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Research Article

Distributed Hybrid Quantum Computing Applications into Battery Cell Manufacturing Industries as per the Industries 5.0

Biswaranjan Senapati[1], Bharat S Rawal[2*]

[1]Department of Computer Science, Capital Technology University, Laurel, Maryland, USA
[2]Department of Computer Science and Digital Technologies, Grambling State University, Gambling, Louisiana, USA
E-mail: brawal@ieee.org

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Abstract: In distributed computing, data trading mechanisms are essential for ensuring the sharing of data across multiple computing nodes. Nevertheless, they currently encounter considerable obstacles, including low accuracy in matching trading parties, ensuring fairness in transactions, and safeguarding data privacy throughout the trading process. To address these issues, we put forward a data trading security scheme based on zero-knowledge proofs and smart contracts. In the phase of preparing the security parameters, the objective is to reduce the complexity of generating non-interactive zero-knowledge proofs and to enhance the efficiency of data trading. In the pre-trading phase, we come up with attribute atomic matching smart contracts that are based on precise data property alignment. The goal is to get trading parties to match data attributes in a very specific way. During the trading execution phase, we use lightweight cryptographic algorithms based on Elliptic Curve Cryptography (ECC) and non-interactive zero-knowledge proofs to encrypt trading data twice and make attribute proof contracts. This keeps the data safe and private. The results of experiments conducted on the Ethereum platform in an industrial Internet of Things (IoT) scenario demonstrate that our scheme maintains stable and low-cost consumption while ensuring accuracy in matching and privacy protection. Especially in battery industrial manufacturing, the application of distributed computing is in huge demand and essential to maintaining a healthier technology integration among various systems and technological nodes to perform the better management of energy cells within the battery management system.

***Keywords*:** quantum computing's, distributed quantum computing, Quality Assurance International (QAI), Quantum Machine Learning (QML), Quarantine Information Services (QIS), Enterprise Resource Planning-Systemanalyse Programmentwicklungt (ERP-SAP), battery cell

1. Introduction

Over time, the processing volume of data surpasses the capabilities of a typical system. Therefore, we utilize easily scalable distributed systems to handle large amounts of data quickly. However, a variety of distributed system issues may impact data processing. We deal with a large amount of data at battery cell production facilities; interfaces and transactions are essential to effective battery energy productivity. As the world struggles to meet the diverse and expanding needs for electrochemical energy storage solutions, Lithium-ion Batteries (LiBs), the most potent energy source in today's generation of Electric Vehicles (EVs), remain the most advanced technology in the battery ecosystem.

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An unprecedented demand drives the world's gigascale production of state-of-the-art batteries, despite the growing need for safer, more cost-effective, and energy-dense next-generation batteries. These advancements fuel the intense hunt for cost-effective, scalable, and sustainable battery manufacturing methods. Digitally modernizing battery production plants can partially meet these expectations. This study provides a comprehensive review of recent and impending developments in the most distributed computing, quantum computing, and the digitization of the battery cell production chain, along with future possibilities in this field. We summarize existing modeling approaches and discuss their integration with data-gathering instruments and communication protocols to develop a digital twin of the battery production chain. Business and academic scientists and engineers hope that the challenges and novel approaches discussed here will provide a path for more intelligent and networked battery production processes in the future. Because of their high energy densities, cheap cost, and extended lifespan, Lithium-ion Batteries (LiBs) are the industry standard for batteries used in Electric Vehicles (EVs), mobile devices, and energy storage. LiB's capacity degradation negatively impacts the reliability and safety of these applications. As a result, life cycle assessment, cost and safety concerns, and battery management systems all depend on the estimation of battery cycling capacity. Model-based and data-driven approaches are the two primary types of methods used to estimate battery capacity decline. Model-based approaches use parametric electrochemical processes to investigate the link between a lithium-ion battery's cyclic aging and its cell capacity [1]. However, predicting and parametrically identifying the chemical properties of the components in a LiB is very challenging and irreversible [2]. Consequently, it is difficult to provide comprehensive results with model-based methods. Additionally, each model-based strategy targets a certain kind of LiB. This limits its potential to expand beyond the initial composition [3]. On the other hand, parametric analysis is not required for data-driven approaches. Empirical observations of battery performance, such as voltage, current, temperature, and capacity data, serve as their basis. This enables them to grow and scale to accommodate different battery sizes and types. Furthermore, the rapid development of computer processors and data-gathering technologies has made it simpler to put data-driven ideas into effect. Experts have employed a wide range of data-based analytical techniques to forecast the breakdown of LiBs [4]. These consist of neural networks, Gaussian process functional regressions, support vector machines, and relevance vector machines. The Artificial Neural Network (ANN), one of the data-driven techniques, is a powerful machine learning tool for managing massive volumes of data involving complex nonlinear systems [5, 6]. The increasing demand for EVs and electronic devices has made it extremely challenging to manage enormous volumes of data, since LiBs are one of the essential components required for this mobility and connectivity boom. When trained on such demanding tasks, traditional machine learning models usually experience a performance bottleneck. Additionally, recent advances in quantum computing have enabled promising performance of Quantum Machine Learning (QML) models [7, 8]. In other words, QML models leverage quantum computing to enhance the capabilities of machine learning [9]. The Quantum Neural Network (QNN), a popular QML model, consists of parameterized learnable quantum circuits [10]. A QNN uses angle encoding to encode the classical attributes into quantum states. The learnable quantum circuit's layers then combine to create a QNN model that makes use of quantum states. The output layer uses a series of parameterized rotation gates along axes to build the quantum circuit, transforming qubit measurements into classical values for input. To assess potential quantum advantages in certain battery learning tasks, this paper develops a QNN regression model to predict battery capacity decline. A subfield of computer science called distributed computing studies how several computers may work together to solve problems. Distributed computing divides large jobs into smaller ones and then transmits the smaller tasks to other computers for communication. Distributed computing uses several computing resources situated in different operating locations to mimic the functions of a single computer. Distributed computing combines different computers, servers, and computer networks to accomplish computing tasks of wildly different sizes and goals. Haddaway et al., presents an R package and Shiny app designed to create Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020-compliant flow diagrams, enhancing the transparency of systematic reviews. The tool offers interactive features to facilitate the visualization of review processes, ensuring adherence to the latest PRISMA guidelines [11]. Distributed computing works even in the cloud. Furthermore, while cloud computing and distributed cloud computing share similar concepts, they differ in their global reach; distributed cloud computing has the potential to expand the reach of cloud computing into new areas. A Local Area Network (LAN) is a way to connect small, scattered computer systems with components near each other. Larger distributed systems use Wide Area Networks (WANs) to link their geographically separated parts. The components of a distribution system communicate with one another using a sophisticated message-passing mechanism, regardless of the kind of network.

Distributed computing typically requires the deployment of shared memory and several components since it often tackles the most difficult and complicated computational issues. Furthermore, distributed computing depends on highly coordinated synchronization and significant processing capability for the entire system to effectively evaluate data, share files when needed, and collaborate toward a common goal. The convergence of Distributed Computing Systems (DCS), cloud architecture for corporate enterprises, and the Internet of Things (IoT) is transforming business models across a range of sectors. IoT devices enable real-time equipment and process monitoring, thereby reducing downtime and enhancing output. Industrial enterprises use IoT sensors for machine monitoring, maintenance scheduling, and breakdown prediction. Furthermore, IoT-enabled automation reduces the need for human interaction, increasing the effectiveness of smart manufacturing and automated supply chains. Companies analyze the vast amounts of data generated by IoT devices to gain a better understanding of consumer behavior, operational inefficiencies, and market trends. Distributed computing systems subsequently process this data, enabling advanced analytics and machine learning to predict future trends and provide useful insights. IoT devices facilitate pay-per-use and subscription-based business models in utilities and transportation, as well as novel consumer engagements like wearable health gadgets. By collecting information on consumer preferences and usage patterns, IoT devices can make tailored goods and services possible, boosting client loyalty and pleasure. On the other hand, real-time monitoring enhances security and ensures operational safety since dispersed systems respond quickly to threats. Moreover, it makes regulatory compliance easier by providing accurate operating data. This study aims to determine the extent to which the competencies enhance the effectiveness and efficiency of business models. After carefully choosing these pieces of literature, we performed a few bibliometric literature reviews of a few researchers' publications. The study's conclusions indicate that these systems work together to provide businesses with a competitive edge, promote continuous innovation, and assist them in adapting to shifting market conditions. All things considered, integrating IoT and distributed systems into business models enhances their numerous advantages. It produces smart infrastructures, such as smart grids; edge computing, which allows data processing closer to the data source, such as autonomous vehicles; predictive analytics, which aids companies in anticipating issues, such as equipment failures; personalized services, such as e-commerce platforms that provide users with tailored recommendations; and enhanced security, which reduces the likelihood of centralized attacks, such as blockchain technology. We suggest future research directions [12-14]. Here are our key contributions and novelty to our research in distributed computing applications into battery cell manufacturing industries as per the Industrial Revolutions 5.0. Below is the list of contributions:

1. Data Trading Security Scheme: The paper proposes a novel data trading security scheme utilizing zero knowledge proofs and smart contracts to enhance data privacy and transaction fairness in distributed computing environments, specifically tailored for battery sale manufacturing.

2. Improved data matching mechanisms: The paper introduces atomic matching smart contracts, which significantly improves accuracy. It introduces attribute atomic matching smart contracts that focus on precise data property alignment, which significantly improves the accuracy of matching trading parties in data exchanges.

3. Integration of quantum computing: The paper explores the application of quantum computing techniques, particularly quantum neural networks QNN to predict battery capacity decline, showcasing the potential of quantum machine learning in enhancing battery management systems.

4. Framework for digital creation: The paper provides a comprehensive framework for integrating modeling approaches with data gathering instruments and communication protocols to develop a digital twin of the battery. Production chain promoting smarter and more efficient manufacturing processes.

The remaining sections of the study are organized in the form of shadows: The literature reviews are summarized in Section 2. The theoretical framework is listed in Section 3. The Philosophies around the Distributed Computing System (DCS) are explained in Section 4, the advantages of DCS and Industrial Internet of Things (IIoT) in the manufacturing sites scheme are explained in Section 5, few use cases in the battery cell manufacturing factory are presented in Section 6. The quantum hybrid cloud computing and DCS are presented in Section 7, future work is presented in Section 8, and the conclusions are provided in Section 9.

2. Related works

In industrial manufacturing and especially in the battery cell technology industries the useful distributed computing networks are increasing and have a strong demand for industrial optimizations. We have encountered numerous problems while not considering a strong Distributed Computing Network (DCN) as these are the key to the manufacturing digitalization business and optimizing their performance key drivers. The rise of distributed computing systems and the Internet of Things (IoT) has completely transformed business models in some industries. Along with changing the technological environment, these advancements have had a profound impact on how businesses function, compete, and provide value to their clients [12, 15]. The confluence of IoT and distributed computing systems is displacing traditional, centralized business frameworks with more adaptable, decentralized, and data-driven approaches. The need for increased productivity, real-time decision-making, and greater emphasis on customer-centric tactics is driving this shift. The Internet of Things, as defined by Dijkman et al. [16], is a network of connected physical items that incorporate sensors, software, and other technologies. This innovation may allow these devices to collect and exchange data. Additionally, the vast network of connected devices produces an unprecedented quantity of data, providing businesses with valuable insights into consumer behavior, operational efficiency, and market trends. Plans for modern businesses now must include real-time information/tasks monitoring, analysis, and reaction. It assists companies in increasing customer happiness, reducing costs, and streamlining processes. At the same time, distributed computing platforms have transformed business operations. According to some great digital solution architecture and their agreement, these advancements encompass a range of technologies, including cloud computing, edge computing, and blockchain. These systems distribute computer resources across several locations rather than relying on a single centralized server [14]. Decentralization reduces latency, increases system resilience, and enables more efficient use of resources. Cloud computing has democratized access to powerful computer resources, allowing businesses of all sizes to benefit from cutting-edge technology without having to make significant upfront expenditures. Business models have changed significantly because of the convergence of distributed computing systems and the Internet of Things. Traditional businesses, which often employ hierarchical and sequential processes, are progressively evolving into more dynamic, networked entities. Businesses may continually monitor operations and adjust to maximize efficiency by utilizing real-time tasks from IoT devices [15]. Predictive analytics powered by data from IoT devices may help firms anticipate issues before they happen, reducing downtime and increasing productivity. Furthermore, distributed computing solutions give business operations more flexibility and scalability. According to Alamouti and his group, decentralized computing resources guarantee that businesses may grow their operations effectively and promptly adjust to shifting needs [16, 17]. By improving security and transparency, blockchain technology builds trust and makes it possible for new kinds of cooperation and transactions to take place without the need for conventional middlemen. These technological advancements also make it easier to create personalized customer experiences. Businesses may better understand consumer preferences and behavior by analyzing data from several angles. This enables them to create more specialized product offers and more focused marketing campaigns. This client-focused approach boosts sales, cultivates a devoted following, and enhances customer happiness. IoT and DCS have been the target of several complaints, ranging from technological constraints to social and economic issues. These complaints include growing susceptibilities to cyberattacks, issues with device compatibility and interoperability, and an excessive amount of data that complicates processing and storing, high maintenance costs, and the displacement of jobs in industries such as manufacturing. The advantages of these systems for business models outweigh this issue. How much do distributed computing systems like the Internet of Things improve business models? This research question guides the desired literature review. This literature review introduces the key concepts, primary problems, and research questions that guide the investigation. The next section describes the review's supportive and guiding approach. We then build the study's information basis upon a theoretical framework [17-19]. A discussion section then examines the impact of IoT and Distributed Computing Systems (DCS) integration on corporate processes.

