Quantum Computing: A Dynamic Breakthrough with Energy Optimization

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ABSTRACT

The world is marching forward with enormous strides embracing the emerging science and technology trends in an effort to create the best out of the better. The curious and innovative motive of the mankind definitely needs a driving force. Physicists have taught the world that for every work done, we need energy. Einstein has taught us how mass and energy are inter related. Though there are lots of energy options around us, we need to be energetic enough to conserve the available energy to help the next generation to carry on its innovative efforts. The Quantum Computing is one of the breakthroughs which will nurture the energy management thoughts. The modern world is an interconnected world with help of innumerable accessories namely, phone, computers, smart televisions, internet or intranet. But the connecting link is still the energy to keep them alive. Thankfully the quantum mechanical properties in spite of its "weirdness" has gifted us "qubits" as a substitute of the "binary bits" which are the lifeline of the Quantum Computing. The Quantum Computing replacing the classical computing will not only help us to handle the data more efficiently saving time but will also be an energy saviour for the future. The Quantum Computing is actually a great breakthrough which will accelerate an unlimited deal of developmental initiative in science, medication or artificial intelligence which will ultimately redefine a broad spectrum of life.

Keywords: Quantum Computing, Qubits, Energy Management, Artificial Intelligence, Developmental initiative.

1. INTRODUCTION

The science and technology and its incessantly innovative moves have definitely kept the mankind on its awe inspiring spree. Before even we have assimilated enough of the latest idea, there is a newer one knocking our brain cells. It is really worth saluting and thought provoking. From macro to the micro, from classical to the quantum and from binary bits to the qubits, the thoughts and applications are sensitizing our knowledge frontiers. In this forward march, the latest of the thought series in on an idea given by Quantum Mechanics. Quantum Mechanics is a branch of modern physics which deals with the mechanics of the quantum particles i.e. particles of the atomic and sub atomic dimensions. This arena of physics is definitely difficult to comprehend due to the "weirdness". While dealing with the sub-atomic particles, we have to come across the uncertainty aspect of matter which has been conceptualised by the famous De Broglie's wave particle duality of matter. But it is amazing to understand that it is actually the root of dynamic breakthroughs which will actually simplify many equations of life if effectively implemented. The whole idea revolves around superposition of states and it gives rise to Quantum Computing.

Quantum Computing is a thought provoking area of research which promises to boggle the humankind and the human mind due to its endless possibilities and intriguing future.

2. BASICS OF QUANTUM COMPUTING

In the present epoch, data and computing have emerged as the essence of our thought revolution. In such a backdrop, we need to keep on innovating the computing techniques to handle the voluminous data with a smart approach. Classical computing requires binary digits which have only two definite states which are denoted by on and off. These on and off are states are denoted by zero or a one. Quantum computing is the biggest leap forward in the computing technology initiated in the 1980s. The recent idea is different from classical computing which is based on transistors. The thought of merging Quantum Mechanics with computation methods actually popped out in 1970s. But it did not garner interest and attention until 1982. In 1982, Richard Feymann opined that the calculations relating to quantum phenomena cannot be classically processed with precision. In spite of this statement, the research interest and activity sparked only after 1994 when mathematician Peter Shor of AT &T Bell laboratory developed the quantum algorithm which showed a promising way forward to factorize very large numbers to prime numbers. Using the edge of quantum concepts, it gives results in few seconds whereas classical computing in some cases would consume years to evaluate.

3. UNIQUENESS OF QUANTUM COMPUTING

Whether its classical computing or quantum computing, the process of solving problems revolves around manipulating data. This process of solving problems is fundamentally different in both the tools of computing. The uniqueness of quantum computing is due to the introduction of two principles of quantum mechanics for operation namely *Superposition* and *Entanglement*.

Superposition is the ability of a quantum object like an electron to exist in multiple states simultaneously. With an electron, the two possible states may be one of low energy state and one with high energy state in an atom. When the superposition of these two possible states occur, there is a probability of that the electron partly remains in lower energy state and partly in the higher energy state. A final measurement will remove the superposition and the consequence will show if the electron will remain in lower or upper state of energy. This thought on superposition help us to comprehend the basic component of quantum computing that is the qubits. While the classical computing deals with the transistors in off (0) or on (1) state, quantum computing handles the upper (1) and lower (0) energy states of electrons. Qubits can be superposed with varying probability assigned by quantum operations during computing but the classical bits are always found in either zero or one only.

