Demonstrating Blockchain-Enabled Peer-to-Peer Energy Trading and Sharing

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Abstract— **Blockchain (BC) is becoming a key technology in securing future businesses and economic competition around the world. It is seen as an enabler for trust and security in the growing sharing economy. In this study, we demonstrate the application of BC to energy peer-to-peer (P2P) trading in smart grid. A smart contract for managing trust and transactions is designed and implemented for a use case in energy P2P trading on IBM platform using hyperledger composer. In addition, current challenges that could be faced when implementing BC for securing energy P2P trading are investigated and discussed.**

I. INTRODUCTION

Blockchain (BC) is a disruptive technology based on cryptography to support real-time transaction management. As the name implies, BC involves a block of data (transaction) interlocked to the previous block in the chain. It is a type of distributed ledger (database) that comprises of immutable, digitally recorded data in a block stored linearly [1]. Each block in the BC registers a completed, time-stamped, and widely approved transaction. Further, each block contains a unique number, a unique hash function, and the hash function of the previous block it attaches to. Thus, providing a transaction that is safe and secure from unauthorized manipulation. BC transactions are recorded on a distributed ledger, where transaction confirmation is based on a consensus algorithm among the peers in the network, thereby eliminating the need of a central administrator prone to single point of failure.

In the recent years, the BC technology has found numerous applications in different sectors such as financial services, sharing economy, e-health systems and Internet of Things (IoT), leveraging increase in trust, reduction of operating costs and enhancing security [2], [3]. In today's smart cities, Peer-to-Peer (P2P) energy trading and sharing transforms the traditional centralized system to a highly distributed energy network where passive energy consumers are motivated to become active prosumers [4]. There are several challenges facing P2P energy trading and sharing [5]. One of the main challenge is the dynamic management of the communication and transaction among the diverse entities involved in the energy network, amongst real-time price fluctuations, dynamically adjusted power consumption plan, frequent electricity fees settlement, security and privacy [6], [7]. BC could play a vital role in the rapid changes of information and value in this system because of the following reasons[8]:

1) Different entities are involved in validating the integrity of information on the BC, thus providing a trusted system;
2) Communication among entities, retrieval and upload of information is simplified as the entities only interact with the BC network;
3) BC technology is distributed requiring no central administrator, this enables reduction of operational and deployment cost of critical infrastructure;
4) The lack of central entity eliminates single point of failure and Single Points of Compromise (SPoC) since end users can interact directly with the platform for information access;
5) End-user authentication and access control are examples of computationally-intensive operations performed on IoT devices including smart meters, these operations can be processed conveniently on the BC platform, relieving the overheads of the devices.

The aim of this paper is to demonstrate the capability of the benefits of BC applied in the smart contract for an energy trading platform. This is achieved by designing a smart trading contract that incorporates the different stakeholders preferences to create a win-win solution. We contribute the following:

1) Propose a prototype implementation of P2P energy trading with BC using hyperledger composer on IBM platform.
2) Design a smart contract using BC technology for P2P energy trading and sharing which enables further development of different use cases.
3) Provide some current challenges in implementing BC technology in power networks.

The rest of this paper is organised as follows. Section II reviews the application of BC to P2P energy trading. Section III discusses the proposed smart contract for energy trading in a sharing economy. Implementation results and challenges in implementing BC technology in power networks are discussed in Section IV. Finally, Section V draws conclusions and identifies potential future work directions.

II. BLOCKCHAIN APPLICATIONS TO ENERGY TRADING

The potential benefits of BC technology and distributed ledger has seen the rise in use in vertical industries including distributed energy trading and sharing. IOTA [9] is a distributed ledger platform that encompasses a generalization of the BC protocol (the Tangle) that resides at the backend of the IOTA platform. It provides an ecosystem based on blockless BC to enable machine-to-machine (M2M) transactions. The use of this platform with IoT devices, e.g., smart meter, allows energy companies and prosumers to adopt new business-to-business or prosumer-to-prosumer sharing models by making every energy resource a potential service to be traded on an open market in real time, with no fees.

