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Blockchain-Based Smart Contract for P2P Energy Trading in a Microgrid Environment

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Abstract. The purpose of this study is to propose a method of peer-to-peer (P2P) energy trading that allow prosumers with energy deficiency to buy energy from prosumers with excess energy in a microgrid system. The proposed method solves the problems associated with lack of trust in P2P energy trading and utilized the blockchain technology that made it impossible to tamper with data. The data is referred as transaction generated by using blockchain. A blockchain based smart contract execute the trading and payment rules without the intermediaries. Thus, the security and fairness of energy trading are significantly enhanced compared to conventional database technology. Without the third-party intervention, a miner that is selected among the participants in the microgrid environment process all the transaction generated from buying and selling energy. The smart contract consists of two main components; bidding and settlement module, payment module. The smart contract deployed in blockchain test network to test the interaction of smart contract. From the simulation, the proposed method is validated using realistic data with the Ethereum Virtual Machine (EVM). The method will be expected to be useful to designers who need to integrate renewable energy in a microgrid system.

1. Introduction

Present power grids are experiencing an ongoing transition from their conventional centralized configurations. The paradigm shift includes the generation, transmission, distribution and utilization of electric power to the masses. The traditional electrical power system is designed to supply massive energy to consumers. Since the transmission and distribution of power are centralized and owned by the grid operator, originally it was never meant to incorporate the consumer-owned generators. However, with the proliferation of distributed energy resources (DER), particularly the renewables, the sense of developing a decentralized generation and consumption is growing.

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The concept of decentralization is widely introduced and applied today. Even the renewable energy is moving towards decentralization. The main idea behind energy decentralization is to spread out the energy generation to be closer to the consumers. Decentralization of renewable energy is important in order to reduce the dependency and burden of the centralized generation [1]. It is known that the traditional grid systems use the centralized architecture which means that it is one-directional power flow. However, the decentralization of renewable energy possesses a number of challenges. The "energy trilemma" has become one of the main challenges in this modern society; environmental sustainability, energy equity and energy security [2]. In order to deal with the "energy trilemma", P2P energy trading provide numerous solutions using current technologies.

In P2P energy trading, the lack of transparency is revealed to become the main challenges in local energy trading between prosumers and consumers. This issue is highly related with decentralization. The reason rises from the removal of centralized authority in energy trading. Thus, the demand for secure transaction mechanism exists in energy trading in at local stage. Hence, a reliable mechanism is required to facilitate the local exchange of energy between prosumers and consumers. P2P is an energy networking that are able to balance the energy locally and deal with high penetration of DER in the future. The emerging of new technology such as blockchain had become a solution in overcoming these challenges [3]. Blockchain technology enables security, transparency and automation to occur. Blockchain technology become popular in energy trading system because of it brings serious disruptions to the conventional business process since the transaction needed third party intermediaries to verify them and allow decentralization to occur with the same level of certainty [4]. Thus, the energy trading system will no longer have to rely on the centralized system.

2. P2P Energy Trading

One of the interests in the distribution systems is the possible electricity exchange between customers and prosumers. The transactions and power exchange process within the participants in the distributed microgrid system is known as P2P energy trading. In P2P, the participants or node owners—which now can be considered as an energy provider and a consumer (prosumer) can manage their electricity and trade between themselves while creating electricity market in the community [5]. To establish the P2P, it involves not only electrical connection between prosumers, but also sharing information among them [6]. They can now conduct, control and manage their energy generation and consumption.

This perspective has brought new opportunities and challenges to the power systems. In P2P network, any house that is capable in generating and store the energy for local consumption is considered as seller and they can sell the surplus energy to a buyer. As illustrates in figure 1, house in the figure is a participant in P2P electricity trading, equipped with solar photovoltaic (PV) or energy storage system (ESS) who can either buy or sell energy among each other to achieve suitable pricing for the buyers to buy energy while sellers are able to gain more profit from the trading.

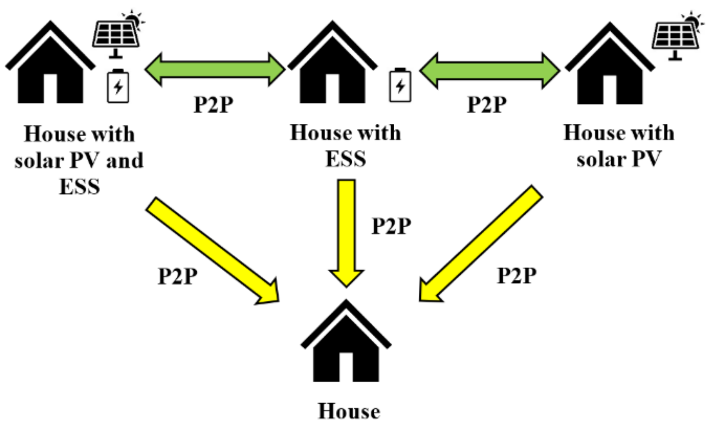


Figure 1. The architecture of P2P energy trading in local energy market environment.

