Peer-to-Peer Energy Trading based-on Blockchain Technology

Mr. Sanyapon Chanpasertsak
Innovation Division, Provincial Electricity Authority, sanyapon.cha@pea.co.th

Abstract

Over the past decades, the rise in distributed generators has led to the change in characteristic of power system. Consequently, consumer could play a new role as "prosumer" and also engage in local peer-to-peer (P2P) energy trading. As blockchain is deployed in many applications, energy trading application becomes one of the applications that researchers are interested in. While there are various fields to study in energy trading, however the details in platform design and implementation are absent in most of the studies. This paper presents guideline to design and implement the blockchain-based energy trading system by applying an open-source blockchain platform "Hyperledger Composer". The descriptions of network architecture, components and smart contracts in the network are provided in detail. Moreover, two case studies for platform integration and system performance testing are carried out. The outcomes prove that energy trading network works correctly according to the defined rules, and the capability of the proposed network is demonstrated by testing query and create operations.

KEY WORDS: Blockchain, Hyperledger Composer, P2P energy trading

1. INTRODUCTION

During the past decades, the increasing number in distributed energy generators (DEGs) has gradually converted the characteristic of power systems. The large fossil-fuel power plants are taken place by small-unit DEGs, thereby transforming the traditional centralized property of the power network to decentralized one. The installation of DEGs at premises encourages the deployment of P2P energy trading among energy users. The traditional consumers thus play a new role as prosumers. As blockchain technology has publicly emerged in the form of Bitcoin in 2008, it draws high attention and becomes one of the advantageous technologies that is applied in various industries (like economy, health or energy management) [1]. According to [1], blockchain could be deployed in many applications including energy management. Most researchers work on topics, such as enhancement of grid security and meter transparency, electric vehicle and grid management, as well as P2P energy trading.

The authors in [2] categorized challenges in P2P energy trading to four different aspects, which they are economics, social domain, regulatory and technical aspect. In terms of technical aspect, most researchers study the implementation of P2P energy trading platform by applying the open-source blockchain tools. In terms of economic aspect, some researchers are interested in the price and market mechanisms. The market mechanism provides rules and market share, it also defines the bidding strategies and languages in the trading process. The price mechanism explains the appropriate algorithm of business for dynamic pricing, so that market can maximize the benefits in the energy trading system. Furthermore, there are other challenges that are described in [3], for example, the scalability and performance in blockchain, the processing time of network, the common standard of interoperability, the energy consumption issue and regulation about blockchain technology in some countries.

It can be noticed that there are various types of research in the P2P energy trading. However, it seems that the implementation of blockchain-based platform is the most attractive topic because it is principle before building the real network, also much research still lacks the detail in network design and implementation. Thus, aim of this paper is to design and implement blockchain-based P2P energy trading platform by providing instructions in detail. Also, simulation of two case studies will be conducted by making electricity exchange and testing the system performance. Overall, this paper could be presented as a guidance for those who are interested in design and implementation of platform for P2P electricity trading.

2. REVIEW OF BLOCKCHAIN TECHNOLOGY

This review aims to examine characteristics of open-source blockchain platforms usually used in other studies and discuss different aspects between them in detail (Hyperledger and Ethereum).

2.1 Hyperledger

Hyperledger is explained as the open-source cooperative that intend to develop the blockchain technology sector. It is hosted by the Linux Foundation and leader organizations in other fields such as finance, supply chain, Internet of Things or energy sector. In the characteristics of Hyperledger, it supports the consortium blockchain with the various level of permissions.

There are some previous researches applying Hyperledger, for instance, the authors in [4] built laboratory for solar energy exchange based on Hyperledger Composer. The design of essential elements (e.g. smart contract, participant, asset and transaction) are well described. The results of simulation showed that proposed platform worked successfully according to the defined smart contract. The conceptual architecture for [4] was proposed in [5], it provided the guideline for the implementation of solar energy exchange platform. These two studies are effectively presented about the design, implementation and outcomes, however more details in the components can be added for more complete network.

2.2 Ethereum

Ethereum is the public open-source blockchain platforms for developing and deploying the decentralized applications, similar to Hyperledger. However, some characteristics are different from Hyperledger. For example, Ethereum has its own cryptocurrency called Ether. Ethereum is permissionless blockchain platform which relies on a lot of nodes around the world.

There are some previous researches applying the Ethereum in their works, for instance, the authors in [6] proposed energy trading platform based on Ethereum, and also presented the trading simulation in the blockchain-based network. Moreover, "ERC20" cryptocurrency was created for using in this network [7]. In [6] and [7], the piece of computer code is presented well however, they still lack more descriptions of the experiment and construction.

2.3 The comparison of open-source blockchain platforms (Hyperledger and Ethereum)

Before starting the implementation, the P2P energy trading network, the suitable open-source blockchain platform has to be selected first. More detail of these two open-source platforms are further investigated.