The substantial improvements in computer systems over the past 60 years have led to the emergence of new paradigms, such as cloud, fog, edge computing, distributed computing, and the Internet of Things. These findings present significant scientific challenges as well as new creative and economic opportunities. The development of computer systems is being influenced by both existing systems and architectures as well as innovative concepts like serverless computing, quantum computing, and on-device artificial intelligence on peripheral devices. The manufacturing and battery manufacturing sectors depend heavily on all these technologies. Industrial revolutions have made advanced and additive manufacturing more cost-effective in battery technologies. Therefore, managing resources, risks, and materials, maintaining production optimization, and implementing digital manufacturing practices are crucial for a successful battery business. This is due to their potential for real-time data collection, enhanced quality control, proactive maintenance planning, and more efficient production processes. Small and Medium-sized Enterprises (SMEs) might find the initial investment in IoT infrastructure to be prohibitively expensive. The IIoT, Cloud, ERP-SAP High-performance ANalytic Appliance (HANA), and IoT all help industrial battery manufacturing sites save money by checking quality, improving production flow, running warehouses, and making the high-quality batteries that the auto industry needs. Actually, advanced manufacturing and additive manufacturing can lower costs, increase quality, boost competitiveness, and develop new business models like Product-as-a-Service (PaaS) [20]. This article looks at the pros and cons of using quantum computing, quantum hybrids, and quantum distributed computers in the process of making battery cells in Lithium-ion Batteries (LiB) in order to make the best final battery cell and to cause the most trouble for new technologies in the industry. 5.0 examines the shift from Industry 4.0 to Industry 5.0 paradigms, provides an in-depth analysis of significant blockchain-based applications for Industry 5.0 pillars, and helps developers create Industry 5.0 apps. By maximizing resource use and reducing waste during the manufacturing process, these applications not only improve efficiency but also advance sustainability. Businesses can achieve new levels of accuracy and speed by implementing quantum computing, which will hasten the development of next-generation battery technologies that are critical to the advancement of renewable energy and electric vehicle technologies. Rapid prototyping, Artificial Intelligence (AI), the IIoT, Machine Learning (ML), photonics, and novel materials are some of the technologies propelling the manufacturing industry toward a future version of sector 4.0. The European Commission has developed a plan to reach carbon neutrality and full digitalization across the European continent by 2050. The future of technology-based production makes it challenging to reconcile planned and actual roadmaps due to the unpredictability of political, environmental, and social factors. Stakeholders must therefore continue to be creative and flexible, constantly reevaluating their approaches to conform to changing technological advancements and sustainability objectives [21]. To develop solutions that not only increase productivity but also encourage environmental stewardship, cooperation across sectors and industries is essential in this dynamic environment. To provide the workforce with the requisite skills, this cooperative approach will necessitate investment in education and training in addition to a dedication to research and development. Stakeholders can address the complexity of the technology landscape and build a robust framework that promotes sustainable growth by accepting this challenge. The best way to initiate an industrial revolution is for groups to collaborate on projects like developing battery cells, applying quantum computing, and disseminating quantum computing, rather than merely responding to issues and threats. Organizations can improve operational efficiency and innovate processes by utilizing these cutting-edge technologies, which will ultimately increase their competitiveness in the global market. With an emphasis on the relationship between innovation and environmental stewardship in battery technologies, this article examines the ways that cutting-edge technology contributes to the creation and maintenance of a sustainable ecosystem. Inventions, the advent of smart materials, renewable energy, artificial intelligence, and the Internet of Things (IoT) have revolutionized environmental sustainability. AI-powered prediction models improve resource management, reduce waste, and increase energy efficiency. The Internet of Things (IoT) enables real-time monitoring and control of environmental factors, enabling data-driven conservation. Renewable energy sources are necessary to decrease reliance on fossil fuels and mitigate the effects of climate change [21, 22]. We believe that the next big thing in manufacturing and digitalization automation in discrete manufacturing sites will be 6G in distributed quantum computing. The upcoming wireless communication technology will speed up transmission, lower latency, and improve reliability. Virtual reality, remote operations, and self-driving cars are just a few of the real-time applications that benefit greatly from its anticipated terahertz frequency range, faster data transfer rates, and latency of less than 1 millisecond. 6G technology will continue to offer cloud services while increasing capacity with higher frequencies and antennae. For businesses in every industry, including the secondary sector, tech-business analytics is an essential tool for making data-driven decisions that enhance productivity, profitability, and operations. Businesses can identify supply chain improvement opportunities and inefficiencies by looking at suppliers, inventory, logistics, and other data. This data can be used to improve quality control systems, forecast machinery and equipment failures, boost productivity, reduce downtime, plan maintenance ahead of time, and analyze consumer and market trends to maximize sales and marketing efforts and identify growth and profitability opportunities. The analytics strategy of the tech company outlines a systematic approach to using data analysis to address problems in the secondary industrial sector while improving corporate performance and decision-making. The study's technical objectives include a review of the history of business analytics and 130 recently released studies on tech business analytics in the secondary industry sector. The paper also looks at the need for Industry 5.0 technology and the socioeconomic effects of technologies [23, 24].

3. Theoretical framework

The concept behind distributed quantum computing comes from applying ideas from quantum mechanics, such as interference, entanglement, and superposition, to a network of quantum computers that are all linked to each other. This enables the distribution of calculations across multiple quantum devices. It is essential to coordinate and manage communication across these devices to perform complex quantum operations on large datasets. The convergence of distributed computing systems and the Internet of Things has brought about significant changes to contemporary corporate structures. These technological advancements have elevated the standards for connectivity, effectiveness, and proficiency in utilizing data to guide decisions [22]. It is possible to increase productivity in factories by using quantum distributed computing and other technologies like IIoT, IoT, ERP-SAP HANA, Business Technology Platform (BTP), Integration Suites, and Production Systems (Manufacturing Execution Systems (MES), Supervisory Control and Data Acquisition (SCADA), Programmable Logic Controller (PLC), etc.). Quantum distributed computing can enhance and integrate these technologies. Real-time information integrations make it possible to gather and analyze data in real time, while platforms for distributed computing improve security, scalability, and flexibility. When looked at, these innovations change the way things are usually done and open new ways to gain a competitive edge by making it easier to come up with new, customer-focused business ideas [23, 24]. This literature review examines the connections between business models, distributed computing, the Internet of Things, and the Industrial Internet of Things. It also looks at different downstream application systems that are used in battery cell manufacturing sites to show a range of possible outcomes. These outcomes highlight the potential for innovation and efficiency in production processes, ultimately leading to enhanced product quality and reduced operational costs. By examining these interconnected technologies, the review aims to provide insights into how manufacturers can leverage these advancements to stay ahead in a rapidly evolving marketplace. Moreover, the study emphasizes the importance of collaboration across various sectors, enabling manufacturers to adopt the best practices and integrate cutting-edge solutions. This holistic approach not only fosters a culture of continuous improvement but also positions companies to respond effectively to emerging challenges and opportunities in the industry.

3.1 *Distributed quantum computing*

The paper presents a novel application of distributed quantum computing in large manufacturing sites for battery industries, considering all key considerations when designing a quantum distributed battery computing model to address real-time optimization in industrial automation. The following factors are crucial when considering quantum distributed computing in the real world for industrial automation's large-scale battery manufacture. These components include scalable quantum networks, effective error correction techniques, and secure communication protocols-all of which are essential for maximizing battery production quality for both government and automakers. By investigating these problems, researchers can unlock practical applications that utilize quantum advantages across various fields. These include complex simulations at battery cell manufacturing facilities, cryptography, and optimization-all of which are crucial components of industrial automation. In addition, the integration of quantum computing can significantly enhance predictive maintenance strategies, allowing companies to anticipate equipment failures before they occur. This proactive approach not only minimizes downtime but also optimizes resource allocation, ensuring a more efficient and sustainable manufacturing process. By leveraging these advancements, businesses can not only improve their operational efficiency but also drive innovation, leading to the development of new products and services that meet evolving market demands. As quantum technology continues to mature, its impact on industries will undoubtedly expand, reshaping the landscape of modern manufacturing and beyond. Here are below points that explain the approach of Quantum Distributed Computing in Battery production:

- Explore specific secure communication protocols that enhance quantum distributed computing security in

Production sites.

▪ Discuss the latest advancements in error correction methods and their impact on computational efficiency.

▪ Analyze how scalability challenges are being addressed in current quantum computing models in Battery industries.

▪ Provide examples of real-world applications of quantum distributed computing in cryptography, such as secure key distribution, production and optimizing the efficiency of Qualitative battery, Battery Parameters (State of Health (SoH), State of Charge (SOC), and Remaining Useful Life (RUL), etc.).

▪ Investigate optimization techniques that benefit from the unique capabilities of quantum distributed systems to make successful batteries production and scaled solutions for customers.

▪ Optimizing battery productions as per customer demand and Make to Order (MTO), Make to Stock (MTS) and Contract orders.

▪ Management of Battery Passport and Key international standards as per the global and Global Trade Services (GTS) compliance and regulations.

The paper states some of the key aspects of distributed quantum computing while taking into account the fact that industrial automation in battery cell manufacturing. Typically, quantum distributed computing has two types and when it comes to distributed quantum computing, the main difference between "Data Distributed Quantum Computing" (DDQC) and "Resource Distributed Quantum Computing" (RDQC) is the type of resource being shared. In RDQC, local quantum computing power is not enough, and information is spread out among several parties.

3.1.1 *RDQC, or resource-distributed quantum computing*

Multiple quantum computers work together to do the required computations when one quantum computer lacks the processing capacity to handle a task. When a single quantum processor cannot handle the computational demands of large-scale quantum simulations, this method is frequently employed in manufacturing automation processing, it could potentially solve and save the major cost in operations as well as warehouse operation in battery cell sites.

3.1.2 *Data Distributed Quantum Computing (DDQC)*

While preserving privacy by not disclosing raw data, several parties with sensitive data can use a distributed quantum computer to execute calculations on their combined data. Data privacy is especially important in industries like battery cell manufacturing as well as other discrete industrial manufacturing sites. Some key battery parameters, like SOC, SOH, End-of-Life (EOL), and RUL for a unique batch of managed items, could be potentially segregated from another, and it would be much easier to identify while fulfilling the order management and warehouse applications in battery management industries.

3.2 *Quantum communications protocol*

In industrial manufacturing practices and safer practices of Quantum Key Distribution (QKD), the communication protocol of quantum computing is the key. Within the Quantum communication protocols enable methods for securely transferring quantum data (entangled qubits) between different quantum computers, including error correction systems to lessen noise and decoherence.