3. Blockchain System and Smart Contract

3.1. Blockchain system

The P2P trading market requires a platform to ensure the integrity and visibility of each transactions process to all participant [7]. This to ensures the trust deficit between stakeholder is removed. Furthermore, it allows for secure implementation of the pricing system for the energy exchange market. The information and communication technologies that are able to facilitate transparent and decentralized transactions is the blockchain [8]. The blockchain can be categorized as a type of distributed ledger, where it can store and verify the data or transactions without involving any third party to validate and manage the ledger. The most common use of blockchain technology are bitcoin and some other cryptocurrencies applications [9]. While the original application of blockchain was to facilitate the trading of cryptocurrencies, blockchain could also be used to facilitate the trading of electricity. Blockchain consists of two different networks, the public and the private blockchain. Both of the blockchain network are for decentralized system and suitable for P2P energy trading system. Moreover, both have similar characteristic and the difference is in the application and type of participation. The difference between public blockchain and private blockchain is represented in table 1.

Table 1. The difference between public and private blockchain network [10].

Characteristic	**Public Blockchain**	**Private Blockchain**
Access Level	**Anyone**	**Single organization**
Participation	**Permission less and Anonymous**	**Permissioned and Known Identities**
Security	**Consensus mechanism**	**Pre-approved by participants**
Performance	**Slow transaction speed**	**Fast transaction speed**

3.2. Smart Contract

The smart contract architecture for P2P energy trading process is usually integrated to a small-scale energy system. A smart contract is self-executing contracts with contain the term and conditions of an agreement between the peers [11]. The terms and conditions of an agreement is written in code. It can be created using various tools and programming language. The most common method is developed by using Remix browser-Ethereum IDE (integrated development environment). It mainly used Solidity programming language. This software allows connection to blockchain test network called Ganache GUI (Truffle Suite).

Each node in the Ethereum platform has address for public and private key. The smart contract triggers by addressing a transaction to it. It operates independently and automatically on every node in the network in accordance with the data supplied in the triggering transaction [12]. In this case, the seller will initiate the auction by deploying a smart contract into the blockchain network. Smart contract allows to set various type of transaction condition or market model in energy trading. The agreement written in smart contract facilitate the exchange of money, shares and others. Besides, it is automated with code which eliminates manual effort for execution and require much lesser time than manual contract. The operational mechanism of smart contract is summarized as [13]:

- The smart contact is design and written in Solidity programming language and compiled in the browser-based Remix. Then, the contract is deployed into blockchain test network.
- The full nodes control and broadcast the transaction in the blockchain system.
- A miner is selected among the participants in the microgrid environment. The selected miner will verify the validity and credibility of the smart contract transaction, and verify whether the energy claimed to be produced by the prosumer is actually available or not.

The operational mechanism of the smart contract execution with blockchain is illustrated in figure 2 assuming that person A needs to send money to person B.

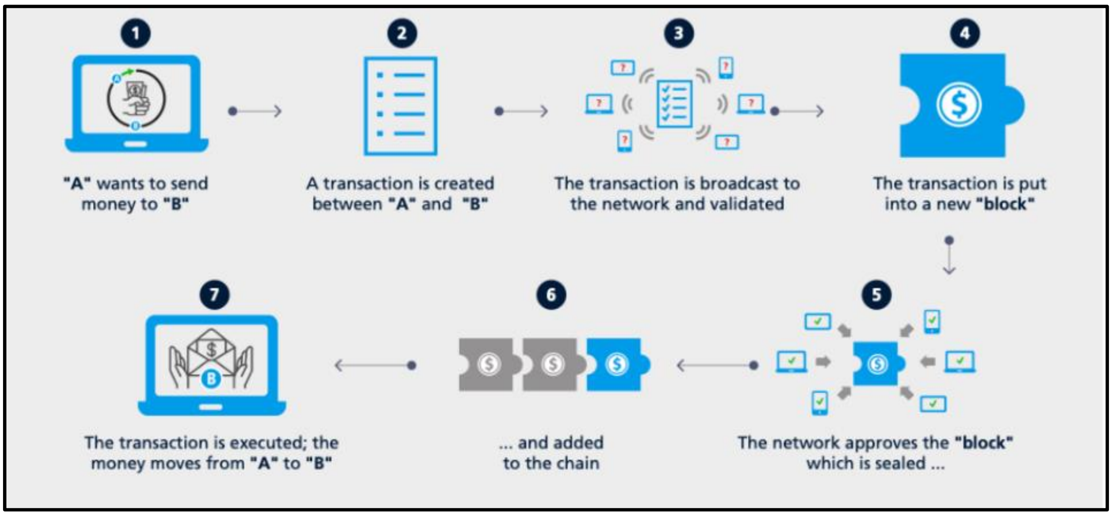


Figure 2. The blockchain based smart contract operational mechanism [13].