In addition, a consortium BC technology is propose in [10] for security and privacy among Plug-in Hybrid Electric Vehicles (PHEVs) trading electricity in smart grids. [7] propose an energy blockchain for secure energy trading that exploit the consortium BC to reduce delay related transaction limitations of BC. [11] propose a BC based transaction settlement for trusted and secure settlement of electricity trading transactions. A privacy enhancing decentralized energy exchange system based on BC technology is proposed by [12] to allow anonymous energy exchange between prosumers without revealing their identities. The authors in [13] investigate and present a review on BC-based energy trading according to energy transaction, consensus mechanism and system optimization as well as identifying the challenges in optimizing the full potential of BC technology to energy networks.

Multilevel communication is prominent in energy consumption system, so privacy can be compromised at any level; data counterfeiting due to using IoT devices including smart meters and such as personal information leaking through block inquiry. The authors of [8] adopted BC to IoT-based trading platform to identify IoT devices and data through registration, storing, organising and sharing for the reliability of the system. The system ensures trust, but privacy remains an issue during identification. The authors of [14] address the issue of privacy leak during communication between different IoT devices in energy consumption system using zero knowledge proof for hiding account and data information. The zero knowledge proof ensure that verifier can only verify the legitimacy of the transacting party without revealing the content of the transaction. Further, the authors of [15] propose an off-chain data storage own and control by the user to ensure privacy of personal data on the BC.

III. Design Methodology for Energy Trading Smart Contracts

P2P energy trading and sharing network is viewed as a business network that trade energy as a commodity. A business network is composed of entities who work together to achieve a certain task. For different entities to agree on working together, there should be some set of rules governing their interactions relating to how and when to trade, who should be involved and how payment should be processed. In BC technology, the set of rules that govern a transaction is termed a smart contract, which is a digital agreement among the parties involved [1]. In this study, the methodology to design the smart contract for the P2P energy trading and sharing platform is described in the following subesctions.

A. IBM Hyperledger Blockchain Platform

The BC enabled P2P energy trading and sharing is implemented using hyperledger composer with IBM BC platform. The platform enables the creation of 'model files', that specify the assets to be exchanged in the network, the participants involved, the transaction logic (smart contract), and the events occurring in the network. In this case study, the asset is the energy in KWh, participants are the prosumers, consumers, and utility companies, whilst, an event is a notification received when the state of the BC changes.

B. Smart Contract for P2P Energy Trading and Sharing

The aim of the smart contract is to ensure that the requested type and amount of energy is transferred to the buyer and the seller gets the equivalent payment on time. Fig. 1 shows the interaction of different entities as energy trading clients [16] on the P2P trading platform.

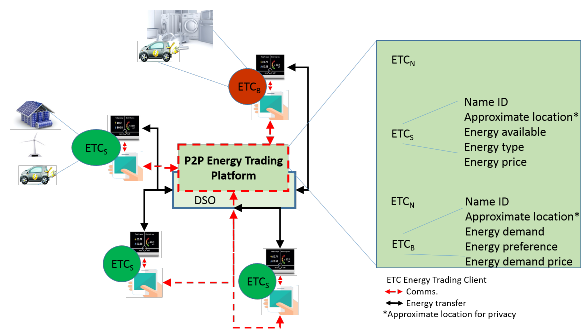

Fig. 1. A P2P energy trading platform showing interaction among the different entities.

Fig. 2 shows the components interaction on the proposed blockchain P2P energy trading platform.

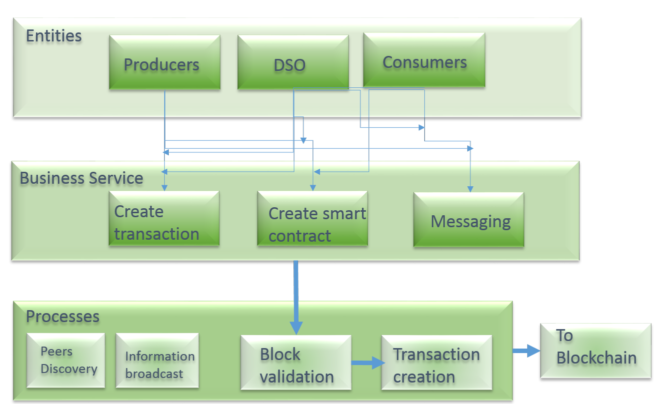

Fig. 2. Proposed Blockchain Enabled Energy Trading Component

It is imperative to define the role of each entity in the network for the smart contract.