3.3 *Entangled qubits for future manufacturing*

The function of the entangled quantum qubits is essential in manufacturing applications and it will create the best techniques to safely transfer quantum data (entangled qubits) across various quantum computers, including error correction systems to reduce noise and decoherence, which is known as quantum communication protocols. Quantum communication protocols are methods for securely transferring quantum data (entangled qubits) between different quantum computers, including error correction systems to lessen noise and decoherence. Due to the enormous computational power of quantum computers that use entanglement, complex simulations of materials and processes, the design of new materials with superior properties, production line optimization, and the creation of new manufacturing techniques with significantly increased efficiency are all made possible by entangled qubits, a quantum phenomenon in which multiple qubits are interconnected and instantly influence one another.

3.4 *Quantum circuit model for automation led industrial manufacturing*

Like conventional circuits, a quantum circuit is a model for quantum computation in quantum information theory. In this theory, a computation consists of a series of quantum gates, measurements, initializations of qubits to known values, and possibly additional operations. This model shows distributed quantum computations as a set of quantum gates applied to qubits spread across several processors. This is because different circuit parts need to be in sync with each other. Bits are binary digits used to store information on classical computers. Bits can have values of either 1 or 0. Depending on the situation, we may consider these numbers to be "on" or "off", "true" or "false", "high voltage" or "low voltage". At their most basic level, all computers process bits, even if they can execute incredibly intricate and sophisticated jobs. Quantum computers have a distinct way of storing data. Information is stored in the state of a two-level quantum system called a quantum bit, or qubit for short, rather than in binary digits on quantum computers. Whether you ask a computer scientist, mathematician, or physicist, the formal definition of a qubit will vary. The following three definitions are comparable.

3.5 *Distribution strategy and entanglement*

Essentially, a "distribution strategy" is a protocol to efficiently share entanglement between desired locations in a quantum network. In the context of entanglement, a "distribution strategy" is a planned method for distributing entangled quantum particles across a network of nodes with the goal of establishing long-distance entanglement by carefully managing the generation, transmission, and manipulation of entangled pairs to overcome the challenges of decoherence and loss during transmission. To perform complex quantum computations with many processors, techniques to efficiently distribute entanglement over a network of quantum devices must be developed within the battery technologies companies to gain their maximum outcomes in industrial manufacturing and applied quantum information sciences. To achieve the entanglement distribution techniques for industrial manufacturing practices, we must consider the key aspects of the below drivers include (Quantum Replicators, Adaptive methods and Entanglement Swapping, etc.) [22, 24, 25].

▪ Quantum Replicators: By participating in entanglement swapping activities with nearby nodes, these intermediary nodes within a network can generate and store entanglement, thereby facilitating its propagation over vast distances.

▪ Entanglement Swapping: This method efficiently transfers entanglement between two remote nodes that were not initially directly connected by measuring entangled pairs in a certain way. Network Topology: The network's architecture, specifically the placement of nodes and connections, significantly influences the effectiveness of entanglement dispersion.

▪ Adaptive methods: Distribution methods can be dynamic, responding to real-time changes in channel quality or evolving entanglement needs, contingent on network conditions and demands.

3.6 *Fault-tolerant in quantum computation*

The term "fault-tolerant" in quantum computation refers to a computer's ability to continue carrying out precise calculations even in the face of errors or noise during operations. This is accomplished through methods such as quantum error correction codes, which enable dependable computation despite the intrinsic fragility of quantum states; in other words, it's the capacity to preserve computational integrity in the face of possible hardware flaws or environmental disruptions. Complex quantum computations involving many processors need the development of techniques to efficiently distribute entanglement over a network of quantum devices. While considering a fruitful objective in fault-tolerance in making quantum computing for manufacturing sites, these factors are essential.

▪ Correction of errors: To recover from noise and carry on with computations, the fundamental method involves the use of specialized "error correction codes" to identify and fix faults that arise in individual quotes during computing. The threshold theorem is an important idea that says quantum error correction can reduce logical errors to any level, allowing fault-tolerant processing, if the error rate on each quote is less than a certain level.

▪ Logical qubits: The error correction code safeguards many physical qubits to create a single "logical qubit" that provides fault tolerance and enables reliable higher-level processing.

▪ Fault-tolerant quantum computing is hard to set up because you need extra qubits for error detection, and you must come up with good error correction protocols that can be used during complex quantum operations.

3.7 *Classical communication overhead*

In Industrial manufacturing and battery cell production industries, quantum information theory and quantum communication mechanisms are the key to establishing safety and secured industrial sites for battery management systems. The time and data cost of information transmission across network entities or the percentage of time spent chatting with team members rather than working are two examples of classical communication overhead:

▪ Communication across networks in Industrial Management: The time and data costs associated with creating and sending information across network entities are referred to as communication overhead in computer science. It might be a serious drawback if you depend on constant cloud communication.

▪ Communication within the team in industrial sites: Industrial management has large and extreme teams of workers and scientists as they need to be seamlessly integrated with the core business practices and industrial automation tools. The percentage of time spent chatting with team members rather than doing productive tasks is also known as communication overhead. A team's likelihood of experiencing communication overhead increases with the number of members. The difficulties in connecting quantum computers over classical communication lines are referred to as "classical communication overhead" in the context of quantum computing.

▪ Latency: Performance can be negatively impacted by latency problems with traditional communication networks. Fault-tolerant quantum computation involves the design of procedures and protocols that use redundancy and error correction strategies to overcome errors in quantum calculations. Because mistakes are more likely to occur in distributed systems, this is especially important. Overhead for classical communication: analyzing the amount of classical communication required to coordinate quantum processes across different distributed system nodes to minimize this overhead for computing performance. Designing methods and protocols that use redundancy and error correction techniques to overcome.

3.8 *Important concepts within this framework/quantum state representation*

Complex numbers in quantum computing represent the state of qubits and the operations performed on them. A qubit is a two-state quantum system that can exist in two superposed states at the same time. A pair of complex numbers represent the qubit's state during a measurement, expressing the probability of its discovery under that condition. Not only do we use complex numbers to represent the qubits' state, but we also use them to represent the quantum gates that manipulate the qubits. Usually, we use unitary matrices-complex matrices that maintain the inner product of vectors-to represent gates. For qubits, unitary matrices represent rotations and other possible operations. Quantum computing can leverage key aspects of quantum physics, such as quantum interference and entanglement, by utilizing complex numbers. Quantum algorithms, by utilizing quantum gates to manipulate the probability amplitudes of qubits, can complete certain computations considerably faster than conventional algorithms. We have observed a significant demand for quantum hybrid solutions and quantum distributed computing to facilitate successful industrial productions and enhance manufacturing practices [24, 25]. Among the main concepts in this framework are: It is possible to describe the quantum state of a distributed system by looking at the connections and entanglement of qubits on different processors using math tools like density matrices. This is called quantum state representation [26].

3.9 *Quantum network topology*

In distributed quantum computing, the topology of a quantum network is the configuration of its quantum processors that optimize communication efficiency and minimize delay. Figure 1, represent the multi-layer architecture of quantum circuit in Distributed Computing. In the distributed quantum computing, we design the topology of a quantum network, or the configuration of its quantum processors, to optimize communication efficiency and minimize delay. Quantum task development is the process of developing quantum algorithms specifically for distributed computing applications, such as simulating complex quantum systems or addressing large-scale optimization problems.

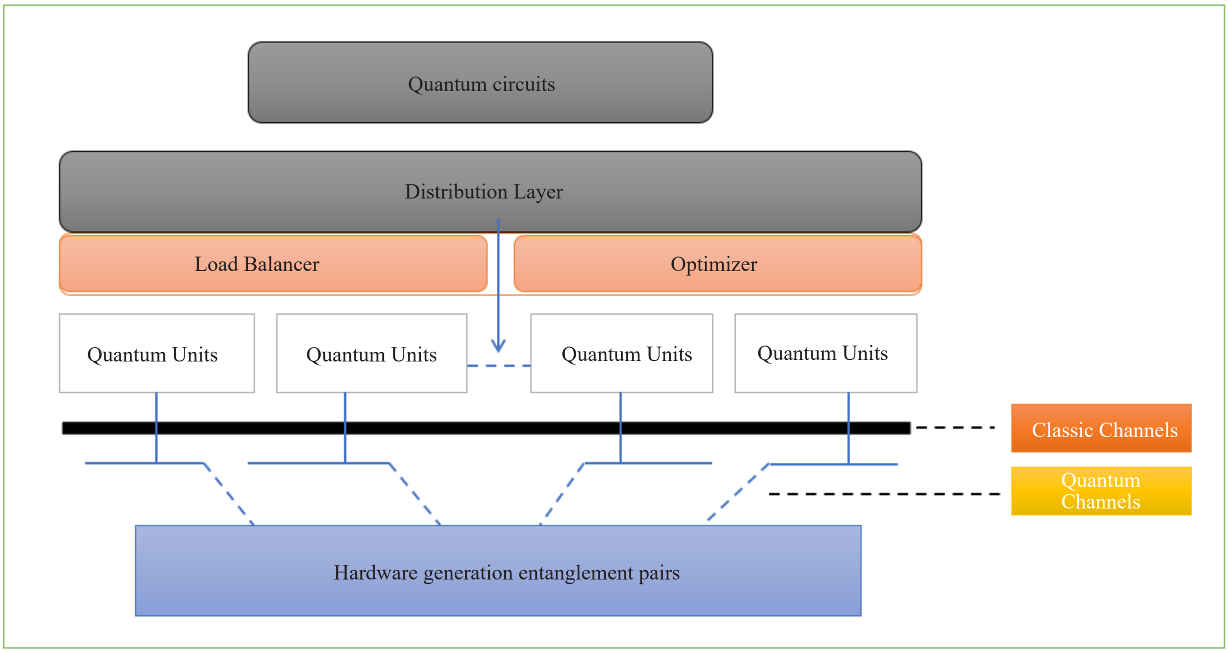

Figure 1. Multi-layer architecture of quantum circuit in distributed computing

4. Philosophies around the Distributed Computing System (DCS)

In distributed computing systems, several interconnected computers, or nodes, work together to process information and perform tasks as a unified whole. Unlike centralized computing systems, which process all data on a single mainframe or server, distributed systems disperse the computational load across several computers, often spread throughout different parts of the globe [23]. By using the capabilities of several computers or processors, this architecture improves scalability, performance, and reliability. Nodes in a distributed computer system coordinate and communicate with each other through a network, or even the internet [24, 25]. Each node can be a distinct computer, server, or other device that contributes to the system's overall computational capacity. To achieve common objectives, such as processing large volumes of data and running complex algorithms, the nodes collaborate. One advantage of distributed computing systems is their horizontal reproduction capability. Adding more nodes can increase scalability and flexibility to manage the growing demand for computing resources [26]. This approach differs from vertical scaling, which often faces hardware constraints when attempting to expand the capacity of a single computer. Distributed systems can also increase reliability and fault tolerance by replicating data and functions across several nodes [27, 28]. If one node fails, others may take over, allowing for better service levels and lessening the overall impact of the system. Furthermore, distributed systems simplify resource sharing and load balancing [29]. To prevent bottlenecks, distributed systems share resources (such as storage) among nodes, optimizing their use and dividing the load equally [30]. This distributed approach automatically distributes tasks according to node capabilities and current system demands, allowing for efficient resource management and improved performance. There are many different distributed architectures and models that distributed computing systems may support, including cloud computing, client-server, and Peer-to-Peer (P2P) models. In client-server architecture, clients send requests to a central computer, which responds with the requested information [31, 32]. Alternatively, P2P networks employ a decentralized approach where each node functions as both a supplier and a client at the same time, exchanging data [33]. One popular example of a distributed system is cloud computing. It makes timely access to a shared platform of Information Technology (IT) resources (such as servers) possible over the Internet [34, 35]. Distributed service providers provide consumers with flexibility, scalability, and cost-effectiveness by administering and operating distributed infrastructure. This idea allows businesses and individuals to access powerful computing capabilities without the need to purchase and maintain equipment. In conclusion, DCS integration with IoT increases the efficacy of IoT deployments by combining the strength of distributed resources with a large network of linked devices. For example, it has the potential to generate copious amounts of data, enhance cloud, edge, and cloud computing on a geographical scale, expedite decision-making, and streamline the deployment of AI models for large datasets [33]. As shown Figure 2, the Industries 4.0 offers new possibilities for intelligence and automation.

