The Energy Blockchain Establishing Policy Exploration Based on Microgird Routing Network

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Abstract: in order to enhancing the operation efficiency of energy internet, and develop the function and value space, it proposes an energy Blockchain of router network by applying the Blockchain to the energy internet. Concretely, a complex is a router’s storage of energy internet with a distributed storage of Blockchain, it establishes the physical bases of energy Blockchain under the structure of router network. Furthermore, by divided the operation information of energy internet into technical data and business data, it gives the operation process, and realize the generation and management of alliance linkage. Finally, Applying the energy Blockchain to energy management, comparatively analyzed these positive change and application value by Blockchain technology.

1. Introduction
The thriving energy Internet has attracted a great many researchers in the field of energy and information to continuously study its theory and application. Despite slight difference in understandings of it among specialists in different fields, generally speaking it is a new energy network that dramatically transforms energy supply, transmission, transaction and consumption through integration of Internet and energy technologies, in particular renewables, so as to make energy consumption decentralized, green and low-carbon, value-driven, and democratic [1]. Its presence benefits from further progress of energy technology, and will in turn serve as a catalyst for change in energy market system and stimulate people to accept the new ideas of green, low carbon, efficiency and sharing in energy supply [2].

Advanced technologies, including information and communications, computing, data processing, and artificial intelligence (AI), are enhanced thanks to the great strides having been made by the basics of information technology, especially big data, which lays a solid technological foundation for the operation of energy system and indirectly accelerates changes of energy supply and consumption modes [3]. Among the exploration of energy Internet is a typical example called the “Future Renewable Electric Energy Delivery and Management (FREEDM) system”, a project funded by the National Science Foundation (NSF) and initiated in 2008 [1,4], which studies the so-called energy Internet, a new grid network constructed on the basis of renewably generated power and distributed energy storage devices. Zha Yabing et al. proposed six major technologies pertaining to large-scale application of renewables to energy Internet, namely technology of advanced energy storage, solid state transformers, intelligent energy management, intelligent fault management, reliable and secure communications, and system planning and analysis [5]. Sun Hongbin et al. pointed out that energy Internet from the perspective of
of its essential features and architectural characteristics was a new generation of energy system integrating energy and Internet technologies, and considered openness as its foremost philosophy and integration of Internet thinking and technologies as its critical feature [6]. Dong et al. indicated from fossil fuel perspective that the development of Internet and new energy technologies were engendering the third industrial revolution, of which energy Internet ranked as a core technology, analyzed its development goals from the point of renewables, Internet, and energy utilization modes, and pictured its prospects [7]. Sun et al. demonstrated the interaction between information and physics during operation of energy Internet using a tailored model in an attempt to analyze concrete issues in such Internet including the difference between information and physical systems [8].

The above-mentioned research covers architectural characteristics, definition, operation and key technologies of energy Internet at the macroscopic level. Among its components and technological systems are energy routers, a distinctive part that can not only manage local energy but meanwhile can be used to construct energy Internet [9,10]. American scientists proposed the idea of energy routers as early as 2008 [1,11], while in the same year a research team from the Swiss Federal Institute of Technology developed “energy hub” [12,13], which derived from the concept of concentrator in computer science and was also called energy control center. Afterwards in 2013 Japanese scientists presented the concept of “electric router” and produced digital grid routers that can comprehensively manage electricity within a certain area and dispatch local electricity through electric routers [14]. Some of Chinese scientists have also made great efforts to explore prototypes and networking mechanisms of energy routers [15-17].

Blockchain is a decentralized, distributed, and peer-to-peer reliable network that underlies digital cryptocurrencies represented by Bitcoin [18]. It is highly transparent, trust-free, collectively maintained (tamper-proof) and anonymous, with the aid of which transaction, coordination and collaboration between nodes are realized in a distributed system through data encryption, timestamp, distributed consensus and economic incentives, which proves an effective solution to resolve common problems in central authority, including high cost, low efficiency, and insecure data storage [19,20]. Although blockchain technology has not yet been largely applied to energy Internet, quite a few experts have conducted research on its technical framework and application method in an attempt to articulate its research framework, typical techniques, prospects and values [21,22].

Appropriate implementation method and technical path are required for such technology to be applied to energy Internet. For instance, construction of distributed storage network based on blockchain, and the acquisition, analysis, processing and mining of operating data in energy Internet remain urgent issues currently. In consequence, this paper analyzes characteristics of energy Internet and blockchain technology and explores how such technology can be applied. Approach to constructing energy blockchain is discussed on the basis of energy routing network that is integrated with blockchain technology by utilizing its existing physical architecture.