Entanglement is the phenomenon in which quantum entities are created and /or manipulated in a way that the description of each one requires references to others as well. The original identities of the individual are lost. This phenomenon is difficult to conceptualize if entanglement persists over long distances. A quantum computer controls entanglement between qubits and the probabilities associated with superposition to carry out a series of operations (called quantum algorithm) such that certain probabilities dominate (corresponding to right answers) and others are meagre or even zero (corresponding to wrong answers). When the calculation is accomplished, the probability of correct answer should be maximum.

Thus uniqueness of quantum computing lies in the approach of handling and utilizing probabilities and entanglement which is different from classical computing.

4. MERITS AND DEMERITS OF QUANTUM COMPUTING

As quantum computing tries to place itself as a replacement of classical computing, a clear picture will emerge if we compare these two counterparts in terms of merits and demerits. The processing in classical computing mainly depends on a string of bits of 0s and 1s. It represents an off or on state or connection or disconnection of an electrical circuit or voltage or current. However the quantum computing depends on the power of qubits. Qubits are generally superconducting electrons or other types of sub-atomic particles. Obviously handling qubits is a huge scientific and engineering challenge. Multiple layers of superconducting circuits isolated in a controlled environment and cooled step-wise to temperatures near absolute zero are used for the operation. All these arrangements are not prerequisites for classical computing. Hence, building quantum computer is tougher than building supercomputers that can perform up to 200,000 trillion calculations in a second.

The solution space of a quantum computer is much greater in magnitude than classical computers including the most efficient ones. The power of a quantum computer can be approximately doubled by the addition of one qubit only. However for doubling the power of classical computers, we need to double the number of transistors involved in the problem.

A qubit can represent a 0 and a 1 at the same time, a unique quantum phenomenon known as superposition which facilitates them to conduct vast number of calculations at once, massively increasing computing speed and capacity. Whether a bit is a 1 or a 0 depends on the direction its

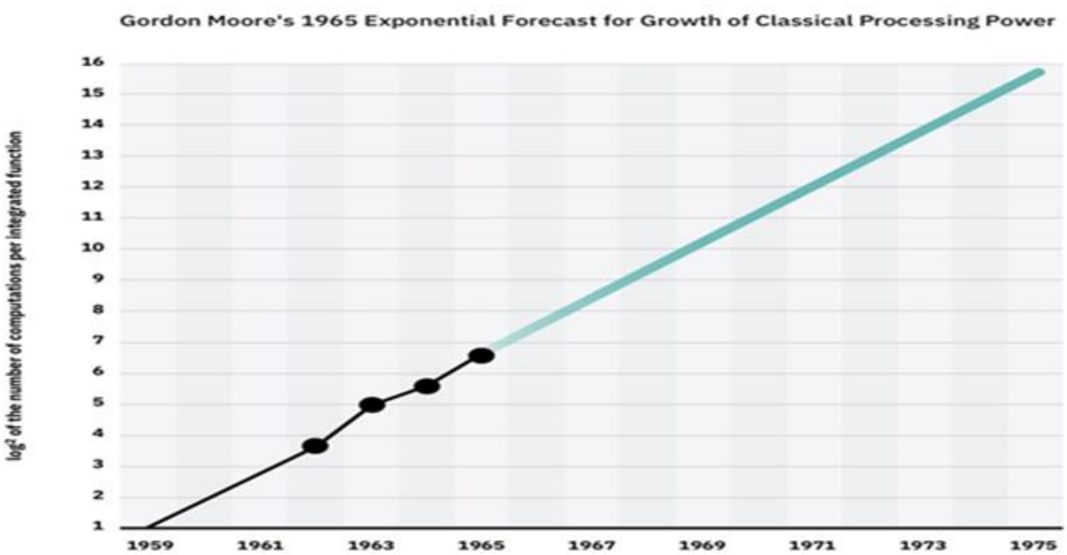

Fig -1 Graphical representation of the variation of classical processing power with time.

electron is spinning. All qubits are fragile, with some requiring temperatures of about 20 milliKelvin to remain stable. Summing up quantum computer is more than just its processor. These computing ideas & systems will also need new algorithms, software, interconnects and a number of other yet-to-be-invented technologies which need to be precisely crafted to be benefitted from the tremendous processing power—as well as allow the computer's results to be shared or stored.

The need of quantum computing is to keep the qubits spinning in the superposition of multiple states for a long time. Noise, temperature change, an electrical fluctuation or vibration can disturb a qubit's operation and cause it to lose its data. Certain types of qubits are stabilized by keeping them very cold using a special isotope of helium to cool them a fraction of a degree above absolute zero (roughly –273 degrees Celsius).

