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Digitalization of Global Cities and the Smart Grid

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Abstract
With today's rapid urbanization, global cities are constantly expanding to accommodate population growth. It is estimated that global cities will add another 2.5 billion new residents by the year 2050. However, along with this rapid expansion also arises the need for cities to provide infrastructure support in order to provide their residents with a good quality of life that is both sustainable and environmentally friendly by reducing the carbon footprint. Digital technology can be harnessed to help cities manage their energy needs through the deployment of the smart grid. Blockchain provides a more secure management of energy data while satisfying the energy needs of a smart city of the future. Blockchain aggregators can be deployed at different layers of the smart grid to protect the data flowing on the network. With the increasing popularity of microgrids as components of the smart grid, 'prosumers' can use the blockchain to sell their own renewable energy back to the smart grid. The blockchain technology platform can be deployed to protect microgrid data resulting in a more secure power grid system, a necessity to keep today's digital cities operating cost-effectively, efficiently, and securely.

Keywords Smart grid · Smart city · Digitalization · Cybersecurity · Microgrid · Blockchain

1 Introduction

Digitalization, in general terms, is defined as the incorporation of digital technology into our everyday life. The literal meaning of digitalization reflects a constantly developing and technology dependent world. It has many forms and permeates our societies, economies, and cities. Digital technology encompasses software development, telecommunications, computing equipment, as well as digital media and increasingly affects industry verticals such as energy, manufacturing, transportation, healthcare, energy, retail, and more.

Digital cities can use technology and data to improve the lives of their residents in the following domains (Fig. 1):

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Fig. 1 Domains affecting digital cities

It drives innovation and changes business models, influencing economy, and offering solutions to address urban issues such as increased demand for power. The decrease in the cost of sensors as well as data processing and storage has enabled the emergence of another digital phenomenon, the "Internet-of-Things" (IoT), [1].

All IoT devices consist of three common components: hardware, network, and software. Advancements in data analytics allow the vast amounts of data generated by these smart devices to be efficiently analyzed. The IoT and its connected smart devices are being deployed in a wide range of verticals from agriculture, manufacturing, and transportation to healthcare and energy. By 2025 it is estimated that about 25–50 billion devices will be connected to the Internet. An increasingly popular application of IoT technology is in the energy sector, namely the smart grid [2].

A digital "smart" city consists of three layers: technology, applications, and public usage [3]. An example of these layers, from the perspective of consumer energy management is shown below (Fig. 2):

A smart city integrates data with digital connectivity and improves core functions such as sustainable energy management.

This paper is organized into six sections. After the introductory first section, the second section describes methods to improve energy management while the third section covers how blockchain technology can be deployed in the energy sector. The fourth section covers

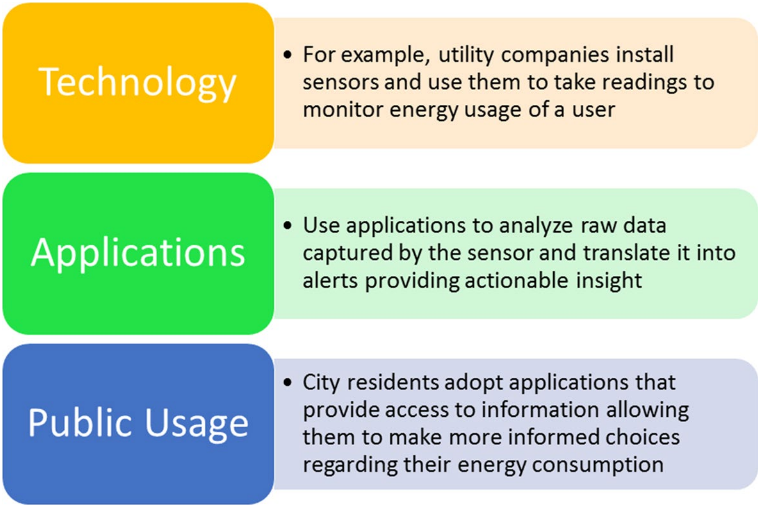

Fig. 2 Foundations of energy management for a digital city

security issues in the smart grid, and the fifth section describes using blockchain technology for securing the power grid in digital smart cities and the sixth and final section provides a brief conclusion.

