Blockchain Smart Contract Technology in Urban Energy Management System

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Abstract

Blockchain technology is considered a disruptive technology with real potential for change after steam engines, electricity, and the internet. The regional electricity sales model based on blockchain technology will become an essential breakthrough in innovative city energy management. The thrustless ingenious contract mechanism, the weakly centralized intelligent power energy micro-grid internal competitive energy business model, is based on blockchain technology. Its physical structure includes multiple levels such as the energy use layer, control layer, and functional layer. All transaction entities of the innovative power energy microgrid have an equal status in the blockchain system. The transaction energy includes cold, heat, electricity, gas, etc., and is distributed after bidding through energy routers and competitive trading platforms. This model uses multi-party bidding to optimize the allocation of resources such as cold, heat, and electricity, restores the commodity and financial attributes of energy and dramatically improves the energy efficiency and economic benefits of the power energy microgrid.

Keywords: Blockchain technology, energy management system, decentralization, distributed transaction, innovative contract technology, multi-party bidding.

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1 Introduction

Blockchain technology is considered a disruptive technology with real potential for change after steam engines, electricity, and the internet. It is expected to reshape the business form of many human industries. Blockchain technology has four significant advantages: (1) distributed accounting and storage; (2) sharing resources between nodes through smart contracts, without relying on data backup and credit endorsements of intermediaries; (3) open and transparent, automatic execution, and mandatory performance; (4) Cannot be tampered with. Blockchain and Energy Internet both have decentralization characteristics, the high degree of autonomy, marketization, and intelligence in technology, thus showing strong application potential. A distributed transaction is the most important application of blockchain technology in the field of intelligent energy. Application scenarios include distributed energy dispatch management, energy trading and settlement, innovative power, energy storage + electric vehicles, etc. At present, attention and research on blockchain technology from all walks of life have shown explosive growth. At the 19th Academician Conference of the Chinese Academy of Sciences and the 14th Academician Conference of the Chinese Academy of Engineering, General Secretary Xi Jinping pointed out: "A new generation of information technology represented by artificial intelligence, quantum information, mobile communications, Internet of Things, and blockchain is accelerating. Breakthrough applications accelerated development of energy technology with the goal of clean, efficient and sustainable will trigger a global energy revolution. "This is the first time that "blockchain" technology has appeared in the speech of the country's top leader. It is believed to have reached a "Chinese consensus" on blockchain technology development [1]. In the future, the combination of Energy Internet and Blockchain technology will reshape the entire energy supply industry chain and promote the sublimation of the existing Energy Internet to the new form of Energy Internet 2.0.

2 Blockchain Technology

Blockchain technology is an integration of a series of technologies. It is a decentralized data recording and storage system formed by combining multiple technologies such as databases, digital currencies, and asymmetric encryption algorithms in a specific way. Satoshi Nakamoto proposed in 2008 that blockchain technology is a "block"-like chain data structure formed naturally in time series. Its advantage is that it does not require a traditional

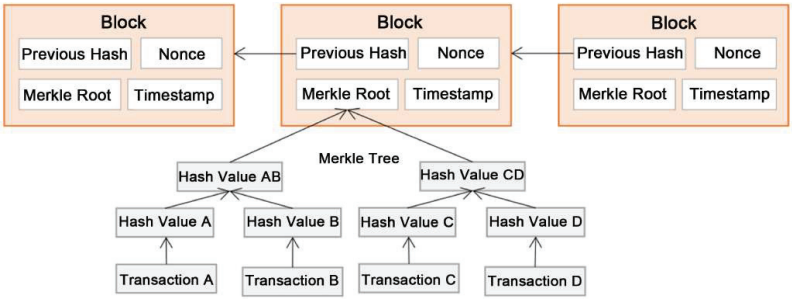

Figure 1 Physical structure diagram of blockchain technology.

central trading platform and will adopt encryption algorithms, consensus mechanisms, time stamps, etc. Means to achieve point-to-point transactions. The blockchain network is a P2P network. There is no central hardware and management organization [2]. Each node in the network is of equal status and can be used as a client and a server simultaneously. The physical structure of a typical blockchain is shown in Figure 1.