2. Constraints for Application of Blockchain to Energy Internet
Blockchain appears so adaptable that it can be utilized when energy Internet has its architecture designed or starts to operate. Nevertheless, how to apply it and what functions it is suitable for remain to be pinpointed during specific design. Therefore, constraints for application of blockchain to energy Internet are analyzed firstly from physical and functional layers.

Energy Internet, which develops according to its own principles, is bound to undergo four stages chronologically from interconnected microgrids to city-level, national and global connection, suggests a study conducted by the Energy Research Institute of State Grid Corporation of China. Blockchain technology currently is at the first stage that will persist for a long period of time. For that reason, constraints on physical space and functions are put in the first place to be discussed when blockchain is applied to energy Internet.

The two technologies are possible to be deeply integrated within local energy Internet not only in decision making, data storage and processing, but in intelligent operation that can minimize human interference in converged systems. Nevertheless, blockchain technology has different application
objects in wide area connection above city level. First of all, higher level of energy Internet causes blockchain network to shift to the higher level of wide area correspondingly, at which distributed storage capacity increases, data categories vary, and operation demand of energy Internet changes. For instance, diversified customer needs at microgrid level remain to be satisfied by blockchain, while the decrease in participants at wide area level leads to less objects that need energy management. Additionally, functions vary. At microgrid level, operation demands are so diverse that blockchain and energy Internet technologies have to be designed and operate as automatically as possible so as to eliminate uncertainties arising from excessive human involvement in system. Therefore, blockchain technology is adopted in the whole process from data acquisition, to analysis and decision making, and to automatic execution in microgrid system. Conversely, at wide area level, participants decrease, while data size in a single decision and energy capacity during a single operation increase, which enables participants to attach greater importance to factors influencing their interests, such as price and transaction, rather than technology itself. As a result, humans carry out more interventions in managing operation of system, leaving blockchain technology fully involved in data acquisition, analysis and decision making but dispensable in automatic execution. Table 1 presents some constraints on data and functions.

Table 1 Application constraints for Blockchain

| data constraints                                      | functional constraints                                      |
|------------------------------------------------------|------------------------------------------------------------|
| energy interconnected microgrids                     | various kinds of data, all-round and full application       |
|                                                      | diverse operation demands, full                            |
|                                                      | involvement in operation                                   |
| wide area energy interconnection                     | large distributed storage capacity, large volumes of data   |
|                                                      | a relatively small number of operation demands, emphasis on |
|                                                      | data analysis, dispensable at executive level              |

3.Construction of Blockchain System Based on Router Network

Energy router, a converged device or system of information and energy that evolves out of the architecture of energy Internet, normally has a local data center used for data storage and processing. Distributed storage is characteristic of blockchain, thanks to which a feasible approach is available for it to integrate with energy Internet by taking energy router and network as physical infrastructures.

3.1. Functionality of router nodes

The integration is analyzed from the two perspectives of local and wide area energy routing network in the following.

A typical example of the first perspective is energy interconnected microgrids based on routing network, which is as shown in Figure 1.

![Fig.1 Energy internet based on routing network](image)

Each router can manage energy within its area and has its processing data stored in a data center.
which can be considered as a storage node of blockchain network, allowing new information generated when blockchain technology is applied to energy Internet to be stored. This center can also follow the technical standards of blockchain technology to operate and get managed. In doing so, all the data centers possessed by routers constitute a distributed storage network for the blockchain.

Energy router and blockchain storage network are the same physical entity despite their difference in concrete storage location. Data can be retrieved as required during energy exchange and management.

In contrast, in wide area energy routing network, local one is regarded as a whole and has all its information contained in a larger data center specifically designed. This larger center constitutes higher level routing and blockchain storage network with the same networking structure as that of local area network.

3.2 Analysis of blockchain performance

Blockchain, which has its own characteristics in data storage and application, complies with the requirements of Internet operation when applied to energy Internet to perform data acquisition, management and application. Table 2 analyzes the adaptability of blockchain’s technical characteristics.

| Performance characteristics | Applicability | Features or paths |
|-----------------------------|---------------|-------------------|
| Decentralized and distributed storage | Applicable | Reusing router storage as blockchain storage |
| Transparent and tamper-proof information | Selectively applicable | Set up by operation center |
| Trust free | Applicable | Trust-free technical data |
| Traceability | Applicable | Authorization-based tracing |
| Anonymity | Selectively applicable | Determined by each entity with different rights |
| Openness | Selectively applicable | Determined by each entity with different rights |
| Autonomy | Applicable | Set up by operation center |
| Shareability | Selectively applicable | Set up by operation center |

It follows from Table 2 that the various performances of blockchain are partially applicable to scenarios of energy Internet. Normally technical data of Internet are largely open and sharing, while information pertaining to business transactions is shared with reservations. Each participant of energy Internet is also allowed to independently determine whether or not to access his or her own information to blockchain data network. Despite that, their rights gained in certain network are of dependence on openness of access. Operators of energy Internet, who take a leading role in the application of blockchain technology, shall set up each function technically.