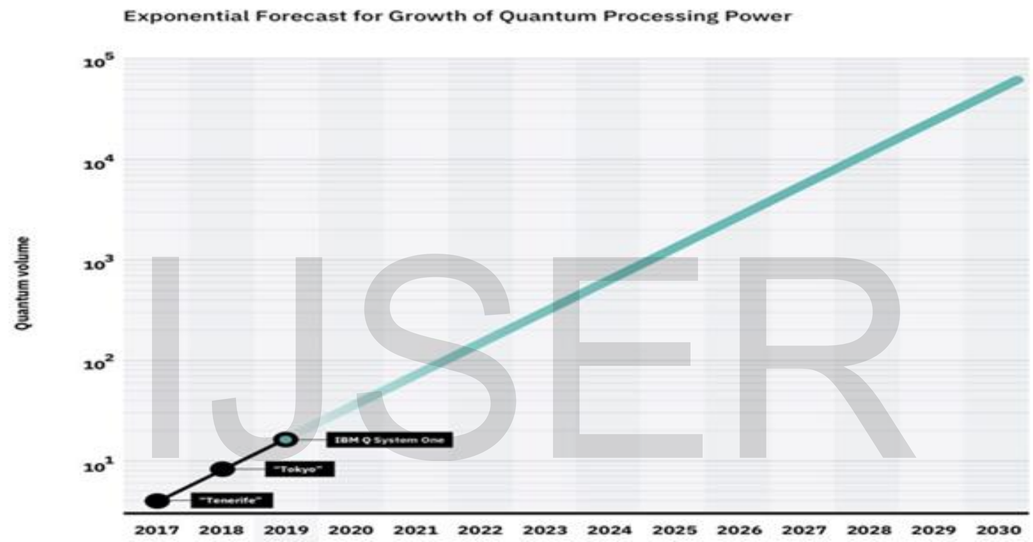

Fig-2 Graphical representation showing the exponential forecast of quantum processing power with time.

5. STATUS OF QUANTUM COMPUTING AROUND THE GLOBE

The journey from classical computing to quantum computing has not been a cakewalk for developing or developed countries. The interest and inclination towards quantum computing has grown significantly since a past few years. Countries like China have increased their investments in this regard voluminously. In 2017 China announced that it plans to open a National Laboratory for Quantum Information Sciences by 2020. This included a 92-Acre, $10 Billion quantum research center. In 2017 in a joint, state-sponsored research project with Japan's National Institute of Informatics and the University of Tokyo it produced the machine, Nippon Telegraph and Telephone (NTT) and shared a prototype quantum computer for public use over the internet. In 2017 Sweden invested 1 billion Swedish Krona (roughly $118 million or 100m €) into a research initiative with the goal of developing a "robust quantum computer". With the fact that building quantum computers is an immense challenge, the effort is now round the globe to try, update and tap the potential of this wonder creation of mankind. There are a few public quantum computers available for anyone to programme on. IBM, Rigetti, Google and IonQ all provide public access to real quantum computing hardware. IBM even sells a quantum computer that we can put in our own data centre (the IBM Q System One). Many organizations, institutes, start-ups and research organizations like Post-Quantum (London), Microsoft, IBM, Rigetti Computing, Google's Quantum AI Lab are storming their brain cells to develop the best version of the computing systems.