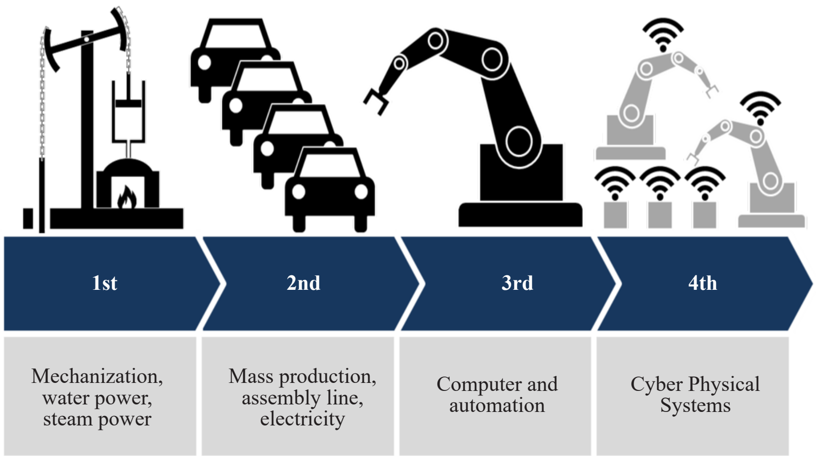

Figure 2. Industrial revolution and Industries 4.0

5. Advantages of DCS and IIoT in manufacturing sites

To link their core and extended core IT/Information Systems (IS) and business applications across the sites and provide scalable and appropriate performance, industrial facilities and battery cell technology production sites require a great deal of innovation and digitalization suites. Because they provide automated control, data analysis, and real-time monitoring, Distributed Control Systems (DCS) and the Industrial Internet of Things (IIoT) both offer significant advantages for industrial facilities. These characteristics improve information as well as decision abilities, optimize production flow, save costs through predictive maintenance, and increase operational efficiency. By utilizing IIoT-enabled technologies and tactics, industrial users can gather and store data from virtually anything at a very high frequency and extraordinarily low cost. This makes work and commercial operations more efficient than they were previously. Programmable Logic Controllers (PLC), distributed computing systems, and control systems equipped with process historians have been implementing some aspects of this for decades. IIoT-enabled systems can provide rather different results than DCS- and PLC-based process automation designs alone, even if they still deal with sensors and computing. Traditionally, the sole goal of creating process automation systems has been to support process control based on the process design features, as indicated by the Process & Instrumentation Design (P & ID) diagrams. Sensors and actuators (such as pumps, drives, and valves) from a Front-End Engineering Design (FEED) process nearly always anticipate linking to DCS or PLC Input/Output (I/O) to enable process control, logic, and operator notification via a Human-Machine Interface (HMI). The design and anticipated results for battery cell production and industrial operations differ greatly from those for PLC, SCADA, MES, Quantum MES, IIoT, and IoT. Process automation generally adheres to the ISA95 Model for Enterprise-Control System Integration and the Purdue Model for Computer Integrated Manufacturing (c. 1980). The primary distinction between the two architectures is that, although the IIoT may reach out to partners, suppliers, and consumers to facilitate new business models and procedures, the ISA95 model concentrates on supplying plant data to the organization [26].

5.1 *Business workflow and data management*

In industrial manufacturing facilities, the core MES transmits transactions of core data (business partner, customer, supplier, material/Stock-Keeping Units (SKUs), order information, invoices, and delivery orders) to extended interfaces in both logical and multiple physical systems. To maximize efficiency, ensure quality, and proactively identify potential issues, battery cell manufacturing companies rely on integrated systems such as Manufacturing Execution Systems (MES) and Laboratory Information Management Systems (LIMS) to track and manage data throughout the production lifecycle. These systems involve a complex system of collecting, analyzing, and using real-time data from various stages of the production process, including raw material inspection, electrode manufacturing, cell assembly, testing, and quality control. The integration of dispersed computing systems with the Internet of Things significantly enhances workflow management and business data. IoT devices may continuously collect massive amounts of data from many operational aspects thanks to a multitude of sensors and networking characteristics [27, 28]. This timely information collection measures performance, streamlines monitoring processes, and identifies inefficiencies that could otherwise go unnoticed. For instance, in an industrial setting, IoT devices may track manufacturing output, assess the health of gear, and spot departures from standard operating conditions [29]. This rapid operational visibility enables proactive maintenance, reducing downtime and enhancing overall productivity. Distributed computing platforms significantly enhance data and workflow management by offering the necessary infrastructure to manage the vast amounts of data generated by IoT computing [30]. By managing data near its source and lowering latency, the decentralized approach guarantees rapid analytics and decision-making. Businesses can handle massive datasets, do complex analytics, and quickly provide actionable insights thanks to distributed systems. Additionally, the synergy between IoT and distributed systems may smoothly integrate and coordinate an organization's numerous departments and operations. Staff members may focus on more strategic work by using these technologies to automate monotonous tasks like scheduling and reporting [31]. For instance, IoT devices may automatically update inventory levels in a warehouse management system, resulting in reorders when stock runs low [31, 32]. Distributed systems ensure that this information is immediately available across the supply chain, enabling quick and efficient responses. Furthermore, integrating IoT and distributed systems supports advanced data management strategies like edge computing and real-time data streaming, which involve constant data interchange with the data center [33]. This method is important for just-in-time tasks, such as robotics. Distributed systems enable real-time data streaming, enabling companies to analyze data in real-time, thereby gaining current insights and enabling prompt responses to changing conditions.

5.2 *Multitasking and scheduling automation in industrial communication*

Automation and job scheduling in corporate operations are made possible by IoT and distributed computing systems, which increase productivity, decrease manual labor, and improve efficiency. IoT devices give companies the resources and connections they need to automate repetitive and regular processes that are usually completed by hand [34]. This competence is especially crucial in industries where accuracy and prompt job completion are essential, such as manufacturing, logistics, and healthcare. To optimize production processes, industrial plants, for example, employ IoT-enabled devices to assess operations performance and resulting defects while automatically altering settings [34, 36]. By leveraging real-time data, these sensors may initiate autonomous maintenance processes that prevent equipment breakdowns and reduce downtime. According to Hossain et al. [37], the ability to collect and react rapidly guarantees that machines run as efficiently as possible, reducing waste, and increasing productivity. Because they evaluate the vast amounts of data generated by IoT devices, run sophisticated algorithms to forecast maintenance requirements, and allocate personnel in the most efficient manner, distributed computing solutions are essential to this automation. Businesses may use sophisticated job scheduling algorithms that consider several factors, including work priority, resource availability, and real-time data inputs, thanks to the Internet of Things and distributed systems. These algorithms may dynamically assign jobs to the most effective resources, guaranteeing the most economic use of people, tools, and time, claim Pham and Huh [37, 38]. IoT devices in a factory, for example, may automatically assess the condition of various production lines and allocate tasks to the lines that are most capable of handling them [39]. It helps avoid bottlenecks and balance workloads. Additionally, human resources may concentrate on more strategic duties by using IoT and distributed systems to automate back-office and administrative chores [40]. Data input and report production are examples of repetitive processes that may be automated to increase productivity and reduce the possibility of human mistakes. These automated solutions are scalable, reliable, and able to handle the needs of an expanding company thanks to distributed computing.

5.3 *Enhanced capacities and decision-making process in battery manufacturing*

In the context of battery manufacturing, "enhanced capacities" refers to raising a battery cell's capacity to store energy. This is frequently accomplished by improving the electrolyte formulation, optimizing the composition and structure of the electrode materials, and streamlining the cell assembly process. In this context, "meaningful decisions for enterprise applications in battery industries process" refers to the use of data analysis and predictive modeling to choose the best parameters at each stage of production to maximize capacity while upholding quality and safety standards. Business decision-making is changing from reactive to proactive, data-driven methods thanks to the Internet of Things and distributed computing technology. Massive volumes of data are continually produced by IoT devices from a variety of sources, including equipment and operator interactions [41, 42]. This information serves as the foundation for prompt and well-informed decisions by offering a comprehensive view of customer behavior, market trends, and corporate operations. The enormous amounts of data produced by IoT devices may be organized with the use of distributed computing platforms [43]. These systems allow for scalable and effective data processing by dividing the computing burden across several nodes. This decentralized strategy lowers latency and allows real-time analytics by ensuring data analysis at its source [44]. In a smart city, for example, IoT sensors may keep an eye on energy use, air quality, and traffic patterns. Administrators and city planners may be able to make decisions more quickly and efficiently if distributed systems that analyze this data in real time expedite its flow, lower pollutants, and control energy distribution. Utilizing sophisticated analytics and machine learning techniques is made easier by the convergence of networked systems and the Internet of Things. These systems have the capacity to predict trends, identify patterns, and promote knowledge [45]. IoT devices may collect economic data, track asset performance, and keep an eye on financial market circumstances. Prospective heuristics can be used in distributed systems for investment planning, business trend forecasting, and risk assessment [46]. Financial organizations may reduce risks, take advantage of new possibilities, and make proactive choices using this type of predictive capabilities. Additionally, distributed computing platforms and the Internet of Things offer a comprehensive view of the business's operations and competitive landscape [47], which may assist executives in making better decisions that support the firm's goals. For instance, key, long-term choices (such as market growth) may be guided by real-time data on market trends, production efficiency, and consumer feedback [48]. Decision-makers can react quickly to changes in the corporate environment thanks to distributed systems, which guarantee that they have access to current and reliable information.

5.4 *Software quality management in industrial computing's*

The shift to widespread usage of electric vehicles requires high-performance, reasonably priced battery technology. As a result, battery makers are pushing the boundaries of cell capacity, energy density, and cost-efficiency to match the operating range and affordability of existing motorized transport.

To guarantee product performance and safety, battery cells go through a rigorous quality control process. To facilitate batch release and illustrate manufacturing and environmental compliance requirements, these procedures produce a lot of data. Figure 3 shows the conventional Lithium-ion Battery (LiB) and Figure 4 shows how sophisticated Laboratory Information Management Systems (LIMS) streamline battery quality analysis to provide easy and effective results reporting. Software quality issues arise in the development and implementation of IoT and DCS applications. Software solutions must be strong, dependable, and able to handle a variety of dynamic situations due to the complexity of these systems [49].

However, with so many links and interactions, it might be challenging to guarantee high-quality software. High degrees of accuracy and dependability are necessary for distributed systems and Internet of Things devices, which frequently handle real-time data [50]. Any component that experiences cascade failures due to software defects or performance problems may affect the system's overall dependability and functioning. Software development and testing become more difficult when it must manage edge situations, unanticipated events, and changing operating conditions, especially when it comes to strategic decisions made for enterprise applications. Using track-and-trace technology and software, digitalization makes it possible to trace components and processes inside a production facility from beginning to finish. Manufacturers can track the origin of resources in real time, keep an eye on the flow of materials through every stage of production at once, and guarantee adherence to rules and quality standards. Beyond the production of battery cells, industrial supply chains depend heavily on upstream and downstream traceability to maintain accountability and transparency.