3.3 Energy blockchain in the architecture of routing network

Distributed storage space, data acquisition and processing serve as the cornerstone of blockchain technology. When applied to energy Internet, it can reuse the storage space of and impose its own rules of data management on energy routers, of which each storage space assembles and forms the distributed one for blockchain network. Descriptions of energy blockchain in the architecture of routing network are presented on that basis.

In this condition, energy blockchain refers to a chain database that connects energy Internet’s
operating data chronologically using cryptography with storage space of energy router network as a physical carrier.

It possesses the following characteristics:

1) Energy routers can not only manage energy but also process blockchain data.
2) Each router serves as one of the data storage nodes and accesses data from local storage when performing energy management within its range.
3) All technical data in network are automatically recorded and updated by a router within its range, while business and transaction data are input and updated by participants through transaction platform.
4) The quantity of distributed storage is in consistent with the number of energy routers.
5) When operation center executes energy management to compensate for the insufficient management capability shown by any of energy router, data will be acquired from the data center in transaction platform. Any of transaction business initiated relies on operation center to decide its execution attribute.
6) Energy blockchain is essentially among consortium blockchains.

Given the above-mentioned characteristics, operation structure of energy blockchain based on router network is as shown in the following:

Figure 2 displays operation process of energy blockchain from the perspective of data management in routing network. Diagram 2 (a) presents acquisition of data which are divided into technical and
business ones based on whether participants need to make subjective decisions. It can be seen that technical data are directly acquired and managed by routers they belong to, whereas business data are managed by data center of the platform. Diagram 2 (b) shows the formation of energy blockchain and demonstrates it is the platform that initiates energy management and decides which router is allowed to execute.

3.4 *Energy blockchain values in practice*

Energy blockchain can be widely applied to energy Internet. Table 3 presents some of its typical application scenarios with interconnected microgrids as an example.

| Typical Scenarios       | Energy Internet                                | Energy Blockchain                                      |
|------------------------|------------------------------------------------|--------------------------------------------------------|
| Carbon emissions trading | based on power generation resources            | based on mixed management of power generation/load      |
| Energy routers          | local energy management                        | improvement of decision/accuracy                        |
| Value delivery          | bidirectional delivery/multiple modes          | expansion of value space                               |
| Data security           | restricted access/non-unique identifier         | with consortium blockchain as a basis/tamper proof      |
| Electric automobiles    | charging network/wireless charging             | smart contracts                                        |
| Demand side response (DSR) | with microgrids as the main part              | intelligence upgrade                                   |
| Energy exchange         | executed by operation platform                 | smart contracts/Bitcoin                                 |
| Virtual power plants    | executed by operation platform                 | smart contracts                                        |

Energy blockchain based on routing network has some noticeable advantages, for instance: storage and existing communication infrastructures can be reused; a larger number of data and decision bases from consortium blockchain are accessible to each router and operation platform, which contributes to the improvement of decision efficiency and optimization of decision scheme; big data of consortium blockchain are favorable to facilitate wider application of artificial intelligence (AI) and other advanced technologies, and to help energy Internet expand its services into the territory of information security and energy finance apart from energy supply.

It also has some limitations, for instance: for microgrids that are composed of routing network, the numerous varieties of data, short period of iterative updates, and apparent randomness of business requirements leave data management extremely complicated.

4. Example of Application Scenario of Energy Blockchain

Figure 3 shows structure of a single energy router, and a routing network composed of several routers. The difference made by energy blockchain is analyzed based on such network.
In this figure the external power grid operates on 380-volt AC. All the access devices of routers and routing network, which contain renewable power station and loads of energy consumption, are connected through standard interfaces to busbar of the energy router that operates on low voltage DC. Energy storage utilizes intelligent devices able to regulate peak-valley difference, store electricity, and help DC busbars adjust voltage sags, flickers, and power unbalance.