Compared with traditional technology, blockchain technology has four significant advantages: (1) Using distributed accounting and storage, system efficiency is greatly improved; (2) Nodes share resources through smart contracts and do not rely on data backup and credit endorsements of intermediate institutions (3) It has the characteristics of openness and transparency, automatic execution, and mandatory performance; (4) It has the characteristics of non-tampering, and the information added to the blockchain is permanently sealed, and the modification of data on a single node is invalid. At present, the blockchain application technology represented by smart contracts and DAPP (distributed applications) is called the blockchain 2.0 version, which pays more attention to implementing the real economy in application scenarios and is an essential innovation to existing business models.

3 Blockchain + Energy Internet

Blockchain technology has enriched the original energy Internet concept and expanded it into two layers: (1) Long-distance complex and massive energy systems, such as energy transmission and sharing between global or intercontinental networks; (2) Realizing nearby transactions of regional energy, Distributed power energy microgrid has become an essential part of the enormous power grid and has formed a large number of centralized + decentralized grid topologies.

Both the blockchain and the energy Internet are technically decentralized, highly autonomous, market-oriented, and intelligent. The kilowatt-hours, cold and heat energy in the blockchain mode have process records, which can achieve accurate management and settlement; By sending a signal through a smart contract, the transmission and storage of energy will be carried out automatically, and the excess energy will be sent to the storage to ensure the real-time balance of system energy. In the future, the marketization of energy commodities, diversification of supply, decentralization of systems and intelligent power grids will become increasingly clear development trends [3]. Through the thrustless innovative contract mechanism, the blockchain can efficiently integrate various distributed energy sources and increase the penetration rate of renewable energy. It will accelerate intelligent grid dispatching and free-market transactions and promote distributed smart energy metering and settlement scenarios. Therefore, blockchain technology has shown strong application potential in the field of energy Internet and new energy.

4 Application of Blockchain in the Field of Intelligent Energy

4.1 Application Scenarios

In 2016, the "China Blockchain Technology and Application Development White Paper" issued by the Ministry of Industry and Information Technology listed six application scenarios with broad prospects or potential values. In May 2018, VeChain and PricewaterhouseCoopers jointly released the "2018 China Blockchain (Non-financial) Application Market Research Report", pointing out that the most non-financial areas can create the value of blockchain technology are logistics healthcare and energy. The innovative energy system is a high degree of coupling between digital technology and the energy Internet. The core is to break all kinds of energy barriers and realize the intelligent supply of multiple energy sources [4]. A distributed transaction is the most important application of blockchain technology in the field of intelligent energy, mainly in the following application scenarios:

4.1.1 Distributed energy dispatch management

Blockchain technology based on distributed ledgers and smart contracts can realize flexible interaction between users and the power grid. User-side loads participate in demand-side response, enhancing the flexibility and transparency of energy consumption and supply. According to reports, European

transmission system operator Tennent, IBM, energy storage company Sonnet, and renewable energy company Vande bron are collaborating on a "smart grid pilot program" based on blockchain technology and plans to use blockchain technology to manage distribution in Germany and the Netherlands. Energy to improve the balance and stability of the power supply. At the EMART Energy Fair held in Amsterdam in November 2016, 23 energy trading companies participated in the alliance and planned to develop an energy blockchain trading system jointly.

4.1.2 Energy trading and settlement

Blockchain technology supports decentralized energy supply. Electricity producers, distribution operators, transmission operators and suppliers directly conduct transactions at all levels through the blockchain. Electricity settlement no longer relies on traditional power companies, individuals or Enterprises can directly conduct transactions, and the commodity and financial attributes of energy will be further highlighted. The comparison between the traditional transaction model and the blockchain model is shown in Figure 2.

In April 2016, the American LO3 Energy Company, in cooperation with Siemens Digital Grid and Bitcoin Development Company Consensus Systems, established the Brooklyn Microgrid. This microgrid is the world's first energy trading project based on blockchain technology. The chain sells or