Table 1. Hyperledger vs. Ethereum

Characteristics	Hyperledger	Ethereum
Founder	Linux foundation, IBM	Enterprise Ethereum alliance
Purpose	B2B business	B2C business or generalized application
Confidentiality	Confidential transactions	Transparent
Mode of peer participation	Permissioned network	Permissionless network
Consensus mechanism	PBFT	Proof of Work (PoW)
Cryptocurrency	None	Ether (ETH)
Smart contract	Chaincode	Solidity

According to the TABLE 1, it can be noticed that basically the differences between both platforms are network characteristics, programming languages and cryptocurrency. For this study, Hyperledger seems to be more suitable than Ethereum as it aims to be a permissioned network, and the cryptocurrency is unnecessary. Moreover, Hyperledger offers the open development toolset and framework called "Hyperledger Composer" that makes developing blockchain applications easier for new beginners [8]. Therefore, the open-source Hyperledger Composer will be mainly applied in this research.

3. THE DESIGN AND IMPLEMENTATION OF PROPOSED ENERGY TRADING NETWORK

The proposed blockchain platform is designed to support the P2P electricity trading among different kinds of people or organizations in the network. There are three parts to be proposed in this chapter.

3.1 Architecture of Hyperledger Composer

Hyperledger Composer is an open-source blockchain platform which it aims to reduce time of blockchain network implementation, by offering simple development toolset and framework for users [9]. A laptop running macOS Catalina operating system is selected for this study.

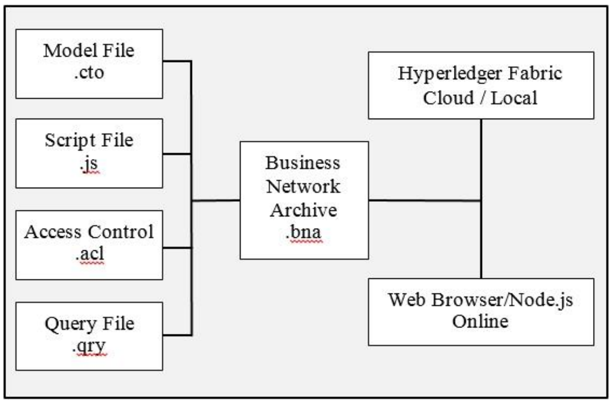

Figure 1. Structure of Hyperledger Composer

Hyperledger Composer allows users to quickly model the business network, by creating the set of files, packaging them up and deploying the business network [10]. The structure of the Hyperledger Composer is depicted in Figure 1.

- Model file (".cto"): this file is used to define the participant, asset and transaction in the network.
- Script file (".js"): this file is used to define the business logic of the transaction.
- Access control (".acl"): is used to define rules and permissions of each type of participant in the business network.
- Query file (".qry"): is used to filter the results in the business network.
- Business network archive (".bna"): packages up the business network definition for deploying.

3.2 Components in the proposed network

Generally, there are three components in the proposed network which they are participant, asset and transaction. In this designed network, generation companies, utility companies and residents could exchange their energy and coins with each other, except generation company and resident. They cannot trade energy directly to each other. Additionally, they can record the energy generation and consumption. Sample of the network is shown in Figure 2.

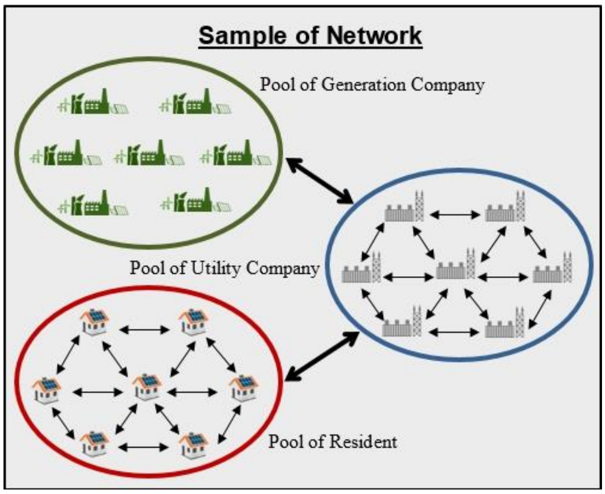

Figure 2. Sample of proposed blockchain network

3.2.1 Participant

In this study, GenerationCompany, UtilityCompany and Resident are created as the participants. These participants act like the people or organizations in the network, who can generate electricity, trade energy and record the energy consumption. These all participants own properties such as coins, energy, generation and consumption which they have relations to the other assets in the proposed network. The properties of each participant are presented in Table 2.