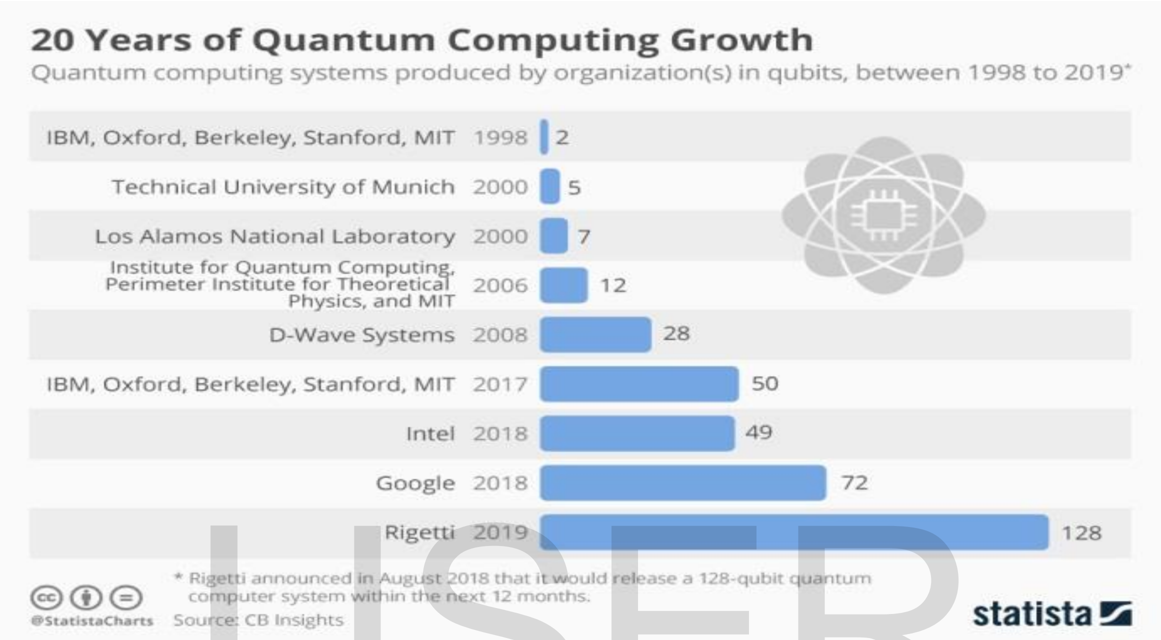

Fig-3 Successive increase in the number of Qubits in Quantum Computing

6. STATUS OF QUANTUM COMPUTING IN INDIA

India has never been lagging in scientific researches. Either it leads the globe or catches up fast with the global innovations. It has done wonders in the area of scientific researches and applications making us proud. India has now taken up the challenge of building quantum computers, which will definitely reestablish India's scientific supremacy. It will also aid in improving national security thoughts by using quantum-level encrypted information .To work on the development of quantum computers, the Department of Science & Technology has set up a programme called Quantum-Enabled Science & Technology (QuEST). DST held the first ever meeting for its QuEST programme at International Institute of Information Technology (IIIT)-Hyderabad on January 8 and January 9. The meeting comprised nearly 50 delegates, including academicians and representatives from various governmental agencies-- ISRO chairman K. Sivan, NITI Aayog member Vijay Kumar Saraswat and India's principal scientific adviser (PSA) K Vijay Raghavan.

During the course of the meeting, the participating delegates discussed a road-map that would help in laying the groundwork, infrastructure and acquiring human resource for building quantum computers in India. India has kicked-off Rs 80 crore project in a span of three years to build machines of future. Vijay Raghavan has quoted the goal of QuEST as "It will ensure that the nation reaches, within a span of 10 years, the goal of achieving the technical capacity to build quantum computers and communications systems comparable with the best in the world, and hence earn a leadership role”

And so, in what is being described as the Phase 1 of India's quantum computing program, the country will be laying out the basic infrastructure that is needed to promote research in this field. Meanwhile, once the basic work has been done, i.e. after three years, the Indian Space Research Organisation (ISRO), Defence Research and Development Organisation (DRDO), and Department of Atomic Energy (DAE) are expected to jointly to push QuEST to Phase 2, that would ensure that India's quantum computing programme matches international standards. India has the unique ability to create low cost solutions and hopefully it will recreate the magic to bring forward low cost quantum computers; lower than companies like D-WAVE offering quantum computers for $15 million (113 crore). Once, this is possible; it will aid the government in fraud detection and data analysis, which the government is already doing and that too in real-time. A Rs 8,000 crore plan is allocated in the budget of this year to assist the quantum dream project.

7. POTENTIAL APPLICATION AREAS OF QUANTUM COMPUTING

On one side the classical computing is still trying to reach the peak of its application areas while on the other hand quantum computing is still is its embryonic stage. But still the world is rich with speculation about the potential areas of applications touching our lives. Some estimates predict that the quantum computing industry will be worth about $5 billion by 2020. Some potential application areas are listed out.

- Cryptography- Advanced cryptography is an important way forward. Though ordinary computers are infeasible to break encryption, quantum computing can lead to safer digital life and assets.
- Data Analytics- It can solve many problems in huge scale such as topological analysis. NASA is looking forward to quantum computing for analyzing the enormous data about universe and safer methods of space voyage
- Forecasting- Predicting and forecasting various scenarios rely on large and complex data sets. Too many factors takes longer simulation time for prediction of actual weather .
- Medical research - Quantum computing can intensely cut costs and time to market and empower computational chemists to make new discoveries faster that could lead to cures for a range of diseases.
- Aviation- Routing and scheduling of aircrafts with quantum computing is supposed to save huge amounts of time and money.
- Self- driving cars - Car companies like Tesla and tech companies like Apple and Google are actively developing driverless cars. Not only will these improve the standard of living for most people, but also cut pollution, reduce congestion and derive other benefits.
- Machine Learning- Today we are ushering in the age of quantum advantage with a belief that quantum algorithms will overtake the classical ones in efficiency. In this backdrop, machine-learning, artificial intelligence, optimization techniques will surely find a place in the application and implementation areas.

