Blockchain-based Solution for Managing Renewable-based Microgrids

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I. Renewable-based microgrids: Key issues

Renewable-based microgrids are considered attractive options for redressing the challenges of energy access and climate change currently faced by the energy sectors worldwide. Their attractiveness becomes even greater in Asia-Pacific countries. In these cases, almost half a billion people still have no access to electricity - most of which live in isolated islands or remote villages that makes grid-extensions to these areas less cost-effective. Additional stimulus for renewable-based microgrids also come from significant oil price fluctuation in recent years, making diesel less attractive than renewables (particularly, wind and solar) for electricity generation.

Over the years, several renewable-based microgrid projects have been undertaken in various Asia-Pacific countries. Emerging outcomes from these projects have however been mixed, and some of them are reported to fall into an under-performing or even into a non-functional state far before the end of technical life [5]. While a myriad of factors (technical, financial, regulatory and social) is considered as responsible for these outcomes, low capacity utilisation, poor facility maintenance and repairs, and lack of community involvement and cooperation are three key such factors.

Microgrid

Microgrid refers to a localised group of distributed energy sources and interconnected loads. It may be either isolated from the main electric grid or connected to the main grid. Isolated microgrid, the main focus of this paper, is typically the case in islands or remote villages where promoting energy access to those areas through grid-extensions is widely considered as economically unviable.

II. Blockchain: A promising Solution

Blockchain exhibits the following four key properties that make it a promising solution for redressing the three issues noted in the previous section.

- Tokenisation that uses digital tokens to represent digital or physical assets in real world. These tokens are exchangeable, and any token exchange can be understood as a process of transferring the ownership of its underlying assets.
- A neutral distributed execution infrastructure for running programs known as Smart Contract. A smart contract codifies the conditions for energy transactions set by an energy producer or consumer. These conditions can be, for example, selling any excess generating capacity between 9:00 AM and 4:00 PM during weekdays. The smart contracts are executed by the blockchain network. The outcomes of the execution are stored on the public immutable data storage.
- A cryptographically secured trading facility through which transactions are authorised by the sender and verified by the blockchain network to avoid double-spending (i.e. every single token is spent no more than once). The verification process takes place across either the entire or a subset of the blockchain network, depending on the network's consensus protocol.
- A public ledger that stores all transactions that have ever occurred in the network. The data structure of the public ledger is an ordered list of blocks, where each block contains a small (possibly empty) list of transactions. Each block is 'chained' back to its previous block by adding a *hash* (i.e., a cryptographic representation of its previous block). Historical transactions cannot be deleted or altered without invalidating this chain of hashes. This can in practice prevent tampering of information stored in a blockchain.

Based on these properties, a blockchain-based data platform can be developed to enable automated (programmable) energy transactions through tokenisation and Smart Contract. This could unlock excess generating capacity in a renewable-based microgrid, contributing to lower unit-cost of electricity, better cost recovery, and improved facility maintenance and repairs. This could also instil a sense of ownership into local communities, as local users are getting directly involved in the management of the microgrids in the form of peer-to-peer energy exchange. In addition, a blockchain-based data platform could also provide tamper-proof record of operational data, transaction history, and customer requests of a microgrid, making effective monitoring and verification of electricity services possible, hence better maintenance and repairs.

Several blockchain-based data platforms have been developed to enable peer-to-peer electricity trading in microgrids [1], [2], [3], and some of these platforms (notably, Brooklyn Microgrid) have already been trialled in real life [4]. Most of these platforms have focused on the developed economies, particularly the United States and some major European countries, where electricity reform initiated in the early 1990s has already resulted in the establishment of competitive generation and retail segments, supported by well-established wholesale and retail market mechanisms (see, for example, [3]). In contrast, our proposed data platform tends to focus on the developing economies, where a considerable debate on the topic of establishing electricity markets has been witnessed, but actual progress is relatively insignificant (e.g., Bangladesh, and Indonesia). It is therefore plausible to argue that energy consumers in these economies would have little experience with electricity markets, and hence, limited knowledge and skills for conducting electricity transactions. In order to address this issue, our proposed data platform seeks to enable automated electricity transactions through tokenisation and Smart Contract. Details about this platform is discussed in the next section.

III. Our proposed blockchain-based solution

This section specifies our proposed blockchain-based solution (see Figure 1). This solution comprises two key elements: energy exchange facility, and data storage facility. Key features of these two components are presented in Table I. Details are discussed below.

A. Energy Exchange

The energy exchange facility uses digital tokens to represent electricity produced by various sources (such as, solar and biomass). It also enables the exchange of electricity tokens through Smart Contracts that facilitate automated (programmable) transactions based on arbitrary conditions set by the sellers and buyers. For example, a household with a rooftop solar PV installed may set the conditions as selling excess capacity at any prices higher than zero between 9:00 AM and 5:00 PM every workday. These conditions are checked and verified by all participant within a blockchain while the transactions are executed. Here, each transaction is first cryptographically signed by the transaction initiator, and then propagated to the whole network for verification. This process ensures that no electricity token is generated out of thin air, and every unit of electricity is only traded once.

We also incorporate a permission control layer into the energy exchange facility. This layer defines three modes of transaction management (namely, centralised, decentralised, and mixed), with a view to make our proposed solution applicable to microgrids with different ownership arrangements (energy provider-owned, consumer-owned, or mixed). Under the centralised mode, energy provider is made responsible for determining the transaction conditions. This mode is more appropriate for energy provider-owned microgrids. In contrast, the decentralised mode is more suitable for consumer-owned microgrids, where household consumers are responsible for making transaction conditions for their own rooftop solar PV capacity. The mixed mode is a combination of both centralised and decentralised modes.