Figure 3. Conventional Lithium-ion Battery (LiB)

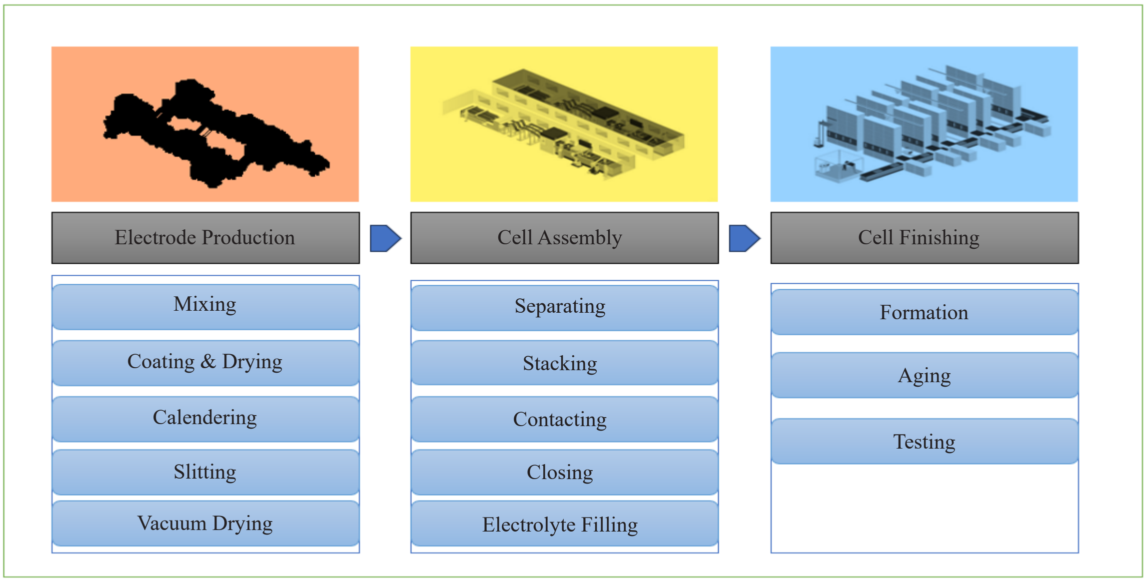

Figure 4. Conventional production line of business in (LiB)

5.5 *Consistent and sync of enterprise data among the industrial operation*

Keeping data synchronized and consistent is one of the primary problems in distributed computing and IoT systems. Multiple nodes, each with the ability to process and update data independently, are often used by DCS to distribute information [51]. It might be difficult to guarantee that system changes are reflected appropriately and that all nodes represent data consistently. Because devices generate data continuously and in real time, IoT networks have a considerably harder difficulty achieving data consistency. Data gathered from several IoT devices must be synchronized and combined to create a coherent image. Operational performance and management of key decisions may be impacted by erroneous or outdated information resulting from data synchronization delays or irregularities. Errors in data transfer, device failures, and network latency make the process considerably more challenging and may have varying implications for the business. Bravyi et al. explores the advancements and future prospects of quantum computing using superconducting qubits. It discusses the potential of these qubits to achieve scalable quantum systems and their implications for various applications in computation and information processing [52].

6. Quantum hybrid cloud computing and DCS

The phrase "hybrid quantum computing" describes a system that combines the powers of classical distributed processing with quantum computing for applications. By enabling several conventional computers to collaborate in a distributed computing network and seamlessly integrate with a quantum computer, a system referred to as a "distributed computing and quantum hybrid architecture" leverages the benefits of both technologies to solve complex problems. The term "hybrid quantum computing" describes frameworks and techniques that combine quantum and conventional computing, allowing the two systems to cooperate to solve an issue. Building quantum gates, controlling the setup of the quantum computer, submitting jobs, and processing quantum computing have always depended on conventional computers. Nonetheless, the most recent generation of "integrated hybrid" quantum computing architectures, which are presently offered by Azure Quantum, enables developers of quantum applications to combine classical and quantum programming instructions in a single application and alter quantum circuits while preserving qubit coherence. A qubit is the basic unit of information in quantum computing. A qubit state has an unlimited number of potential values, which may be described as a linear combination of states 0 and 1, as seen below, in contrast to a conventional bit, which has only two possible values: 0 or 1. This is defined in the below Equation (1):

$$|q\rangle = \alpha|0\rangle + \beta|1\rangle \tag{1}$$

The qubit state's projections onto the eigenstates are denoted by the coefficients and, respectively. In that sense, they are complex numbers. The qubit fundamental states are commonly represented as and in two dimensions (2D) vector space. The Figure 5 represent the Bloch sphere is commonly used to depict a qubit state in three dimensions (3D), as below.

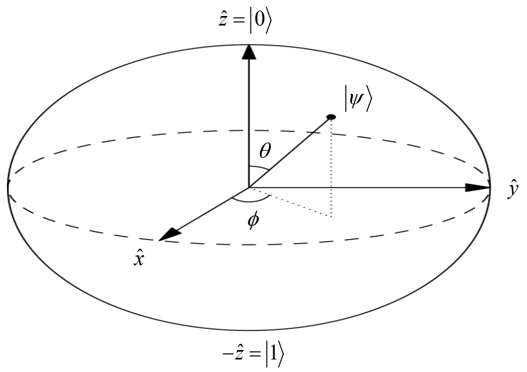

Figure 5. Probabilistic qubit state

Where α and β represent the projection of quibit state on the eigenstates $|0\rangle$ and $\rangle$ respectively.

A popular quantum technique for determining the solution of a given system of linear equations represented by an input matrix and a vector is the Harrow-Hassidim-Lloyd (HHL) algorithm. The HHL technique operates more well with sparse matrices and intuitively applies the inverse of the matrix to the vector. The HHL method has a significant influence on other quantum applications, including the high-order quantum algorithm 4 for solving differential equations and the quantum machine learning algorithm, as it shows how to employ quantum computers for mathematical problems, and the general equation is

$$\hat{A}\vec{x} = \vec{b} \tag{2}$$

Where, $\hat{A}$ is an $N \times N$ matrix and $\rightarrow b$ is a vector. Throughout the application, it is assumed that the matrix $\hat{A}$ is

Hermitian and the vector →b is unit. Ten the matrix $\hat{A}$ has a spectral decomposition

$$\hat{A} = \sum_{j=1}^{l} \lambda_j \left| u_j \right\rangle \left\langle u_j \right| \tag{3}$$

Where λ_j is an eigenvalue of $\hat{A}$ corresponding to the eigenstate $\left| u_j \right\rangle$. From this decomposition, a unitary operator $U_{\hat{A}}$ is defined as follows:

$$U_{\hat{A}} = e^{2\pi i \hat{A}} \sum_{j=1}^{l} e^{2\pi i \lambda_j} \left| u_j \right\rangle \left\langle u_j \right| \tag{4}$$

It is easy to see that for any non-zero eigenvalue λ_j of $\hat{A}$ there exists $\lambda'_j \in (0, 1)$ such that = π λ′ π λ e e 2 2 i i j j. Tus, for convenience, we have assumed that the eigenvalues of $\hat{A}$ are in (0, 1) in hybrid cloud applications.

6.1 *Hybrid quantum-classical computing in battery management solution*

To achieve the best results, we have combined classical computing, quantum computing, and hybrid quantum computing in our industrial battery production process. This has allowed us to confirm that conventional supercomputing can assist intermediate-sized defective quantum computers in reliably handling large issue cases. We suggest a mixed quantum-classical architecture that breaks up bigger quantum circuits into smaller sub-circuits that can be tested separately on a quantum processor or a quantum simulator running on a regular supercomputer. Figure 6 represent the decomposition of quantum circuit in industrial applications.

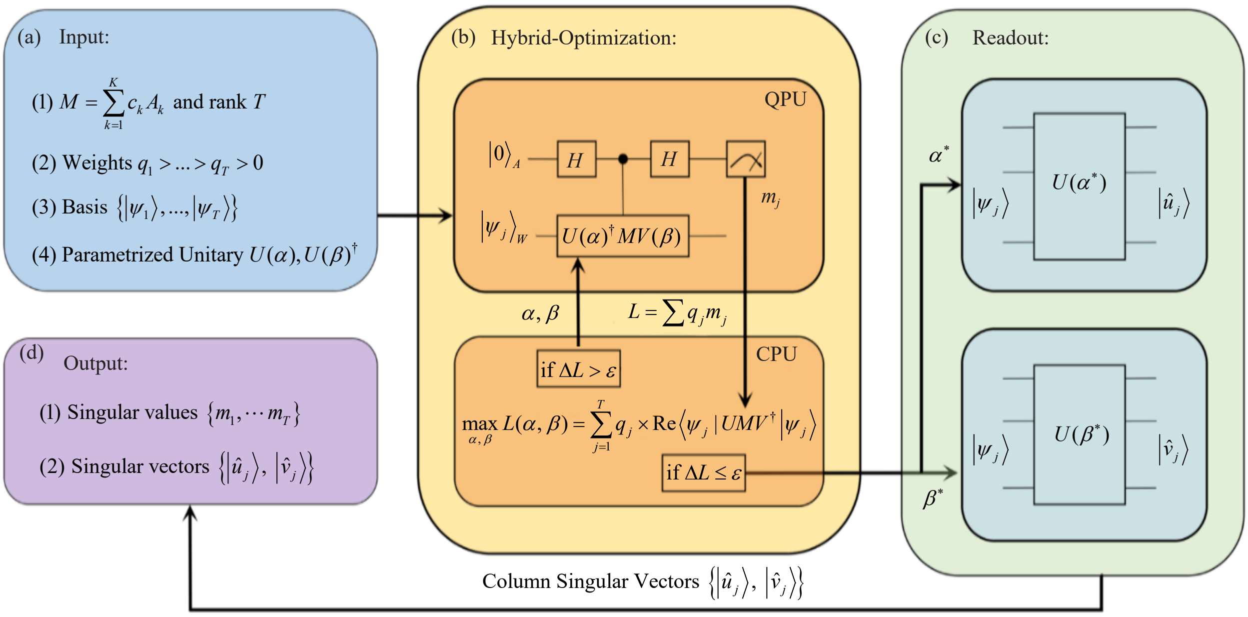

Figure 6. Decomposition of quantum circuit in industrial applications

To balance runtime and circuit dependability, circuit compilation techniques-which decide which qubits to imitate classically-will have a substantial influence on system performance. Using the term "hybrid" to refer to software that executes both conventional and quantum codes is incorrect. Figure 7 represents the hybrid quantum architecture. When used in this context, the term "quantum code" describes a collection of quantum gates that are applied to one or more qubits on a quantum device or Quantum Processing Unit (QPU). Software created in any programming language that can be run on a standard computer is referred to as "classical". You would pick a program that is simple to connect to a quantum computing service. Although it seems straightforward, there are several ways to turn a quantum program into a hybrid one. Sending the quantum portion to a quantum cloud provider while running the classical portion on your machine is the most straightforward method. Such a program frequently explains a parameterized quantum circuit running on a QPU in a traditional optimization loop. It follows from this that each iteration of the loop creates a new freestanding quantum circuit with a unique set of parameters to feed into the parameterized quantum circuit. In industrial battery solution/battery optimization manufacturing, "Hybrid batch quantum computing" refers to the use of quantum computing technology to process large datasets concurrently to solve complex optimization problems within a manufacturing process. This approach allows for much faster and more efficient solutions than traditional computing methods, especially when working with large batches of data or production runs. In real-world applications, hybrid and classical quantum computers may solve complex optimization problems that would take classical computers an unfeasible length of time because they use superposition and entanglement to have the best performance as requested in quality management, production scheduling and controlling, and some of the key. The manufacturing process as we go further into industrial revolutions in battery manufacturing Production sites within Industries 5.0.