2 Improving Energy Management

Technology has introduced smart grids, micro grids, and distributed energy generation for digital cities. The smart grid helps the distribution system integrate renewable energy sources such as wind and solar. To meet their exponentially growing energy needs, digital cities are looking into techniques for intelligent, connected local energy storage systems to harness these renewable energy sources and integrate them into the grid. Micro grids can be integrated in the local, distributed energy infrastructure and protect the critical infrastructure of cities against power outages from natural causes such as storms and wildfires.

In the smart grid infrastructure, a system of devices such as sensors, smart appliances, or intelligent electronic devices (IEDs) are strategically installed on the M2M communications network and transmit and receive data which is then collected, analyzed, and accessed through a gateway such as the Internet. The smart grid allows utility companies to integrate two-way M2M communication and electricity flows. Sensors and advanced control mechanisms are used to capture then analyze real-time data related to power delivery, generation, and consumer usage. Utility providers process the information using big data analytics to gain visibility into events across smart grid networks. This example of digitalization allows utility companies to optimize energy efficiency and stability of the power grid, as well as more efficient customer billing [2].

The integration of information and communication technology (ICT) and the smart grid will enable cities to implement the following smart applications and improve the efficiency of their energy infrastructure through 2025:

- Home energy automation systems.

- Home energy consumption tracking.
- Smart streetlights.
- Dynamic electricity pricing.
- Distribution automation systems.

Smart utilities are helping digital cities create cleaner and healthier living environs that are also environmentally sustainable. For example, Dubai has deployed smart energy meters and achieved the wide-scale adoption of home automation systems as well as behavior-based electricity consumption tracking. Vienna, Austria is involved in the testing of technological solutions for future energy-efficiency in urban areas using real end consumers [3].

The cost of renewable energy sources such as wind and solar by 2022 is estimated to be $60 per MWh (Megawatt hour) in 2022. The high cost associated with the use of fossil fuels is accelerating the deployment of smart grid solutions for reliable usage of renewable energy. Through the deployment of smart meters, energy-saving policies, and advanced sensors to improve its reliability and efficiency, smart grids are estimated to be able to give city residents energy cost-savings worth about $14 billion by the year 2022 [4].

With the emergent trends of electrification, de-carbonization, and de-centralization, smart grid operators must partner with digital cities and manage its integration in the city's infrastructure. Proper deployment of the smart grid will help reduce carbon emissions in global cities through the electrification of basic infrastructure components such as transportation, water, housing, and even industrial processes. In the area of transportation, 55% of new car sales worldwide are projected to be electric by 2050. With the drive to generate cleaner electricity, emission-free sources such as wind and solar power are being harnessed by the smart grid and are estimated to reach 48% of total global electricity generation by 2050. Thus, through efficient management of energy infrastructure can help global cities improve the lives of their citizens [5].

3 Energy and Blockchain for Smart Cities

A smart city needs to be able to balance consumer energy needs with efficient energy management strategies. Microgrids can also be enablers in local energy schemes in which communities can sell their own renewable energy back to the grid or their neighbors.

The city of Austin, Texas is installing solar Photovoltaic (PV) panels with integrated storage and software that allows homeowners and businesses with on-site solar panels to automatically switch between grid power and their owned stored electricity based on current load and other factors. This is an example of how autonomously managing energy storage can contribute to the energy eco-system in smart cities.

A microgrid project in Brooklyn, a borough of New York City, that is a collaboration between LO3 Energy and Siemens plans to introduce a microgrid-supported local energy market which allows local city residents with rooftop solar panels to sell their excess power to their neighbors. This Brooklyn-based microgrid project uses blockchain technology.