B. Data storage

The data storage facility centres on a public ledger that provides tamper-proof record of operational data, transaction history, and customer requests of a microgrid. It also has a multi-signature mechanism that requires consent from all participants of interest for making changes to the recorded data. For example, a request for maintenance lodged by a customer is recorded in the data storage. A local contractor assigned to address this request cannot change its status to 'resolved' in the absence of consent from the customer. Thus, better incentives are given to local contractors to improve the quality of their services. Besides, data recorded in the storage also provides an audit trail of what has happened in the microgrid. This data is easily accessible by all network participants (including, the regulator), making effective monitoring and verification of electricity services possible.

C. Possible Extensions

Three extensions are possible in our proposed blockchain-based data platform. One, exchange of electricity for other resources (such as, clean water). This can be achieved by assigning digital tokens to these resources, and allowing exchange of electricity tokens for these resource tokens. How to determine the exchange rates between electricity and water tokens is however a challenging task. One possible solution for redressing this challenge is to fix the exchange rates based on regulation. The exchange rates could also be determined by market forces.

Two, energy exchange across inter-connected microgrids. Our proposed energy exchange facility supports energy exchange within a microgrid, which is the most common case for energy exchange in a microgrid [6]. It could also be extended to include energy exchange across various inter-connected microgrids. This extension could improve the competitiveness of energy markets, lowering energy prices. This extension however requires the existence of interconnection between various microgrids that may not always available due to factors, such as difficult topography, and lack of funds. Another issue associated with this extension is how to take network constraints into account. This issue can be overcome by, for example, introducing a cap on total energy exchange across various microgrids.

Three, facility for managing complex battery storage system. This system may comprise small-scale battery storage owned by individual household consumers as well as large-scale battery storage owned by large business and industry or local community. The incorporation of battery storage system into a microgrid can increase the flexibility of electricity demand, which could in turn improve the overall reliability of the microgrid. The availability of battery storage capacity may however pose significant challenge to this extension. One possible solution for redressing this challenge is to provide incentive for better maintenance of battery storage capacity.

IV. Conclusions

This paper has proposed a blockchain-based solution for redressing three key issues currently faced by renewable-

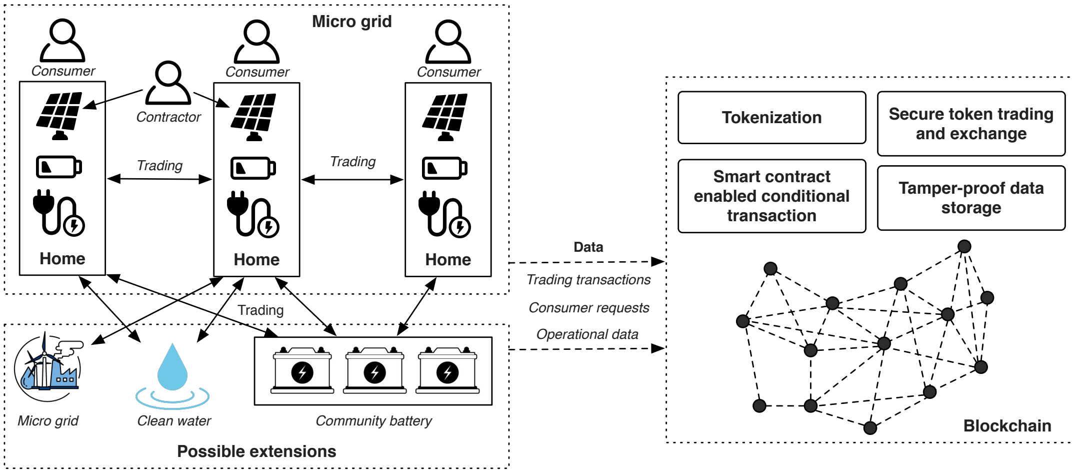

Fig. 1. Blockchain enabled renewable-based microgrid management.

TABLE I
BLOCKCHAIN ENABLED RENEWABLE-BASED MICROGRID MANAGEMENT.

	Blockchain enablers	Proposed solutions
Energy exchange	Tokenisation	Tokenization of energy and other resources
	Token trading and exchange	Electricity trading Electricity and resources trading
	Conditional transaction via smart contracts	Automated electricity transaction based on pre-determined conditions
Data storage	Blockchain-based public ledger	Multi-signature mechanisms for approving any requests to change the recorded data Tamper-proof record of operational and administrative data of a microgrid

based microgrids, namely, low capacity utilisation, poor facility maintenance, and lack of community involvement and cooperation. This solution seeks to encourage more effective use of existing generating capacity by enabling automated energy exchange through tokenisation and Smart Contracts. Enabling peer-to-peer energy exchange could also instil a sense of ownership into local communities, which is widely considered as essential for developing a microgrid with 'good' performance. In addition, our solution also provides tamper-proof record of operational and administrative data of a microgrid, making effective monitoring and verification of electricity services possible, and hence, better maintenance and repairs.

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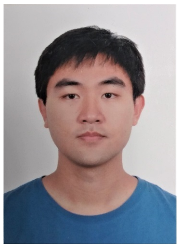

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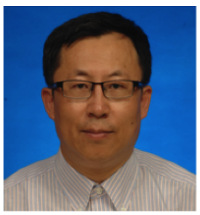

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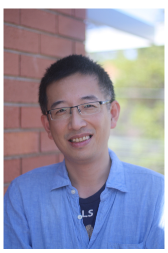

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