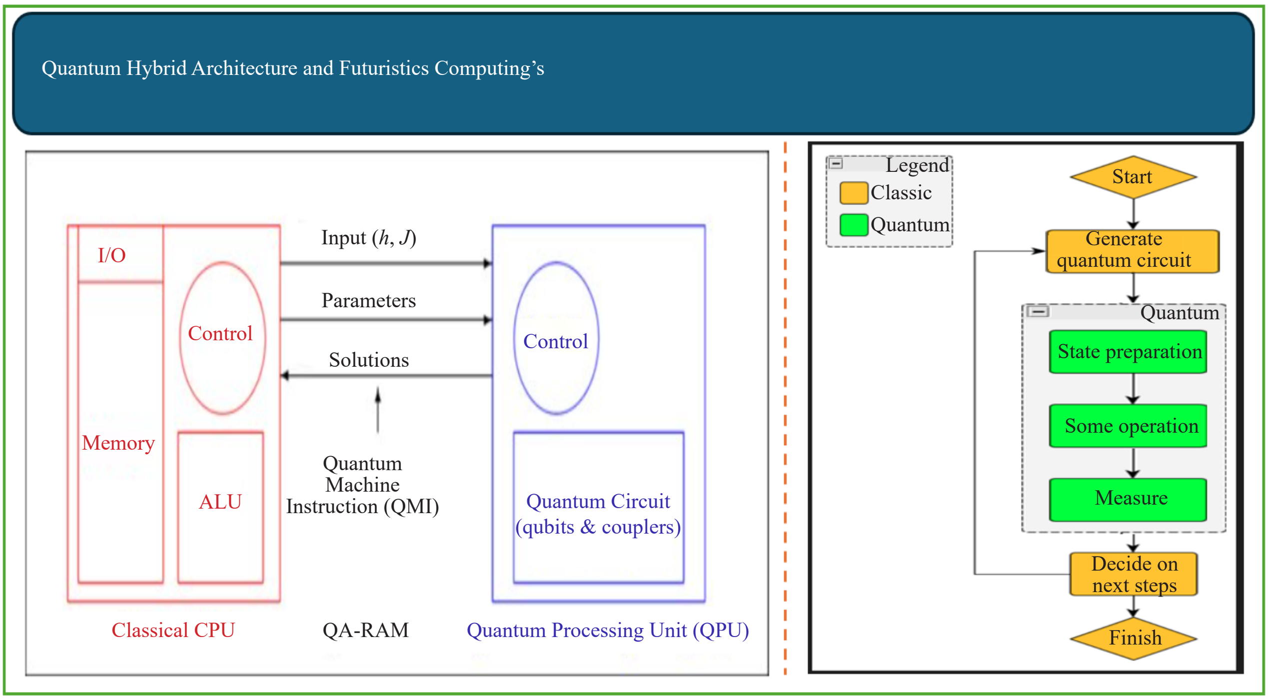

Figure 7. Model to access the quantum circuit and QPU

6.2 *Example scenario/use case 1*

The term "job in any industrial revolution or even current battery industries" is typically used to describe the unit of work we have ever attempted this kind of task. Each job is linked to a "Result" that has the qubit measurement data and is generated once a quantum circuit is submitted. The hybrid software returns many outcomes when you submit many jobs. Many jobs are created by this kind of approach, as we may have noticed. Every task is backed up. For our hybrid execution model, if in case our unit of work is a program that produces circuits rather than a single circuit, a more integrated approach would be helpful. Hybrid quantum-classical cloud services have potential in this context. Figure 8 illustrate the hybrid QPU architecture for industrial applications and Figure 9 explains the hybrid quantum computing process for industrial modeling.

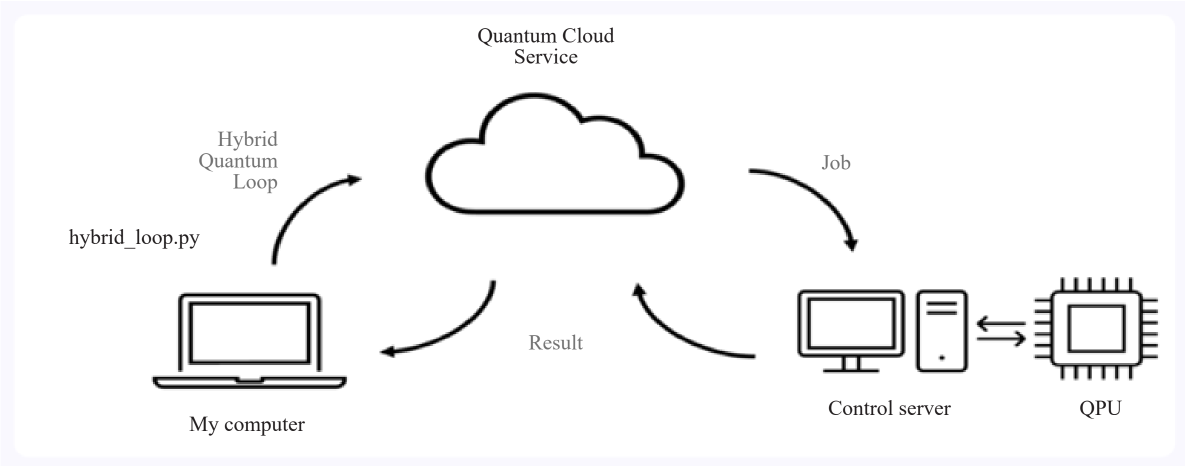

Figure 8. QPU and hybrid architecture modeling for industrial computing

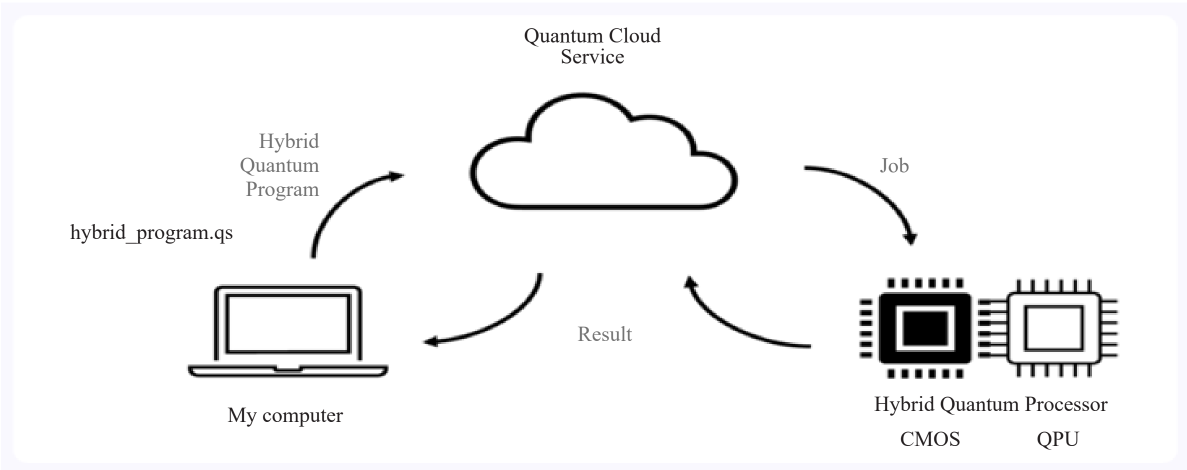

Figure 9. Hybrid quantum computing and processer in industrial modeling

Instead of submitting a single circuit, in hybrid architectural designing, we will submit a classical program that creates quantum circuits to such a hybrid cloud service. Additionally, by using this execution paradigm, we can create a single job for each hybrid program, removing the need for churn and data processing that comes with mixing input from many circuits and making it easier to provide results later. This type of paradigm may help hybrid applications and even improve performance, such as by reducing wait times on the QPU queue, but the quantum circuit itself is still quantum-only. Consider the possibility of incorporating hybrid quantum operations into a quantum program, such as rotation or conditional gates that rely on measuring qubits. Here, the model that utilizes what I will refer to as a hybrid quantum processor is relevant. Such a hybrid quantum stack integrates both classical computation and the quantum gadget. This implies that a program that employs hybrid operations to construct quantum circuits may be developed in addition to one that uses a conventional loop. For example, instead of only giving measurement data, the processor may now send a value to a conditional or rotational gate by doing basic computations with several measurement results using conventional computing.

Intriguing applications of hybrid quantum algorithms include repeat-until-success, iterative phase estimation, and quantum error correction. As the features and complexity of the quantum control stack grow, more traditional processing can end up at the bottom. The increasing demand for more efficient quotes may also allow quantum developers to take advantage of quantum error-correcting capabilities. As expected, there are likely numerous models for the operation of hybrid quantum programs. Further Variations of the previously outlined architectures may include a further cloud computing stage, or distributed quantum computing, for instance. To cover them completely, I hope this post has given you a better understanding of the models available for hybrid quantum-classical programs and the situations in which they are most effective.

6.3 *Batch quantum computing and multi-grouping circuits*

A method known as batch quantum computing combines many quantum circuits into a single task that a Quantum Processing Unit (QPU) can process. By doing away with the waiting period between job submissions, this technique speeds up the program. Traditionally, quantum computing transmits circuits one at a time, with the client waiting for the result of one circuit before adding the next to the queue. Batch quantum computing submits numerous circuits as a single job, eliminating this wait time. Batch quantum computing can help with several issues, such as basic quantum phase estimation and Shor's algorithm. Unlike the bits used in classical computing, the fundamental unit of information in quantum computing is known as a qubit or quantum bit. Even a small vibration or temperature change can cause a quantum computer to lose stored data, and these devices are sensitive to noise. Multiple quantum circuits can be sent to the quantum hardware as a single job thanks to batch quantum computing. Usually, a quantum hardware target receives quantum circuits as single tasks, one at a time. The subsequent circuit is added as a new job to the queue when the client receives the outcome of the previous circuit. However, by batching several circuits into a single task, you can perform several jobs more quickly because there is no waiting period between job submissions. Shor's method and basic quantum phase estimation are two examples of issues that can benefit from batch quantum computing. Batch computing allows you to combine several preset circuits into a single job. There is less waiting time between work submissions since the circuits are sent to the quantum hardware as soon as the one before it is finished. Figure 10 illustrate the software development lifecycle of a hybrid systems with quantum optimizer.

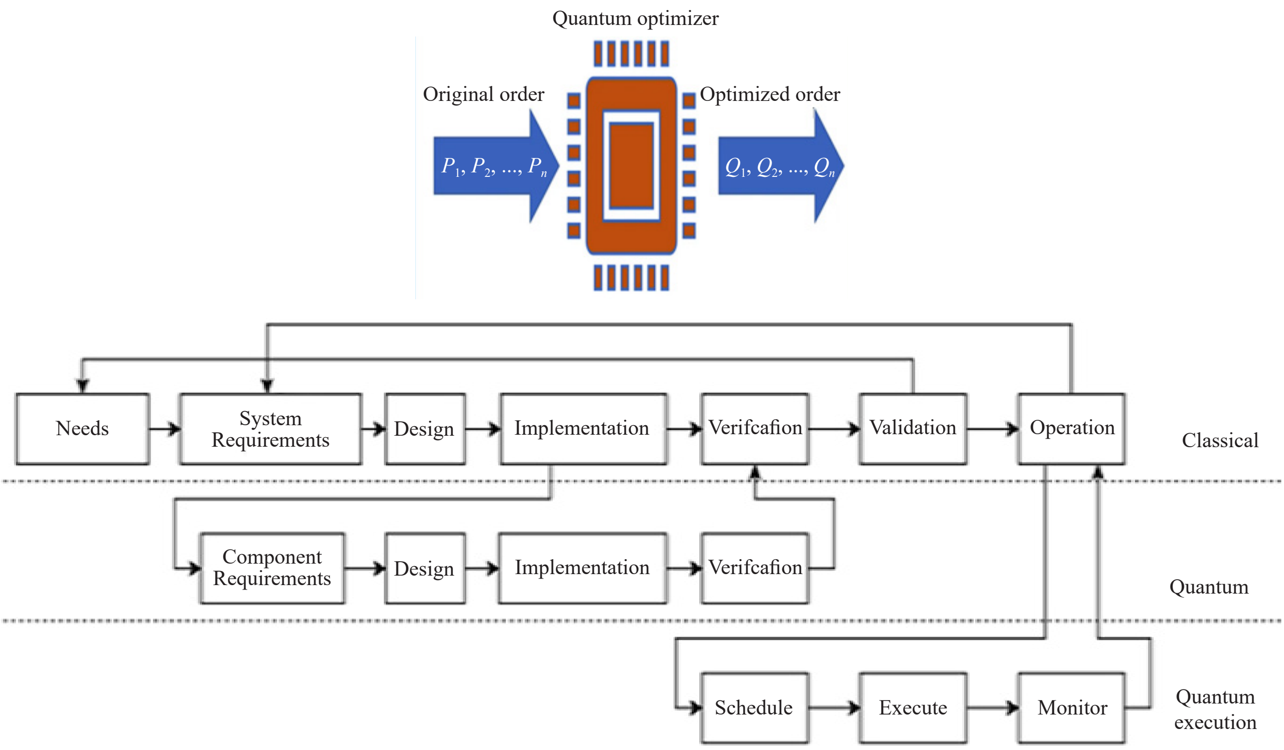

Figure 10. Software development lifecycle of a hybrid systems (classical and quantum technology)

6.4 *Disadvantages of distributed computing systems in battery manufacturing industries*

Distributed computing systems face numerous security challenges in manufacturing, particularly in battery cell technologies and companies within the industrial automation sector. These challenges include complex network topology, vulnerabilities in legacy equipment, open protocols, a lack of standardized security practices, data integrity issues, the possibility of unauthorized access, difficulty in monitoring and detection, and the possibility of coordinated attacks across multiple system nodes due to their interconnected nature. As a result, it is imperative to implement strong security measures to safeguard vital industrial processes. Figure 11, illustrates the security challenges in current distributed Battery manufacturing process and Figure 12 represent possibly solutions with use of quantum cryptosystem.