A blockchain is an open, continuously growing distributed database. It processes and tracks transactions between contributors in the absence of a central administrator. The Blockchain, or distributed ledger technology (DLT), process is illustrated below (Fig. 3):

The participants in a blockchain network each keep a replica of the digital ledger and update it using the consensus protocol. The blockchain ledger is replicated on all computer

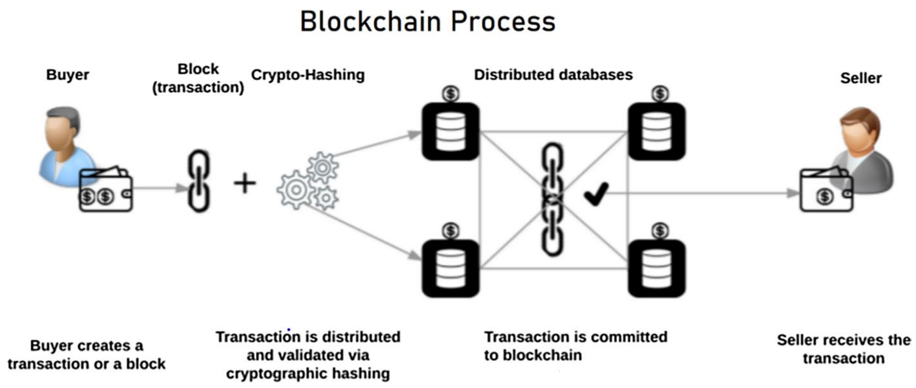

Fig. 3 Blockchain process

nodes across the blockchain network, eliminating the possibility a single point of failure and making it more robust.

Some applications of blockchain technology in the energy sector are shown in Fig. 4.

Blockchain security is implemented by linking and securing blocks of data using cryptography which makes it difficult to alter records. Blockchain ledger transactions are reviewed and visible to all participants, reducing the chances of fraud.

The properties of blockchain closely matches the needs of the smart grid such as decentralized power generation and the exchange of large volumes of real-time digital data. This