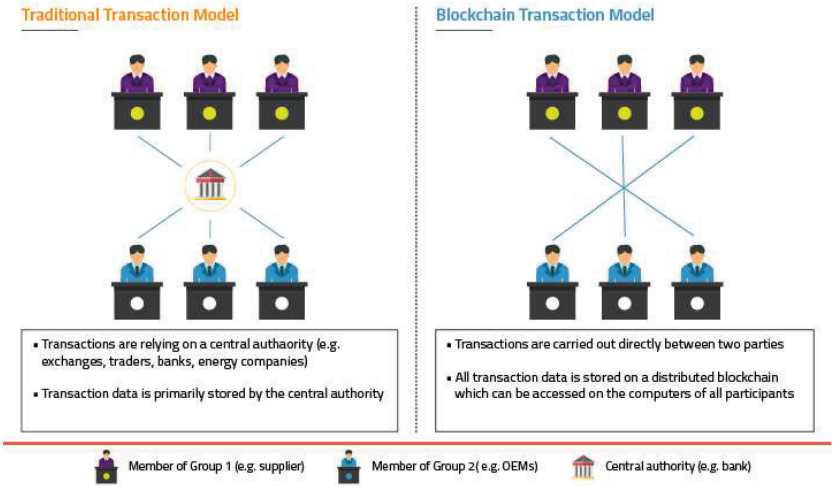

Figure 2 Comparison of traditional transaction model and blockchain transaction model.

buys electricity to others, realizing peer-to-peer transactions that do not go through the public power company or the central grid.

4.1.3 Smart power

Limited by resources and economic conditions, Chinese energy consumption has long been faced with a mismatch between supply and demand, a shortage of flexible resources, and relatively independent energy systems. Blockchain technology is the best choice to solve these problems. The traditional energy and power industries use provinces as a unit to optimize resource allocation. Provincial power dispatching and trading centres are responsible for the province's power balance. The larger the provincial energy system, the higher the cost of system decision-making. Compared with the traditional energy and power industries, the energy Internet + blockchain technology will develop from a centralized overall balance to decentralized decision-making and Pareto optimal partial micro-balance [5]. Through the smart grid's digital operation, distributed new energy power generation can be connected to the existing grid, and point-to-point direct transactions without centralized settlement can be realized. Resource utilization is more intensive and efficient. Energy Internet + blockchain technology will also establish an intelligent connection between power supply and electricity consumption, significantly reducing transaction costs and improving transaction efficiency.

4.1.4 Energy storage + electric vehicles

Energy storage + electric vehicle charging is a highly applicable sector of blockchain technology. In 2016, the German power company Rheinland Group (RWE) cooperated with automotive technology company ZF (ZF) and Swiss Bank to realize the use of blockchain electronic wallets to complete charging and even highway toll services. This solution was introduced by Oxygen Initiative, a California start-up company in 2017, and promoted in California.

4.2 Domestic Research and Application

Chinese research and application in the field of energy blockchain have also started. Beijing Energy Chain Zhonghe Technology Co., Ltd. established its first energy blockchain laboratory in May 2016 and launched its main chain Demo. The State Grid Zhejiang Electric Power Research Institute is the earliest domestic research institution to apply blockchain technology to the energy Internet and undertook the State Grid's first blockchain technology project,

"Research on the Application of Blockchain Technology in the Energy Internet." Jointly developed a blockchain platform with independent intellectual property rights with the State Grid Information and Communication Industry Group. The platform has been deployed and tested at Zhejiang Electric Power Research Institute.

In February 2018, the signing ceremony of the energy blockchain project co-sponsored by China Merchants Charity Foundation, VNORD, New Energy Exchange, Panda Green Energy, and Huawei was held Shekou, Shenzhen. Panda Green Energy provided it in Nanhai Yi, Shekou. With the new energy distributed power station power in the library, users can choose to use traditional energy or new energy power on the blockchain platform. This project has formed a typical energy blockchain application scenario and is a Chinese creative blockchain practice project [6]. The China Electric Power Research Institute is also actively exploring blockchain technology in power dispatch and trading. It has initiated the research and development of blockchain technology-based power system frequency modulation business and distributed source-load market trading systems. For the research on energy blockchain technology, China and other countries are currently at the same starting line. The next few years will be an essential period of opportunity and window period for countries to compete for this technology's leading advantage.