Table 2. Property of each participant

GenerationCompany	UtilityCompany	Resident
■companyID ■name ■coins ■energy ■generation	■utilityID ■name ■coins ■energy	■residentID ■firstname ■lastname ■coins ■energy ■generation ■consumption

3.2.2 Asset

In this study, Coins, Energy, Consumption and Generation are created as the assets in the network. Some properties in these assets have relations to the transactions in the network. For example, coinsID and energyID are used in the CoinsToEnergy transaction for exchanging the energy among participants. The properties and function of each asset are presented in Table 3.

Table 3. Property of each asset

Coins	Energy	Consumption	Generation
■coinsID ■value ■ownerID ■ownerEntity	■energyID ■energySource ■latitude ■longitude ■units ■value ■ownerID ■ownerEntity	■consumptionID ■energySource ■latitude ■longitude ■units ■value ■ownerID ■ownerEntity	■generationID ■energySource ■latitude ■longitude ■units ■value ■ownerID ■ownerEntity

3.2.3 Transaction

In this study, EnergyToConsumption, GenerationToEnergy and CoinsToEnergy are created as the transactions in the network. The logics behind these all transactions are defined by programming smart contracts in script file. The properties and function of each transaction are shown in Table 4.

Table 4. Property of each transaction

EnergyToConsumption	GenerationToEnergy	CoinsToEnergy
■energyValue ■consumptionInc ■energyDec	■energyValue ■generationInc ■energyInc	■energyRate ■energyValue ■coinsInc ■coinsDec ■energyInc ■energyDec

3.3 Smart contract

Smart contract is also known as the business logic or algorithm in the blockchain network. It is used to define the rules for the transactions and turned into computer programming language. The working principle of smart contract is to execute the programming code based on the defined rules, then register new facts to the ledgers in the blockchain network [11]. In this proposed blockchain network, there are three transactions that have different functions and purposes. The algorithms for CoinsToEnergy, EnergyToConsumption and GenerationToEnergy transactions are explained in Figure 3, 4, and 5.

```
Algorithm CoinsToEnergy function
Function CoinsToEnergy for exchanging energy and coins
Find change in coin from the product of energy value and rate
if coin or energy are negative or insufficient for exchanging
    return error message
Update new values in Coins assets
Update new values in Energy assets
Register new values of Coins assets to network
Register new values of Energy assets to network
end function
```

Figure 3. CoinsToEnergy algorithm

```
Algorithm EnergyToConsumption function
Function EnergyToConsumption for recording consumption
if energy is insufficient or negative
    return error message
Update new values in Energy assets
Update new values in Consumption assets
Register new values of Energy assets to network
Register new values of Consumption assets to network
end function
```

Figure 4. EnergyToConsumption algorithm

Algorithm GenerationToEnergy function
1: **Function** GenerationToEnergy for recording generation
2: **if** energy is negative
3: return error message
4: Update new values in Energy assets
5: Update new values in Generation assets
6: Register new values of Energy assets to network
7: Register new values of Generation assets to network
8: **end function**

Figure 5. GenertionToEnergy algorithm

4. ENERGY TRADING SIMULATION

This case study simulates the energy trading by applying energy data from the 24-hour simulation V2G system in MATLAB, consisting of renewable energy elements, diesel generator unit, EV, and residential load. This simulation adopts Python to read the energy deficit in each hour, then sending requests to execute transactions for 24 hours. The overall diagram of experiment is presented in Figure 6 and an energy profile in experiment in Figure 7.

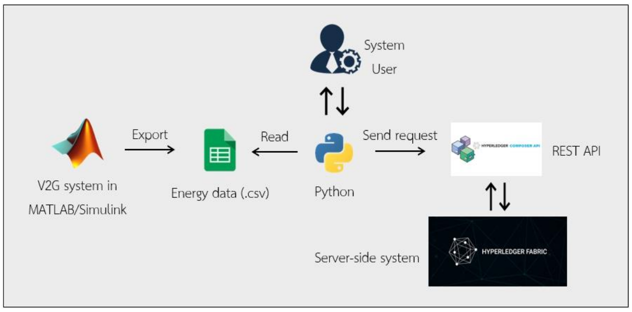

Figure 6. Overall diagram of experiment

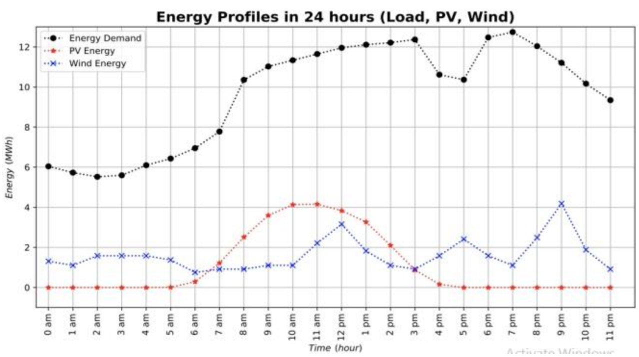

Figure 7. Energy profile in 24 hours

This case study assumes that there is community having energy demand shown in black line. While this community could generate energy from renewable sources shown in red and blue lines (PV and wind energy). The energy deficit will be imported from utility company. The CoinsToEnergy transaction will be called for this time because it is exchange between Coins and Energy assets. In Table 5, JSON data of all assets for are presented.