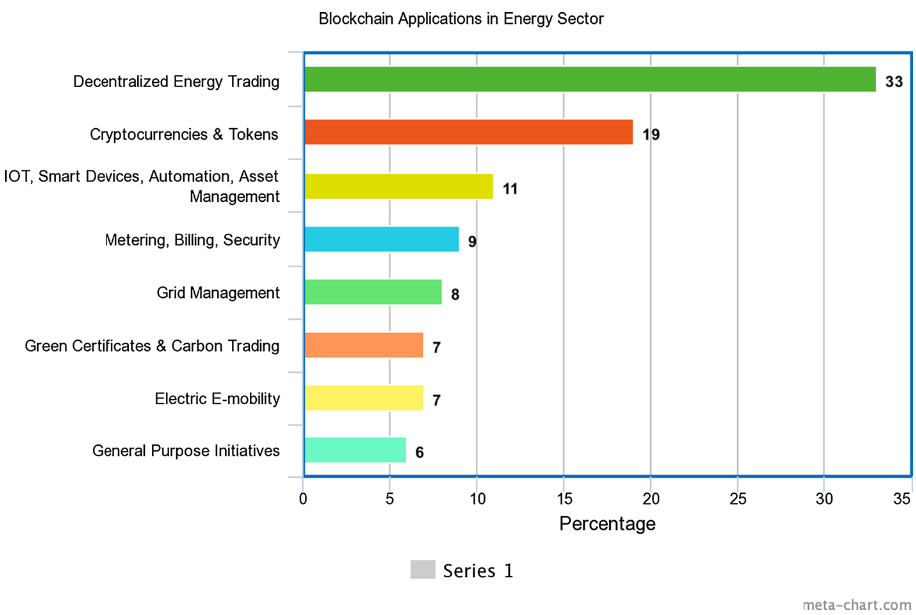

Fig. 4 Using blockchain in the energy sector

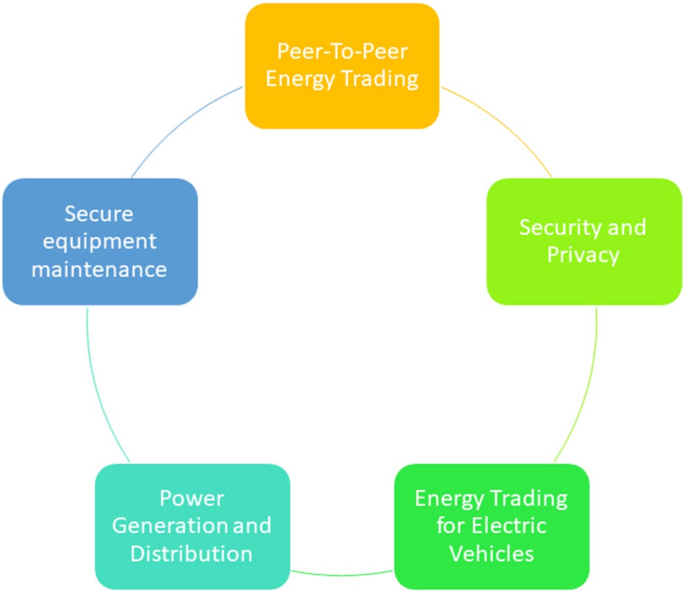

Fig. 5 Blockchain user cases in the smart grid

makes blockchain technology eminently suitable for deployment in the smart grid. Some use cases of blockchain in the smart grid are shown in Fig. 5.

This digital blockchain ledger system is the basis for cryptocurrency transactions and applying the blockchain concept to distributed renewable energy generation and distribution provides urban energy consumers with a flexible energy market. Using blockchain technology reduces accounting errors and provides a more secure, transparent smart energy management system [5–7].

4 Smart Grid Security

With the growth of urban populations, digitalization of the power grid reduces the carbon footprint of the electric power system and improves the city's power infrastructure making it more efficient. Using digitalization, utility companies are deploying pilot programs in many global cities to test new techniques for the efficient generation, delivery, and consumption of electrical energy using smart grids, the next-generation electrical power system that combines OT (Operations Technology) and IT (Information Technology). Utility companies around the world are evaluating, planning, and implementing smart grid technologies by deploying Advanced Metering Infrastructure (AMI) and other electronic communications technologies that enable the utility to monitor and analyze their networks and provide customers with a more reliable and efficient power system both at the smart grid level and micro grid level. Data generated by the smart grid is referred to as 'big data'—data that is high in volume, data rate, variety or a combination of all three. This data allows utilities to gather higher resolution consumer energy usage data compared to the legacy centralized electrical power plant and distribution grid.

However, the smart grid is a more complex system compared to its predecessor, the legacy power grid. The digitalization that is responsible for its "intelligence", also makes it more vulnerable to cyber threats. Utility companies will have to improve security of critical power infrastructure and protect consumer digital data if they wish to realize the true potential of the Smart Grid. Vulnerabilities in the smart grid range from access to and manipulation of smart devices such as IEDs, proliferation of malware, denial of Service (DoS) attacks, hacked smart meters, deliberately modified sensor and SCADA systems data, to the unauthorized modification of routing in wireless networks and these can all disrupt grid operations. Consumer data protection and privacy are also equally important for digital cities around the world who are powered by the smart grid [8].

5 Securing Smart Energy in Cities Using Blockchain

Cyberattacks against the power grid of IoT-powered smart cities can lead to massive power outages and the destruction of power network infrastructure.

The cyber threats facing the power grid infrastructure in IoT-powered smart cities can be classified in the following categories (Fig. 6):

Blockchain technology is a peer-to-peer distributed data processing technology that records transactions, agreements, contracts, sales, and allows network participants to distribute and store data. Blockchain can be harnessed to provide scalable solutions for securing the networks of IoT-powered smart cities. The cryptographically secure and

Fig. 6 Cyber threat categories facing smart city power grids

decentralized blockchain technology may be harnessed to secure the exchange of energy-related data across smart city networks, prevent the leakage or alteration of personal information from grid users, and protect the critical smart city infrastructure with its connected IoT devices. The primary advantage of using blockchain technology to prevent cyberattacks is that the attacker has to compromise 51% of the blockchain network systems in order to successfully succeed in an attack and this will be computationally very difficult, if not impossible to achieve [9–11].

As mentioned earlier, deploying blockchain technology provides a secure energy trading system that protects a smart grid prosumer (i.e., prosumer + consumer) who is involved in energy production as well as energy trade. The data generated for all blockchain transactions is transparent to all prosumers's who share the generated data, in an anonymous mode, thus making the transactions more secure compared to those in the archaic power grid with its centralized architecture.