4.1 Data changes and corresponding effects
Take energy routers and network in Figure 3, Table 4 presents specifics of data acquisition while the system is running, and some data characteristics when blockchain technology is applied.

| types                      | changes                                      |
|----------------------------|----------------------------------------------|
| rated power                | no change                                    |
| measured power             | higher accuracy resulting from data processing |
| the properties and number of devices accessed | no change                                    |
| technical data             |                                              |
|     data range of the single router | wider                                         |
|     sampling frequency     | no change                                    |
|     storage features       | traceable linked storage                      |
| power purchase (residents/factories/business/vehicles, etc.) | wider range of transaction information        |
Changes occur in both technical and business data due to application of blockchain technology. For one thing, increase in data type and size of the single router contributes to a higher accuracy of decision on energy management; for another, since data are traceable and subject to no time limitation, operation platform is enabled to deal with business more comprehensively and better tackle fluctuations in energy, information and financial demand.

4.2 Improvement of energy management performance
Blockchain imposes a positive influence on energy management performance and causes changes in management strategies. In Figure 3 (b), under the circumstance that a power supply is out of service due to any breakdown, the energy router without using blockchain technology will force the load with the closest power value to exit and have it accessed to another adjacent router so as to address its own power unbalance, which, nevertheless, reoccurs in this adjacent router and requires iteration of the exact same operation, causing recurrence of power unbalance in surrounding routers. In contrast, router using blockchain technology, whose rich and accurate stored data makes it possible to access in time energy supply information in other routers, will continue its energy management decision by directly injecting the redundant power of grid busbar rather than forcing one load out. Such process avoids a series of switching operations and thus appear more user-friendly.

Under the circumstance that a load is out of service because of any breakdown, router without using blockchain normally force the power supply with the closest power value to quit and have it switched to another adjacent router, spreading power unbalance to this router. On the contrary, if blockchain has been used so that comprehensive information is available, a router will increase its power to meet the requirements of grid busbar without needing any switching.

Long period and multiple incidents are characteristic of power grid operation and dispatching. In this background simulation of multiple incidents is performed when a load gets out and in service if blockchain is not applied. Types of incidents and sequence are as shown in Table 5, and switching of access devices is as shown in Figure 4.

### Table 5 Switching incident and sequence

| Sequence | Types of incidents |
|----------|--------------------|
| 4        | access a new load to energy router 1 |
| 10       | access a new load to energy router 2 |
| 20       | sequence 4 withdraw the accessed load from energy router 1 |
| 29       | access a new load to energy router 1 |
| 38       | withdraw a certain load from energy router 2 |
The second waveform in Figure 4 is of relevance to switching and power regulation of energy router 2, which will no longer occur in energy blockchain. Insufficient or excessive power is regulated by power grid or energy storage in compliance with the decision made by controller based on big data, or has its loads increased or decreased in line with demand side response. In doing so, original passive power regulation in accordance with physical attributes of energy devices is shifted to positive regulation on the basis of big data and demand side response, of which blockchain technology serves as a cornerstone. Accordingly, power balance stability and energy management performance of routing network will be optimized.

4.3 Improvement of power quality

Energy Internet, a new generation of energy supply network with information and energy deeply integrated, poses stricter requirements of power quality. Unified power quality conditioner (UPQC) and others functioning identically appear substantially effective in addressing harmonic pollution and voltage sags. Traditionally harmonic detection and analysis entail complex algorithms that are time-consuming. The whole response process takes nearly 10 ms in total if additional time spent on control and decision-making algorithms and On/Off time of electric and electronic executive devices are counted. In the case of power frequency voltage at 50 Hz, voltage or current compensation is postponed for a half cycle, severely affecting power quality.

Since in energy blockchain historical data abound and test data of UPQC in different locations are shareable, big data-based detection methods and data-driven control strategies are fully applied, which significantly reduces time spent on detection and output of control commands. Take 150 MHz CPU as an example, a clock cycle lasts for about 6.67 ns. Even though detection and control algorithms consume 0.1 million cycle, the controller will output its commands in around 0.67 ms, which greatly shortens delay time of voltage compensation and contributes remarkably to the improvement of power quality.

5. Conclusion

This paper concentrates on the application of energy blockchain to energy interconnected microgrids and studies blockchain construction based on routing network. A type of energy blockchain architecture targeted for interconnected microgrids is presented based on analysis of constraints for blockchain and on design of technical approaches, before its values in practice are discussed from the three perspectives of energy management conducted by routers, networking performance
improvement and power quality. The construction and application of energy blockchain is a complex and systematic project that remains in the primary stage currently and requires continuous research on its theoretical methods and technical realization.

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