Table 5. JSON data of assets

Residential community	Utility company
Coins asset (JSON), {"$class":"org.blockchain.energy.trading.Coins", "coinsID": "coin_R1", "value": 200, "ownerID": "R1", "ownerEntity": "Resident"}	Coins asset (JSON), {"$class":"org.blockchain.energy.trading.Coins", "coinsID": "coin_U1", "value": 0, "ownerID": "U1", "ownerEntity": "UtilityCompany"}
Energy asset (JSON), {"$class":"org.blockchain.energy.trading.Energy", "energyID": "energy_R1", "energySource": "Diesel", "latitude": "xx.xxxx", "longitude": "yy.yyyy", "units": "MWh", "value": 0, "ownerID": "R1", "ownerEntity": "Resident"}	Energy asset (JSON), {"$class":"org.blockchain.energy.trading.Energy", "energyID": "energy_U1", "energySource": "Diesel", "latitude": "xx.xxxx", "longitude": "yy.yyyy", "units": "MWh", "value": 200, "ownerID": "U1", "ownerEntity": "UtilityCompany"}

After 24-hour energy trading simulation is done, the transaction data is recorded in the blockchain network. The example of transaction data is shown in Table 6 and the amount of energy imported in each hour is presented in light blue line in Figure 8.

Table 6. Transaction data

	JSON data
23rd June 2020	{"$class": "org.blockchain.energy.trading.CoinsToEnergy", "energyRate": 1, "energyValue": 4.732916255, "coinsInc": "resource:org.blockchain.energy.trading.Coins#coin_U1", "coinsDec": "resource:org.blockchain.energy.trading.Coins#coin_R1", "energyInc": "resource:org.blockchain.energy.trading.Energy#energy_R1", "energyDec": "resource:org.blockchain.energy.trading.Energy#energy_U1", "transactionId": "81db7e0eb0342cf79743a49cd045ecbae241a6347ce7a76ac2f5c087fdcecad8", "timestamp": "2020-06-23T00:05:16.909Z"}

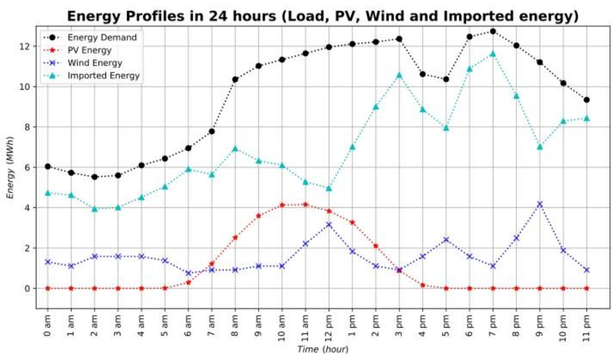

Figure 7. Imported energy in each hour

5. SYSTEM PERFORMANCE TESTING

The system performance testing is evaluated by sending the HTTP requests to attack system, then analyzing the successful and failed percentage, as well as response time. An open-source "Locust" is used in this testing, its concept is to create simulated users to participate system regarding the behaviors defined by Python. Thus, this testing is beneficial to the developers because it could evaluate size and capability of the system.

The system performance is tested by sending the number of GET and POST requests to the proposed network. For GET request, it is query operation to retrieve the information from the system. For POST request, it is the operation that create new data to the system. The result of the test is presented in the Table 7.

Table 7. Testing results of GET and POST request

Request type	Request (request/second)	Median response time (ms)
GET	600	40,000
POST	200	50,000

It can be seen that the successful request rate of GET is higher than POST as GET request only calls data from the system, whereas PSOT creates new data. At request rate more than the results shown in Table 7, it will result in high failure percentage of making requests. Based on the specification of laptop, rate of request and median response time, the appropriate size for this proposed energy trading platform is small community with the number of household around 100.

6. CONCLUSION

To sum up, the characteristic of power network is changing to be decentralized according to the rise in number of DEGs. This results in P2P energy trading in power system in the future. The blockchain technology could play as an important role to support electricity exchange business due to its strengths and benefits. In this paper, it delivers concepts of design and implementation of energy trading network by using an open-source blockchain platform "Hyperledger Composer". It firstly reviews blockchain technology, then implementation and design concepts are proposed. Next, the network architecture, components in the platform, smart contracts are explained in detail. Finally, two case studies (electricity trading simulation and system performance testing) are investigated.

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