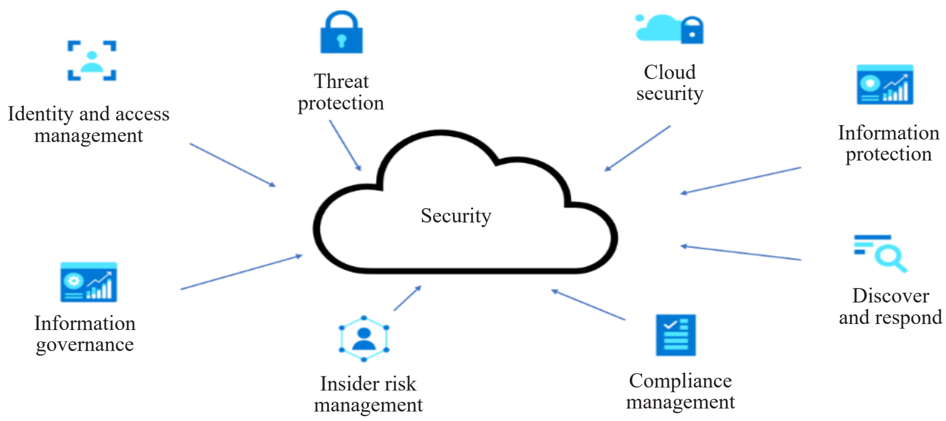

Figure 11. Security challenges in Battery Management Solutions (BMS)

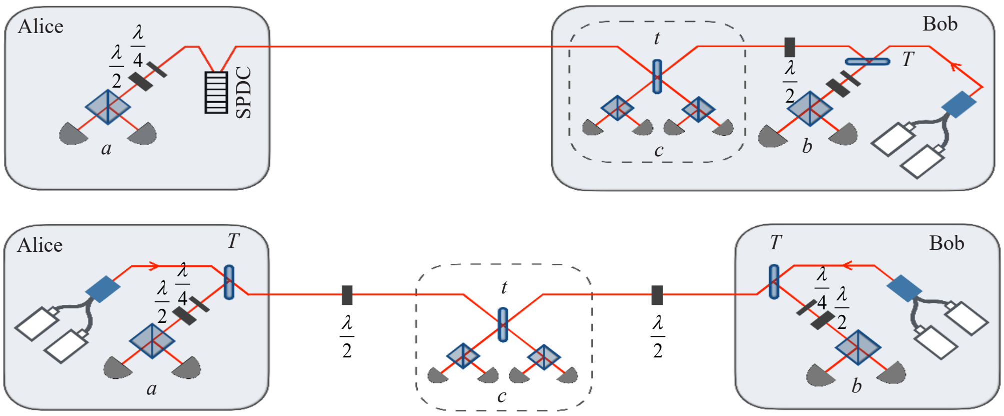

Figure 12. Security challenges in BMS could possibly be managed through quantum cryptography

7. Few use case in battery cell manufacturing factory

A "hybrid quantum-classical computing model" is a method of using computers to simulate and enhance complex battery chemistries at the molecular level in the context of battery cell production. This approach capitalizes on the distinct advantages of both classical and quantum computing. Specifically, quantum computing handles the most complex parts of the system, enabling more accurate predictions and improvements in battery cell design, while classical computing handles data processing and management. Traditional methods alone could not achieve this much.

Eventually, all the EVs and Battery industries will go for the best distributed computing systems and hybrid distributed computing systems for better battery life prediction, management of EOL, SOC, SOH and RUL for the most key criterion in BMS. The benefits of hybrid quantum-classical computing in battery production are significant. Quantum computers are essential for comprehending and improving battery performance because they can faithfully model the interactions between molecules in a battery cell, including the behavior of ions, electrons, and electrode materials [53].

7.1 *Forecasting and battery energy attributes management*

A well-liked hybrid technique called Variational Quantum Eigensolver (VQE) uses a conventional computer to determine the parameters that will result in the state with the least amount of energy. The quantum computer determines part of the system's energy, which is essential for predicting battery stability and capacity. Enhanced design of the material: By simulating complex chemical interactions at the atomic level, researchers can make new battery materials that have better properties, like more energy per unit weight, faster charging times, and longer cycle life. It is extremely difficult to manage and forecast battery energy metrics (SOH, SOC, RUL, and EOL) in industrial sites using traditional computer interfaces. To obtain the right predictive analytics and the previously specified energy parameters, we must train a quantum model and a lot of datasets. "Forecasting and Battery Energy Attributes Management" is the process of estimating future energy requirements using predictive analytics, then planning how to charge and discharge a battery storage system based on those estimates, making the most efficient and valuable use of it. To minimize costs and maintain grid stability, one method is to charge it during periods of low demand and discharge it during periods of high demand. Some battery characteristics, such as power capacities and State of Charge (SOC), as well as battery degradation, are exceedingly challenging to predict using traditional computer techniques.

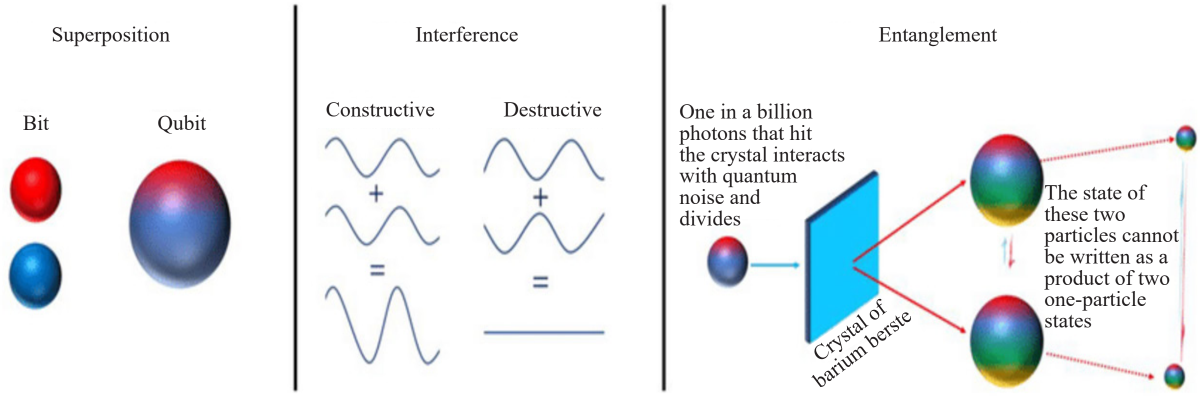

Figure 13. Quantum computing architectural view for manufacturing business

7.2 *Electrolyte optimization*

By using quantum simulations to understand the behavior of electrolytes, we may develop new electrolyte formulations that minimize negative reactions and increase battery life. Rechargeable Lithium-ion Batteries (LiBs) are becoming increasingly popular in electric cars, mobile devices, and grid-level storage systems due to their high-power density, low discharge rate, and declining cost. Developing a system to appropriately simulate the nonlinear deterioration of LiBs becomes a significant research subject since it is essentially a supervised learning problem. This paper proposes a classical-quantum hybrid machine learning technique to capture the LiB degradation model that uses operational parameters to evaluate battery cell life loss. Recent developments in quantum computing and the similarities between quantum circuits and neural networks serve as the driving force behind our research. Figure 13 shows the quantum computing architectural view for manufacturing industries. Like weight parameters in traditional neural networks, the parameters of the quantum circuit, i.e. the degree of freedom of the qubits, may be altered to train a nonlinear function in a supervised learning manner. As a proof-of-concept, our numerical results show that quantum neural networks can simulate the nonlinear connection between diminishing capacity and operating cycles using the National Aeronautics and Space Administration (NASA) battery dataset. We also explore the potential benefits of the quantum approach over traditional neural networks in classical computers for handling massive amounts of data, considering the impending widespread use of EVs and energy storage [54].

7.3 *Quantum key distributions in cell and energy management*

The battery manufacturing sector may employ Quantum Key Distribution (QKD), which provides a very safe way to send encryption keys, to protect private information about supply chain logistics, intellectual property, and production procedures. Even in the face of sophisticated quantum computing breakthroughs, this offers security against possible cyber-attacks, which is particularly helpful when handling sensitive data like battery design specifications, manufacturing procedures, and quality control data. Quantum Key Distribution (QKD) is the most advanced quantum technology [55]. Numerous QKD systems are available on the market from various manufacturers, and both domestic and international initiatives are assessing the systems' performance in a variety of real-world use cases as well as their ability to integrate into existing communication infrastructures. A post-processing stage and quantum communication are often included in the establishment of a secret key between two reliable users, Alice and Bob (see Figure 14). In the first stage, Alice encodes random bits on non-orthogonal photonic states, which Bob receives over a quantum channel. Every signal that is received is measured, and Bob logs the data. The two users then openly post-process their classical data to produce the final information-theoretically secure secret key. Primarily, the post-processing step consists of key filtering, mistake reconciliation, error verification, and privacy amplification. It is expected that each of these processes will be completed successfully and without any noticeable errors, yielding a final secret key. Nonetheless, the possibility of any of these stages failing undetected and compromising the security of the protocol is always there.

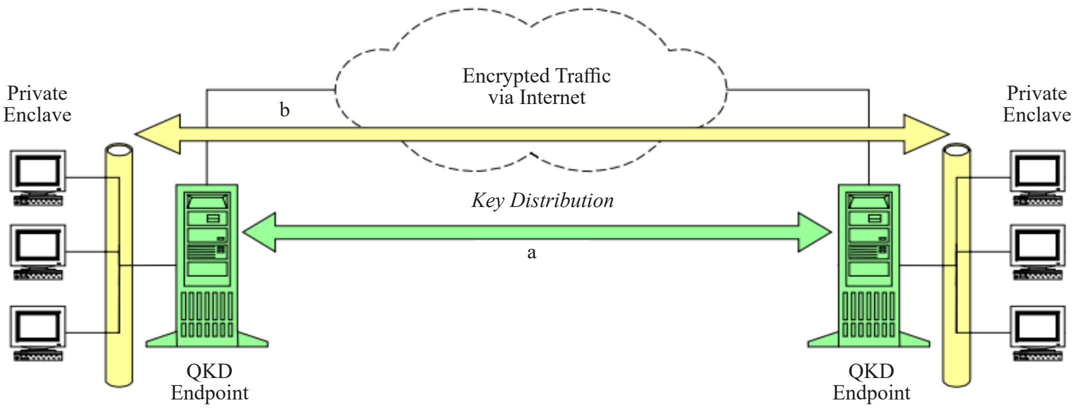

Figure 14. Schematic representations of a point-to-point QKD link (a) and of the man-in-the-middle attack (b)

7.4 *Industrial data protocol management and cryptography*

The Figure 14 illustrates how the two users must verify the source of the messages they exchange while processing their data to safeguard the protocol against a man-in-the-middle attack. In this extremely simple attack, an adversary (Eve) controls the quantum and conventional service lines connecting Alice and Bob. Attaching her QKD devices to the loose ends of the channels, she may play the roles of Alice to Bob and Bob to Alice. As a result, she can generate two secret keys-one with Alice and one with Bob-that she can use, for instance, to decode and modify any messages Alice sends to Bob (or vice versa). The only approach to prevent such an attack is to use ITS message authentication protocols for authentication, which is the natural choice for QKD techniques as they provide Information-Theoretically Secure (ITS) distribution of random keys [55, 56]. Nevertheless, typical ITS Message Authentication Codes (MACs) require that the two users utilize a secret, highly random key to execute their QKD system for the first time. A man-in-the-middle attack (b) shows an eavesdropper (Eve) placed between Alice and Bob, intercepting, and altering the quantum states before forwarding them, thereby enabling her to listen in on the key generation process undetected in a conventional setup. A schematic representation of a point-to-point QKD link (a) would show a single, direct connection between a sender (Alice) and a receiver (Bob), where quantum states are transmitted through a quantum channel.

