilizing quantum algorithms and quantum machine learning in electrical grid management include:

- grid simulation and modeling - quantum algorithms that calculate accurate power flow, fault analysis and stability assessments – thus enabling grid operators to test scenarios, optimize grid parameters, and strengthen overall reliability,
- grid optimization – quantum algorithms working on large-scale combinatorial problems related to grid topology optimization, capacitor placement for stabilization purposes, and fault detection with tremendous cost savings,
- energy market optimization – quantum algorithms making energy trading and pricing more efficient (including real-time optimization),
- energy forecasting – quantum algorithms enhancing the process of forecasting energy demand and supply can help to achieve grid stability and efficient resource allocation.

In short, quantum algorithms can help grid operators achieve better load balance, reduced energy losses, optimized power distribution, and lowered energy prices [40].

F. Conclusions

According to the areas discussed above regarding information quantum technologies within the power system, it should be stated that these technologies are not a necessary element for the implementation of the considered SST transformers, while their application can improve this process, as well as allow the full potential of this technology to be realized (by improving the performance of these devices, as well as their operation).

VIII. The Research of MIMO Antenna System with Quantum Computing

A. The basic background of MIMO antenna system

After entering the 21st century, The mobile phone antennas need to cover more and more frequency bands; A new type of antenna wireless communication system (multi-input-multi-output, abbreviated as MIMO system) has emerged in the new era. MIMO technology has become a critical component of modern wireless communication systems. By employing multiple antennas at both the transmitting and receiving sides, it boosts data throughput and system capacity without requiring extra bandwidth or higher transmission power. This impressive performance is made possible by utilizing the spatial domain as an independent resource [41]. Consequently, MIMO has established itself as a foundational element in contemporary standards like LTE, 5G, and Wi-Fi. However, the maximization of the inherent benefits of MIMO systems presents a myriad of challenges [42]. These challenges predominantly revolve around optimizing system parameters to enhance throughput, minimize interference, and improve signal-to-noise ratios. Traditionally, these optimization problems have been approached through classical algorithms and heuristic methods [43].

B. Quantum computing techniques in MIMO system optimization

Quantum computing, which merges principles of quantum mechanics and computer science, leverages the distinctive features of quantum bits, or qubits. Unlike classical bits, which are confined to a state of 0 or 1, qubits can exist in a superposition of states, representing 0, 1, or any combination of the two. When qubits become interconnected through quantum entanglement, they can collectively represent an exponentially larger number of states at once [44]. This unique characteristic enables quantum computers to process a vast array of possibilities simultaneously, potentially outperforming classical systems for certain problems. In the design of multi-user MIMO system, how to efficiently solve the optimization problems such as beamforming and resource allocation is the key, and the Quantum Approximate Optimization Algorithm (QAOA) and the Grover Algorithm can efficiently deal with these optimization problems [45]. On the other hand,Building on the fundamental principles of quantum mechanics, quantum information theory expands Shannon capacity in classical communication, offering a novel approach to calculating channel capacity for MIMO systems.

C. The simulation results analysis

Through detailed numerical simulation, the application of quantum computing technology in optimizing MIMO system is deeply studied. A comprehensive simulation framework is established to accurately simulate MIMO systems under various antenna configurations and environmental conditions. Quantum simulation uses a quantum computing simulator to simulate the behavior of real quantum hardware, taking into account noise and computational errors. By adjusting key parameters, including the number of antennas, modulation scheme and signal-to-noise ratio, the performance of quantum algorithms under different conditions is evaluated. The study focuses on QAOA and Grover algorithms, comparing metrics such as The quality of solutions, convergence speed, and computational resource efficiency [46].

The initial simulations focused on optimizing beamforming, The Table 1 revealing significant enhancements in solution quality through quantum algorithms. These algorithms showed

TABLE I
BEAMFORMING OPTIMIZATION RESULTS

Number of Antennas	Based Optimizer (dB)	QAOA (dB)	Grover (dB)
4	10.1	12.5	12.1
8	15.4	18.6	18.2
16	20	25.4	25

TABLE II
POWER ALLOCATION EFFICIENCY RESULTS

SNR(dB)	Based Optimizer(%)	QAOA(%)	Grover(%)
10	59	74	73
20	69	83	80
30	71	86	83

superior signal directivity and better interference management. Notably, both QAOA and Grover's algorithm consistently outperformed classical methods, with their advantages becoming more pronounced in configurations involving a greater number of antennas.

Efficient power allocation plays a crucial role in boosting the signal-to-noise ratio and minimizing energy consumption in MIMO systems. Table 2 highlights the substantial improvement in power allocation efficiency achieved through quantum algorithms. Specifically, QAOA demonstrated superior performance in optimizing power distribution, consistently enhancing signal quality and mitigating interference more effectively than classical approaches.

User scheduling, a challenging combinatorial problem, is a key aspect of optimizing MIMO systems as it involves determining the sequence and resource allocation for each user. The study compared the efficiency of quantum algorithms with traditional methods, focusing on throughput and computation time. The Table 3 illustrated that implementing quantum algorithms notably increased the throughput of MIMO systems, demonstrating their effectiveness over classical approaches.

D. Conclusion

Despite the current limitations of quantum computing technology, particularly in hardware accuracy and scalability, the study highlights the clear advantages of quantum algorithms in optimizing MIMO systems. As advancements in quantum technology progress, its potential to transform MIMO system optimization becomes increasingly evident. The integration of quantum computing with MIMO antenna systems is expected to redefine the wireless communication landscape in the near future.

TABLE III
USER SCHEDULING RESULTS

Users	Based Optimizer(Mbps)	QAOA(Mbps)	Grover(Mbps)
10	50	67	64
20	90	122	115
30	130	177	170

IX. DISCUSSION, CONCLUSIONS

The convergence of Quantum Information Science and Technologies (QIT) with established disciplines in Information and Communication Technology (ICT) presents both formidable challenges and unprecedented opportunities. Our exploration, guided by the perspectives of diverse engineering students engaged in specialized research areas, has unveiled the intricate interplay between QIT and domains like biomedical engineering, electronics, software, communications, machine learning and cybersecurity.

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