But we can stay assured that this is just the beginning and many more arenas are just lined up to derive the benefits of quantum computing.

Quantum computing's impact potential and tool used during value creation

Step	1 Design of chemicals[1]	2 Design of products[2]	3 Supply chain	4 Production	5 Marketing
Impact potential	Early killer application	Early killer application	Mature quantum computing	Potential early application	Mature quantum computing
Quantum tool used	• Quantum simulation • Optimization • Quantum AI[3]	• Quantum simulation • Optimization • Quantum AI[3]	• Optimization	• Quantum simulation • Optimization • Quantum AI[3]	• Optimization
Examples of future applications	• Design molecules and solid materials with required properties, reducing lab work • Use computers to define shape of proteins to make better active ingredients	• Discover more effective formulations by modeling how ingredients affect processes or how complex mixtures behave	• Use quantum computing to optimize supply chains and logistics and to reduce costs	• Improve yields and suppress by-product generation through better understanding of reactions and finding new catalysts • Use quantum algorithms to solve complex optimization problems in heat and mass transport	• Use quantum AI[3] to help handle B2B and B2C cus-tomer relations

[1]New molecules.
[2]Formulations and complex assemblies.
[3]Artificial intelligence.

Fig 4- Quantum computing: A dynamic breakthrough

8. Energy optimization and Quantum Computing

It is conceptualized that quantum computing has the potential to solve certain problems faster than classical ones and that too with comparatively less power consumption. We need to look into the actual energy equations involving the same. In the Google's Quantum AI Lab, the latest generation D wave systems has come up already and the facts suggest that these machines can increase the number of qubits without any significant increase to the existing power required. This is so because the computing hardware consists of specially designed Niobium loops which act as superconductors when cooled to a temperature of around -273° C. Much of the energy (around 25 KW for this machine) requirement is for running the refrigeration unit to keep the processor cool. On the contrary the energy requirement to run the processor is comparatively meagre. The officials assure that in spite of raising the number of qubits in this unit, the total power required now will remain more or less same for upcoming improvements. When compared with classical unit it is less power efficient due to the energy necessities for extreme cooling requirements.

Matthias Troyer, a computational physicist at ETH Zurich suggests that the power requirements for quantum computing to be linearly proportional to the number of qubits and their couplings and also to the number of times operators must run and cool the system before it finds the solution. We understand that quantum system can execute more number of calculations at the same time than its classical counterpart. But still quantum computing will be in a winner in power efficiency if it can solve a problem with much better time to solution scaling than classical computers. As understood major power requirements are consumed in cooling units to keep the qubits stable. Newer methods can be thought of to stabilize qubits for a longer interval with lesser errors. Artificial atoms can come in need for these thoughts and actions.

9. CONCLUSION

Having travelled in the quantum computing world in some detail now, it would be wiser enough conclude that the days have not yet come where we can safely predict that it is an era of quantum supremacy. The best option till now is to have a wise mix of both classical and quantum computing skills. In this data loaded world, when the processes of handling and executing the data into information becomes tedious, complex and less efficient, quantum computing can come out to be a relief to us. But as already argued, the advantage of quantum computing rests on the algorithms support to implement it. It is indeed an accepted fact that the quantum computing is a commendable feat of science and engineering but it will be misleading to the general public that quantum supremacy reigns. To put it in the correct perspective, quantum computing is not reigning supreme rather it will work in consensus with classical computing, both having its own set of virtues.

If quantum computing wants to leave its positive impact in the society it needs to work on building extensively available, powerful and programmable quantum systems that can efficiently implement the thoughts through advanced algorithms and programs. The actual spirit of research lies in percolating the research findings to the masses and practically absorbing them in general life. Thus the entire fraternity of physicists, engineers and computer scientists need to keep on churning ideas and actions how to fundamentally change the landscape of information technology through quantum computing in an energy and time efficient framework.

The generation next is in an ardent need of an energy optimized intelligent workplace and quantum computing can potentially be the way forward.

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