7.5 *Optimization gains for the BMS industrial application*

In the industrial and battery manufacturing sectors, data is essential for providing manufacturing facilities with the best possible assistance. There are a lot of possible applications for quantum distributed computing in AI and ML. Large datasets can be processed faster, optimization can be enhanced, and complicated issues that are now outside the scope of conventional computers may be resolved. Particularly in fields, this can lead to quicker model training durations and more accurate forecasts. Via material forecasts, choices, and solutions, the cathode and anode integrate energy sustainability. Only quantum distributed computing will be able to do this. Quantum computers can examine large datasets tenfold quicker than conventional computers because of superposition, which might significantly speed up machine learning tasks like model training and inference. Additionally, quantum computers can operate in several states simultaneously. Optimization benefits: Complicated optimization problems can be successfully resolved by quantum algorithms such as the Quantum Approximate Optimization Algorithm (QAOA), which improves model parameters and critical aspects in areas like resource allocation and routing. Quantum computing enables more intelligent data analysis and the discovery of new interconnections by identifying patterns and connections in large datasets that may be challenging to discover using conventional methods. Secure communication between manufacturing facilities: Protect sensitive data exchanged between different production sites, including quality control reports, production schedules, and technical specifications. Data protection for research and development: safeguarding critical research findings on new battery materials and designs, especially when collaborating with external partners, however, the secure communication with suppliers and distributors: Encrypting sensitive information shared with suppliers regarding raw materials and with distributors regarding product details and delivery schedules.

Overall, while there are technical challenges, quantum key distribution holds significant potential for enhancing the security of sensitive data within the battery manufacturing industry, especially as concerns about cyber threats continue to grow [56].

7.6 *Quantum Federated Machine Learning (QFML) in battery overall productions*

Federated Learning (FL) has grown in popularity recently, coinciding with increased privacy concerns about the use of large-scale datasets and cloud-based deep learning. A federated learning process's basic components are a central node and several client nodes. The central node receives the learned parameters from client devices and keeps the global model. The aggregation process is performed by the central node, which generates the new global model and distributes it to all its client nodes. To train locally using the provided model, the client nodes will utilize their portion of the data, usually a very small portion. In our proposed architecture, the circuit parameters are educated using a hybrid quantum-classical technique, and the local customers are quantum computers or simulators. Each training cycle will involve the selection of a fixed number of client nodes to do the local training. Following the completion of client training, the central node will compile the circuit parameters from every client node. There are several methods for aggregating the model. The meaning of the client models is used in this study. It shows the federated quantum machine learning scheme. We have used the Federated Learning (FL) scheme in our core battery technology and battery cell productions. Figure 15 describes the quantum federated machine learning for battery cell manufacturing process. This scheme consists of multiple clients or local nodes learning on their data, with a central node aggregating the models collected from those local nodes. Nevertheless, as far as we are aware, no Quantum Machine Learning (QML) study has been conducted in a federation setting. The federated training on hybrid quantum-classical machine learning models is demonstrated in this paper, even though our approach may be used for pure quantum machine learning models. We study the merging of a Quantum Neural Network (QNN) with a conventional pre-trained convolutional model. Our distributed federated learning method demonstrated much faster distributed training with almost the same trained model accuracy. In terms of size and privacy, it points to a potential direction for future research [57].

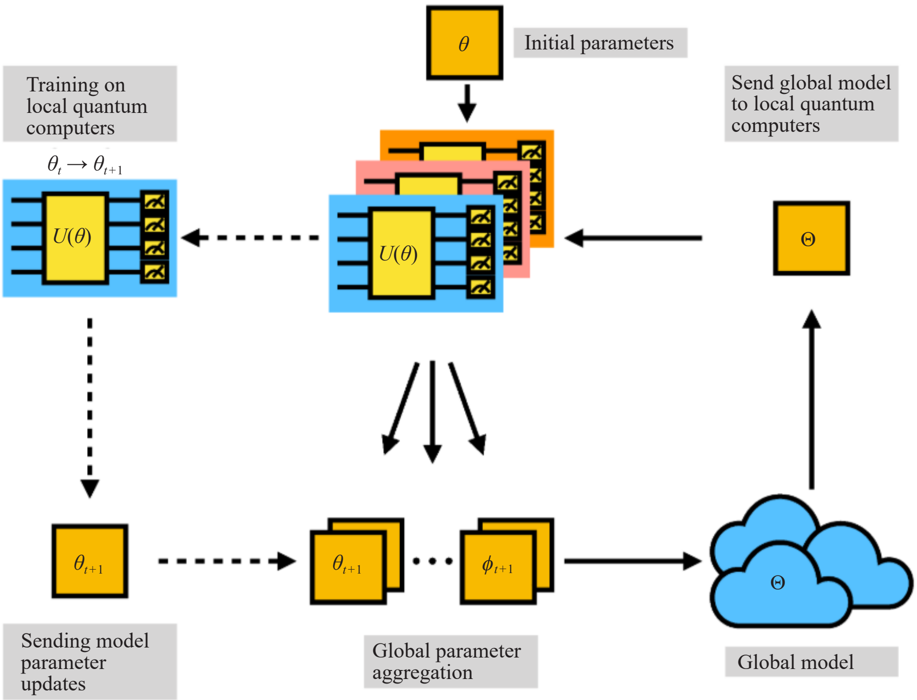

Figure 15. Quantum federated machine learning in BMS and battery cell manufacturing

Table 1. Comparison of battery parameters and quantum federated machine learning

Parameters in battery cell	Optimized-QFML	Scalable	Application agnostics
Data privacy	Highly recommended	100%	LiB/Lithium Ferro-Phosphate (LFP)
Resource optimization	Highly achievable	100%	LiB/LFP
Enhanced security	Highly recommended	100%	LiB/LFP
Scalability	Highly achievable	100%	LiB/LFP
Processing capabilities	Higher than classical Pc	100%	LiB/LSF
Efficiency optimization (VQE/QAOA)	More accurate	100%	LiB/LSF

In addition, Quantum Federated Learning (QFL) combines the benefits of quantum computing and federated learning (collaborative model training) without sharing data about important battery parts (SOH, SOC, RUL, etc.). This could make battery manufacturing sites safer, training faster, and better use of resources. This is especially useful in settings where privacy is a concern within the production of large-scale battery cells as well as Battery Management Solutions (BMS) for many automakers or even government customers. The two types of federated learning-quantum federated learning and classical federated learning-will be crucial for large-scale battery production and order optimization. This is especially true for managing MTO, MTS, and large contracts for both government and corporate customers. By leveraging these advanced methodologies, companies can enhance their operational efficiency while ensuring data security. As a result, organizations will be better equipped to meet the evolving demands of the market and maintain a competitive edge in the rapidly changing landscape of manufacturing. Moreover, the integration of these technologies will facilitate improved collaboration among stakeholders, enabling real-time insights and meaningful decisions [58, 59]. This collaborative approach not only streamlines processes but also fosters innovation, allowing companies to adapt quickly to new challenges and opportunities in the battery cell industries as well as being beneficial to manufacturing automation. The Table 1 explains the comparison and key parameters that can be applied through Quantum Federated Machine Learning (QFML) for better productivity and management of manufacturing sites in battery cell technology [60, 61].

7.7 *Quantum encoder in make to order and make to stock order management*

The crucial step in enabling a quantum circuit to function on a classical dataset is defining the encoding technique, which converts the classical vector into a quantum state. Because it affects both possible quantum benefits and the effectiveness of hardware implementation, the encoding strategy is significant. Both the circuit depth and the number of qubits are constrained in the Noisy Intermediate-Scale Quantum (NISQ) era. The classical values must thus be encoded using a limited number of qubits and a limited number of quantum operations. For a more thorough explanation of the several encoding techniques utilized in QML. In manufacturing and industry, the term "Quantum enabled Encoder" usually refers to a high-precision, optical rotary encoder produced by the company "Quantum Devices", which is extensively utilized for motion control applications because of its accuracy, dependability, and capacity to provide precise position feedback in a variety of industrial settings, such as robotics, Computer Numerical Control (CNC) machines, and packaging equipment; in essence, it is a specialized encoder made to satisfy exacting industrial requirements with high resolution and customization options.

8. Discussion

Despite its effectiveness and promising nature, quantum distributed computing in the manufacturing space, especially in the battery cell industry, has enormous potential for future research on the topic. In future research, the quantum-distributed computing framework can be made bigger to handle more work and real-time applications that will help make battery cells more efficient while keeping the battery parameters the same for better future use. Incorporating additional parameters, such as external environmental conditions and digitalization priorities aligned with future trends in the battery industry's scaling, could potentially improve the efficiency of hybrid quantum distributed computing systems. Furthermore, the energy sector as well as the EV markets are increasing rapidly, and quantum distributed computing could solve the problems and promise better outcomes for industrial innovations. We will also need to know about the next generation of quantum hardware and software, as well as mathematical formulas and error-corrected quantum algorithms. These could help us make better batteries and support their data centers, integration tools, and manufacturing systems in a way that is better for the environment and saves money. Friendly and cost-saving ways. By leveraging these advanced technologies, companies can enhance their operational efficiency, reduce waste, and ultimately create a more sustainable future for the electric vehicle industry. Furthermore, collaboration between researchers and industry leaders will be essential to drive these innovations forward and maximize their potential impact.

9. Conclusions

The battery industry needs more automated and self-guiding systems in the digital age to deal with real-world issues in smart manufacturing sites and boost production levels to meet customer needs (MTO, MTS, and fulfilling). Quantum hybrid and distributed computing and technology are the most embraced by the industrial manufacturing sectors along with many batteries industrial sites. While there are numerous advantages to quantum distributed computing and technologies that are highly demanded in manufacturing process automation, there are also some disadvantages related to quantum error corrections. Researchers need to focus more on preserving the quantum computing power compared to traditional computers. The hardest aspect of this technology is security. We created a three-tiered encrypted private cloud communications architecture. We developed a novel custom method and combined it with steganography to provide an additional layer of protection for cloud-based data transfer. The suggested method works well as a roadmap for making successful solutions for the battery cell technologies industries. This way, most of the manufacturing sites could connect through quantum computing terminals with different technologies and manufacturing inter connections, giving them a lot of different ways to save time and money while making a lot of high-quality lithium-ion battery cells for big cars in the automotive segments. We are going to use a lot of real-time datasets from the battery cell industries and train with the quantum simulator to see what the possible outcomes are, and which models will save the most money. These models will then be added to digital innovation solutions in the industry through quantum AI, quantum ML, and quantum information science to help all digital battery cell production. As these technologies converge, businesses are discovering novel ways to enhance efficiency and reduce costs, ultimately transforming traditional manufacturing processes. Quantum distributed computing and the Internet of Things (IoT) can work together to analyze data in real time and plan preventative maintenance. This makes it possible for factories to become smarter so they can respond quickly to market needs and promote long-term growth in many areas. Numerous issues have significantly impacted certain business models within the battery cell manufacturing industries. Traditional computing can't handle as much data or have as much processing power as quantum hybrid and quantum distributed technologies. These new technologies offer more powerful and scalable solutions for the next generation of battery manufacturing industries. Some of the most important things that could happen because of distributed quantum computing and quantum technologies are changes to industrial revolutions. These contributions touch on several important aspects of industrial automation. In particular, the following results arise from integrating distributed technologies and the industrial Internet of Things into business plans: (a) Smart Infrastructure: By integrating IIoT with distributed systems, we can create smart factories, production sites, and infrastructure, enhancing shop floors and making them highly efficient. For instance, smart grids use IoT sensors and distributed computing to manage energy distribution and consumption more effectively; (b) Predictive Analytics and upholding: IoT data blended with distributed computing powers predict analytics, helping businesses anticipate issues before they arise (e.g., manufacturing companies use predictive maintenance to foresee equipment breakdown, mitigating delays and repair expenses); (c) Personalized Services: the incorporation of IoT and distributed framework supports the delivery of personalized services at scale (e.g., e-commerce platforms use data from IoT devices and distributed systems to offer personalized recommendations to users); and (d) Enhanced Security: distributed systems emphasize the safety of IoT networks by fostering decentralized data storage and processing, reducing the risk of centralized attacks (e.g., blockchain can secure IoT transactions and data exchanges). The paper specifically talks about how quantum distributed computing, platforms for quantum-inspired distributed computing, and the industrial Internet of Things are altering business models, promoting innovation, and creating new chances in many different fields in places that make battery cells. It does this by looking at the new trends, challenges, and chances that the Internet of Things and distributed computer systems have created as possible areas for business model research for the next generation of industrial manufacturing.

Conflict of interest

The author confirms that there is no conflict of interest.

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