1) Producers: The producers have three functions: To register basic information on the platform including the type of energy they are selling, the price and quantity available; they can update the quantity of energy available, offer/bid in the system; and finally, they can sell energy over a time interval or in real time, from storage, electric vehicle or direct from generators.

2) Consumers: The consumers also have three functions: To register their basic information on the platform including the type of energy they wanted; update their demand request; and buy an asset on the platform.

3) DSO: The function of the distribution system operators (DSO) or utility company is to complete the transaction between the buyer and the seller entity by transferring energy to the buying party after the payment has been confirmed by the selling party.

4) Access control: Access control for the business network limit who has access to what. For instance, the DSO can be seen as a trusted certified entity that have access to the profile of all the entities on the platform to aid its function (transfer of energy) in the network. In addition, a particular user can update the offer/bid on their profile, while other user can only see the details of the power available and choose to buy at the selling price. Fig. 3 shows an exemplar of access control declaration, that defines what resource and who can access the resource on the BC network.

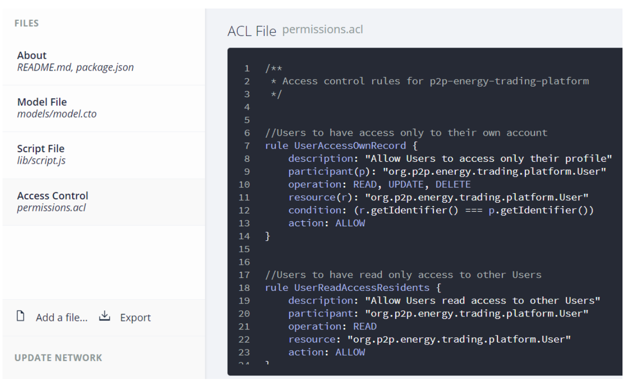

Fig. 3. The "model" interface showing the access control definition

The business service layer is required for the smart contract creation and it involves creating transactions and sending messages. The internal process layer involves discovery of the network by new peers joining the network; broadcast of information; block validation and creating new transaction block to be appended to the BC network.

IV. Use Case: Implementation and Result

We use the hyperledger composer on IBM platform [17] for implementing the use case. The transaction process is as follows:

1) Producer create a smart contract to sell $10KWh$ of a particular type of energy at $\$1/KWh$;
2) The consumer accepts the offer and signs the contract. Once the contract has been signed, it is unchangeable;
3) The consumer pays the producer based on the smart contract;
4) The smart contract is then forwarded to the DSO for verification. After verification, the DSO appends an ID and forwards the asset to the buyer based on what is on the signed contract. To aid in reducing carbon footprint, the energy supplied by the producer does not necessarily have to be the transferred energy to the consumer. It is recommended that the DSO accept the energy supplied from the producer and transfer the equivalent in its repository closest to the location of the consumer to the consumer;
5) The accounts of both producer and consumer are updated and the contract is terminated by the producer;
6) The completed transaction including the terminated smart contract is then appended to the BC network which remains immutable.

Fig. 4 shows the definition of the participants on the blockchain network, while Fig. 5 shows the addition of participants to the network.