For example, Home A is connected to a microgrid and produces its own electricity through solar panels. The homeowner-prosumer can share this real-time energy data (i.e., Transaction A) through a two-way communication network, as mentioned earlier. This energy data is encrypted (i.e., Hash value #A) and recorded in the block. This block may contain energy production data, energy usage, surplus energy information, and energy transaction information, which is stored in the chain, in real-time, then used to construct a database. It is mathematically impossible to steal or alter data in the continuously growing blockchain database, allowing prosumers (e.g., Home A, Home B, Home C, and Home D) shown in Fig. 7, that are connected to the same microgrid network, to safely buy or sell energy (if they have surplus) based on their energy needs.

This additional security layer will deter cyberattacks against energy transactions between prosumers while monitoring data related to energy usage patterns, in real-time, will provide digital cities with a secure efficient energy management system [12].

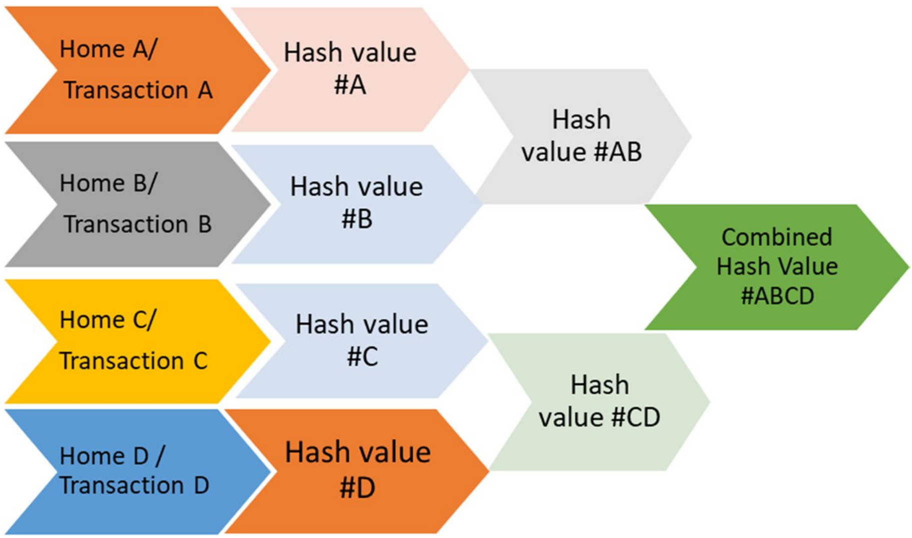

Fig. 7 Microgrid blockchain process flow

Data protection can be further strengthened by deploying distinct blockchain aggregators at different smart grid layers as shown below in Fig. 8:

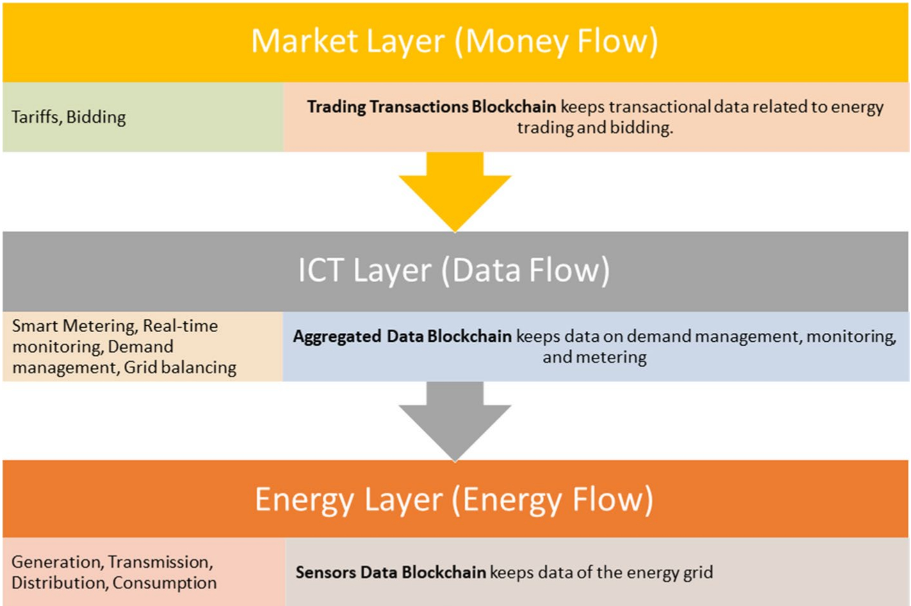

Fig. 8 Microgrid data protection using blockchain technology

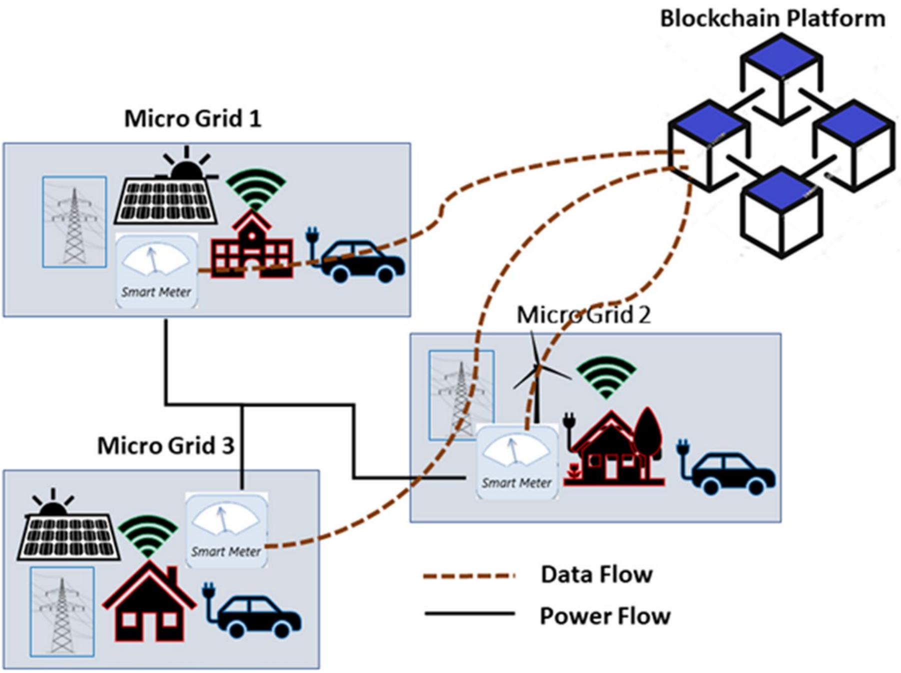

Fig. 9 Microgrids connected to blockchain platform

Since the Blockchain platform does not directly link the identity within the Blockchain environment with the identity of a specific prosumer, the probability of a cyberattack against the smart grid is greatly reduced and improving its security posture. Now if we take this concept one step further, multiple microgrids may be connected through a decentralized blockchain platform as shown in Fig. 9 above:

The participating microgrids will be able to share their computing resources with their peers, thus increasing the available computational capacity and providing a more secure, reliable, and scalable operational structure within the smart grid [13].

6 Conclusions

This paper has provided a brief overview of digitalization, smart grid technology, blockchain technology and its impact on global cities. Digitalization of cities resulting in significant economic and social change is at the forefront of the so-called "Fourth Industrial Revolution". The combination of pervasive communications, innovative energy solutions, and transportation advancements, among others are creating a connected, data-rich, and sustainable urban environment. The related global smart city technology market is anticipated to reach $1.7 Trillion by the year 2028, [14].

Improving the intelligence of the city infrastructure, including the smart grid, leads to a smarter "digital" city that allows its residents to achieve their renewable energy goals, reduce their carbon footprint, improve power distribution including the ability to control their utilities, ultimately leading to a better quality of life [15].

In our next paper, we will explore the blockchain security challenges in the smart microgrid energy sector, faced by digital cities so they can achieve the full potential of the digital urban economy of the future.

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