4.3 Blockchain + Electricity Retail will Become a Breakthrough

In the future, power generation equipment will gradually show the characteristics of decentralization, and the topology of the power grid will also change with the power generation end. As a new link in the industrial chain, energy storage will play an essential role in peak shaving and valley filling. Blockchain technology can realize the digital management of energy [7]. The production, transmission, and consumption of each kilowatt-hour of electricity have a path record. The point-to-point transaction of regional power will be the most critical blockchain application in the energy industry. Decentralization and decentralization have realized the "direct connection" between electricity producers, electricity sales departments and consumers. Therefore, regional electricity sales based on blockchain technology will become an essential breakthrough for intelligent energy. Following the market trend of electricity retailing, with distributed power generation flexibility trading as the starting point, electricity retailing, demand-side capacity trading, operation and maintenance, and energy-saving services can all be realized through off-site Internet e-commerce platforms.

5 Innovative Energy Business Model Based on Blockchain

5.1 Smart Energy Business Model

The characteristics of the innovative energy business model based on blockchain technology are shown in Figure 3: (1) Realize point-to-point power transactions between users and generators; (2) Decentralized decision-making; (3) Decision-making scheduling: The objects of future power scheduling are distributed in large numbers Distributed energy, and smart electricity load is used to generate scheduling decisions through the blockchain; (4) Realize the Pareto optimization of market competition and high resource allocation efficiency.

5.2 Weakly Centralized Intelligent Energy Competitive Energy Consumption Business Model

The weakly centralized intelligent power energy micro-grid internal competitive energy business model based on blockchain technology, its physical structure includes multiple levels such as energy use layer, control layer, and function layer [8]. The structure of the intelligent energy power energy microgrid is shown in Figure 4. The energy consumption layer is composed of multiple industrial enterprises, household users, business districts, DC power users, electric vehicles, energy storage devices, etc.; intelligent competitive trading platform, Energy routers, two-way smart metering devices, etc. make up the control layer; photovoltaic power generation, wind power/heat, gas

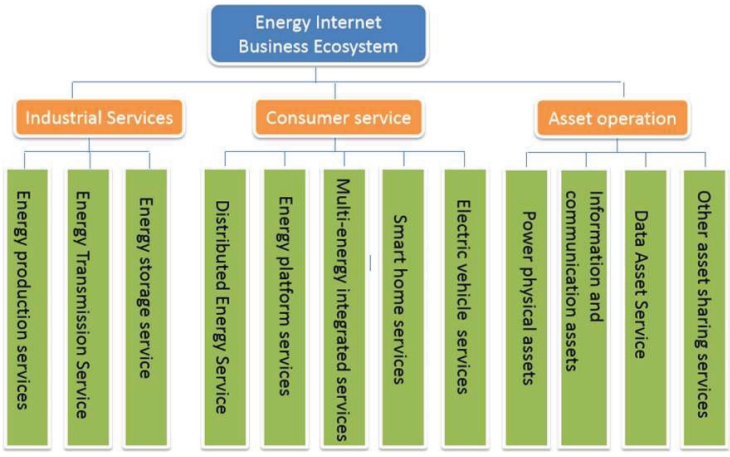

Figure 3 Characteristics of energy internet business model.

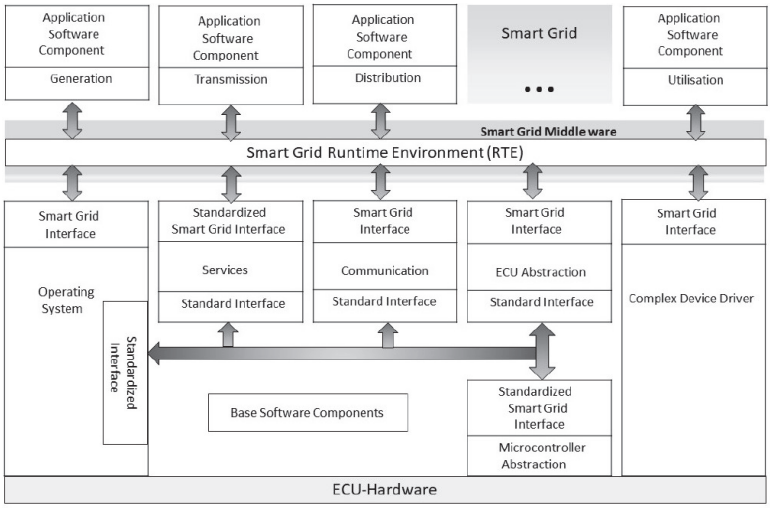

Figure 4 Innovative energy power energy microgrid composition structure.