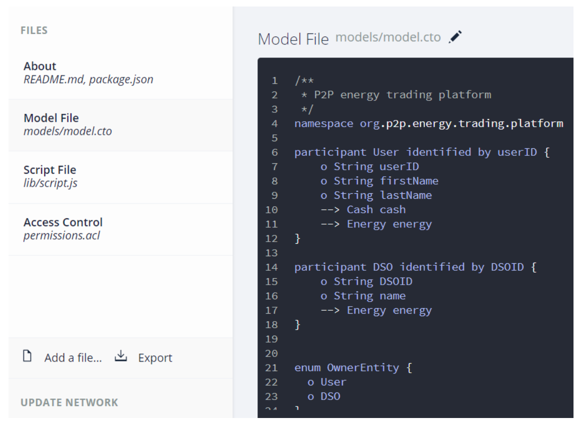

Fig. 4. The "model" interface showing the participants definition

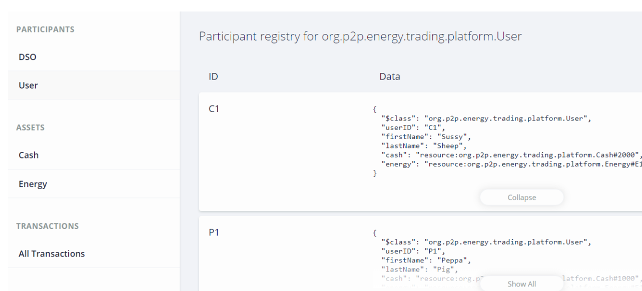

Fig. 5. The "test" panel showing the participants on the network

An updated profile after an energy transfer is demonstrated in Fig. 6. Fig. 7 shows all the network transaction updates, while Fig. 8 shows the completed transaction block created which will be appended to the previous blocks in the BC network.

The feasibility of a BC inspired P2P energy trading and sharing platform has been demonstrated. It offers convenience and choice to the users as they only interact through the platform and select their preferred energy choice and price. Moreover, since all new entrants to the market would be documented on the platform, it would increase the efficiency of the grid in managing the numerous distributed energy generation in terms of balancing the demand and supply. Furthermore, the utility grid will benefit from this

Fig. 6. Interface showing the asset update after a valid transaction

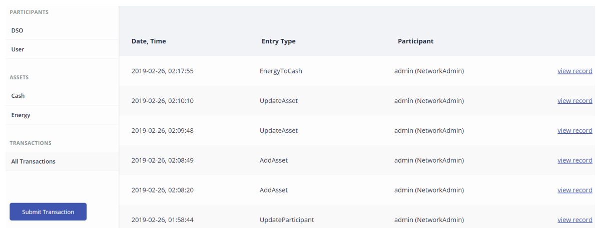

Fig. 7. Interface showing the network transaction update with timestamp

scheme as it helps to adjust peak-hour load and predict users behaviour more effectively. Current challenges in implementing BC in smart grid include designing BC architectures to meet government, industry and consumer objectives; identification and authentication of demand side response using IoT devices; and data privacy and governance in BC technology. For instance, utilizing BC in smart grid potentially means exposure of your energy generating capacity or consumption data to participants on the network, resulting in personal data leakage.

V. Conclusion and Future Outlook

In this study, we have demonstrated the feasibility of implementing BC technology in P2P energy trading and sharing over the hyperledger composer on IBM platform. The BC technology has potential in securing transaction management in smart grid network. It offers a decentralized system with reduced operational cost, complete transparency and trust. This is an ongoing research into adoption of BC technology to P2P energy trading and sharing, thus our future work will be to extend the presented model to allow real time transaction among participants and to incorporate hardware devices (e.g. smart meter) for real data capturing.

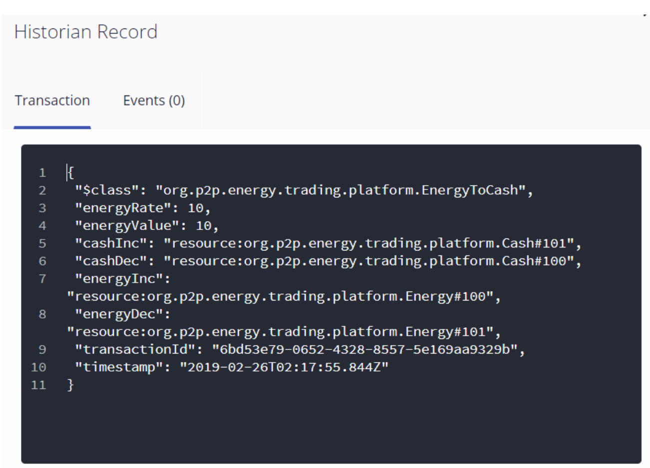

Fig. 8. The transaction block showing the transaction ID and timestamp

Acknowledgment

This research has been carried out within the Peer-to-Peer Energy Trading and Sharing (Multi-times, Multi-scales, Multi-qualities) project funded by EPSRC (EP/N03466X/1).

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