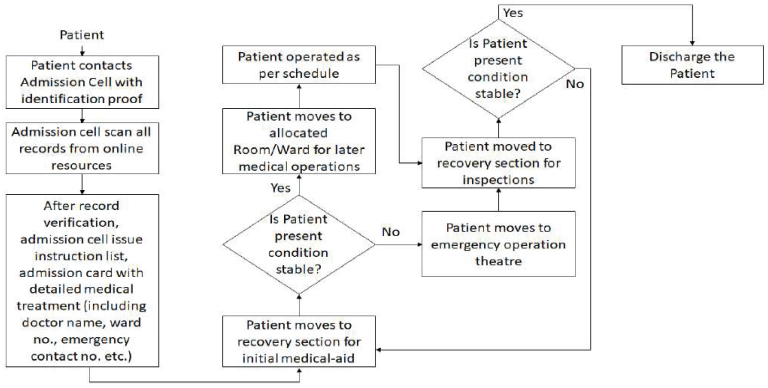

Figure 5 Blockchain-based intelligent energy competitive energy use flowchart.

turbine power plants, biomass power generation, ground/water source heat pumps, etc., make up the energy supply layer.

All transaction subjects have an equal status in the blockchain system and are connected and interacted in a flat topology [9]. Trading energy includes cold, heat, electricity, gas, etc., and is allocated after bidding through energy routers and competitive trading platforms. Figure 5 shows the competitive energy use process within the power energy microgrid.

(1) Construct smart transaction contracts between entities, including energy supply contracts, energy use contracts, storage contracts, clearing

methods, payment contracts, etc. The intelligent trading platform is initialized, defining the successful transaction counter intnum1=0, the failed transaction counter intnum2=0, intnum3=0, intnum4=0, the array numbers of the two parties to the successful transaction supply_suuccess1, consumer_success1, the fixed price of the energy pool double fixed_ price = 0.43 (expressly subject to the local electricity price).

(2) The trading platform receives the energy and price data sent by the energy supply and energy users and publishes them to the outside world [10]. The energy supply array is composed of the number supply_id, the energy supply price supply_price, and the supply quantity supply_output; the energy use array is composed of the number Consisting of consumer_id, energy pricing consumer_price, and demand consumer_consumption; the supplied array of the energy supply body and the consumer array of the energy consumption body are assigned an initial value of -1.

(3) In the first scenario, individual energy supply and energy users use the platform to bid on individual energy. Successful transactions need to meet the following two conditions: maximizing energy supply economic benefit $BS_{\max}$ and minimizing energy cost $BC_{\min}$. The supply is greater than or equal to demand (supply_output $\geq$ consumer_consumption). The bidding principles in this scenario are:

   (a) The energy supply quantity of energy supply individual $S_1, S_2, S_3 \ldots$ is $S_1, S_2, S_3 \ldots$, and the price is $P_{S_1}, P_{S_2}, P_{S_3} \ldots$; the energy consumption quantity of energy supply individual $P_{S_1}, P_{S_2}, P_{S_3} \ldots$ is $P_{S_1}, P_{S_2}, P_{S_3} \ldots$, and the energy price is $P_{S_1}, P_{S_2}, P_{S_3} \ldots$.

   (b) Trading principles of energy supply individuals:

$$\begin{cases} N_{s_x} \geq N_{c_n} + N_{c_m} + N_{c_k} + \cdots \\ B_{S\max} = \max(N_{c_n} P_{c_n} + N_{c_m} P_{c_m} + N_{c_k} P_{c_k} \cdots) \end{cases} \tag{1}$$

   When the energy supply satisfies the condition (3) and $B_{S\max}$ is the largest, the system will sort the energy-consuming individuals $C_n, C_m, C_k \ldots$ according to the ranking value=max (energy use quantity $NC_x \times$ energy use price PC_x) from high to low. Subsequently, the energy supply individual S_x sends tradable signals to the energy-consuming individuals according to the order and conducts transactions according to the principle of the first order transaction.

(c) Trading principles of energy-using individuals:

$$\begin{cases} N_{C_x} \geq N_{S_q} + N_{S_w} + N_{S_e} + \cdots \\ B_{C\min} = \min(N_{S_q} P_{S_n} + N_{s_w} P_{s_w} + N_{s_e} P_{s_e} \cdots\cdots) \end{cases} \tag{2}$$

When the energy consumption satisfies the condition (3) and $B_{C\min}$ is the smallest, the system sorts energy supply individuals $S_q, S_w, S_e \ldots$ according to the sort value = min (energy supply quantity $NS_x\times$ energy supply price PS_x) from low to high. Subsequently, the energy-consuming individual E sends tradable signals to the energy-consuming individuals according to the order and conducts transactions following the highest priority transaction principle. After the energy supply and energy users reach an agreement, they will conduct peer-to-peer transactions [11]. The system writes the energy supply and energy users who successfully traded into the energy supply transaction array suppy_suuccess1 and the energy transaction array consumer_success1. After multiple cycles, the unsuccessful traded idle energy is integrated into the energy pool at a fixed price, and the number of the energy supply body array is removed. The number of the energy supply body that has not completed the transaction is written into the energy pool energy supply array supply_id_pool. In this scenario, platform companies charge specific commissions to energy supply and energy-consuming companies and increase or decrease transaction commissions to encourage bidding based on the transaction's priority.

(4) In the second scenario, the energy users and the platform bid on the platform energy pool or energy storage energy. The bidding principle in this scenario:

(a) Energy-consuming individual $C_1, C_2, C_3 \ldots$ sends bidding data to the platform, and its energy consumption is $P_{C_1}, P_{C_2}, P_{C_3} \ldots$, and the energy price is $P_{C_1}, P_{C_2}, P_{C_3} \ldots$; the energy number provided by the platform energy pool or energy storage device is $P_{C_1}, P_{C_2}, P_{C_3} \ldots$, and its quantity is $N_{O_1}, N_{O_2}, N_{O_3} \ldots$, the price is $P_{O_1}, P_{O_2}, P_{O_3} \ldots$.

(b) Transaction principles between energy-consuming individuals and the platform:

$$\begin{cases} N_{C_x} \geq N_{O_d} + N_{O_f} + N_{O_g} + \cdots \\ B_{C\min} = \min(N_{O_d} P_{O_d} + N_{O_f} P_{O_f} + N_{O_g} P_{O_g} \cdots) \end{cases} \tag{3}$$

If the condition (5) is met and $B_{C\min}$ is the smallest, the system will proceed to the individual O_d, O_f, O_g in the platform energy pool or energy storage device according to the sort value = min (energy supply quantity $NO_x\times$ energy supply price PO_x) from low to high sort, and perform transactions in order according to the sort.
After a successful transaction, the remaining energy consumption array number is the energy-consuming subject of the uncompleted transaction, written into the remaining energy consumption array consumer_ id_rest. The energy supply number of the completed transaction is written into the energy pool transaction array. When there are multiple (or single) energy suppliers and energy users, transactions are conducted on the principle of cost minimization [12]. The calculation cycle t for the platform to perform statistics, feedback, and judgment is tentatively set to 30s. After each transaction is completed, real-time judgments will be performed again. The income from the transaction between the energy-consuming individual and the platform belongs to the platform enterprise.

(5) All transaction data is packaged and stored in the data block, plus the digital fingerprint generated by the hash calculation (SHA-256) and the transaction timestamp to form a data block. All data blocks are arranged in a sequential relationship to form a chain. Storage in the system [13]. The innovative energy competitive energy use business model based on blockchain technology restores the commodity and financial attributes of energy, establishes a competitive, open, and orderly energy supply and energy market, and uses multi-party bidding for cold, heat, and electricity Optimized allocation of other resources, to achieve a state of competitive supply and demand balance, can significantly improve the energy efficiency and benefits of the power energy microgrid.

6 Conclusion

Blockchain technology, which is still in the exploratory stage, will lead to a new round of technological revolution in the energy sector due to its significant advantages such as decentralization, distributed decision-making, transparent performance, and intelligent settlement. Blockchain technology + energy Internet can solve the core problems that restrict the development of distributed energy. It is an essential innovation in the business model of distributed trading. It will inject new vitality into the future development of Chinese carbon trading, microgrid, intelligent energy and other industries. It

will also play a huge role in promoting the smart energy industry's ecological and institutional reconstruction.

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Biography

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