4. Proposed Method

The blockchain network allow participants in each node to involve in a secure P2P energy trading. Each node in the microgrid environment is divided into two categories; buyer and seller. The buyer is prosumer with energy deficit while the seller is prosumer with excess energy. In a microgrid environment, energy to be trade depends on the excess power from the solar PV and the amount of power generation from PV panels is depends on the weather. Therefore, the power produced can be self-sufficient or deficit in such a small area.

Due to this reason, this project assumes that the proposed model of microgrid does not eliminate the connection from the AC main grid for possible reasons of the shortage of local generation of energy and gap between demand and supply in the microgrid known as non-autonomous microgrid. The smart contract designed for this project is divided into two; the bidding module and the payment module. Bidding module utilized double auction method to determine the market clearing. The participants in the smart contract trade between peers in the microgrid using the market clearing price and clearing quantity obtained from the double auction. Next, the payment module allows the transfer of money into the respective account of successful participants from the bidding module. The condition is set where the payment is released when energy confirmed to be received by the buyer for. However, the payment is refunded back to the buyer account if energy purchased is not received by the buyer.

In this project, it focused only on the selling and buying mechanism in the microgrid environment. It does not involve the modelling of microgrid to demonstrate the energy trading in the microgrid environment.

4.1. Smart Contract

There a two smart contract created in this project. The first smart contract is for bidding and market settlement purposes. Meanwhile, the second smart contract is created of the successful participants in the double auction to transfer money into the accounts. For this project, the stages of smart contract development used can be divided into four stages which consist of writing code based on the chosen market model, compilation, deployment, interaction of smart contract and also client side.

Bidding and Settlement. The technique used for the market clearing or settlement depends on the market based on the probabilities, market design structure, players (peers) behaviour and particular regulations of the market. Thus, based on the system design, several approaches can be used for the market clearing technique in local energy trading. These approaches are typically not employed individually and a combination method is possible to be applied in the market clearing to improve the accuracy and efficiency of the modelled system. The double auction price model is used to facilitate the usage of renewable energy that benefits of producers and consumers. This model creates competition among buyers and sellers in microgrid environment as they bid to meet their own needs. The purpose of using this auction approach for market clearing is to satisfy both prosumers and consumers in the energy market [14].

In developing the market structure, the demand curve of the market needs to be established. The intersection of these constructed supply and demand curves represents the market equilibrium as shown in figure 3. To execute the process, both buyers and sellers are asked to submit offers specifying the quantity of energy needed and price to be offered. The value of bid price is initialized in array form for both buyers and sellers bid price. If the bid price of the seller is overlapped with another seller, the price will be queued in chronologically order of the bidding. After the sorting process of the bid price from the buyers and sellers, the market clearing is determined in the platform.

Figure 3. Double auction market technique to obtain the market clearing price [15].

4.1.1. Payment. Whenever a smart contract is invoked, it is deployed into the platform. However, each smart contract has deployment cost in gwei (1/10^9Ether). Once the settlement of double auction had taken place, only the successful participants are allowed to use this module in order to transact the money into each other accounts. The currency used in this platform is called ether (ETH). The rule that is set for the payment module is set as such:

- The amount of ETH to be transfer should be according to the settlement price from double auction market clearing model.
- The smart contract should be invoked by the seller in the platform by inserting the amount of energy in Wh to be sold and the energy to price of energy in cent/kWh. The seller can also withdraw from selling the energy.
- There are three states; “created”, “locked” and “release” for the amount of ETH involved in this transfer. A state is “created” when the buyer confirms its purchase. Then, a state is “locked” when the amount of ETH is not transferred to seller and only change to “release” whenever the energy is received by the buyer. The state “release” also act as a refund function, where buyer can retrieve back the amount of ETH if the energy is not transferred by the sellers.
- The transaction of ETH among buyer and seller is stored in block and are chain to the previous block or genesis block.
- Both buyer and seller also able to see the increase and decrease in the amount ETH in each respective accounts through the recorded logs in Ganache GUI (Truffle Suite).

5. Results and Discussion

The smart contract created in Ethereum platform for both the bidding module and payment module is tested to as result in this project. In this project, six different accounts will be utilized to test the smart contract in Ethereum and blockchain test network which is Ganache GUI (Truffle Suite). Each account has its own address and has the amount of 100 ether in their respective account.

5.1. Result of Bidding and Settlement Module

Once the smart contract for double action is compiled, it is deployed into JavaScript VM. Next, input data is inserted including sellers' submitted offers and buyers' submitted bids. The bids are sorted and arranged as tabulated in table 2. Then, the following bid price and amount is submitted into the smart contract in Ethereum platform. Once all the bid is submitted, the market clearing will take place. Assuming that initially, there are one buyer and seller as the participant of the bidding module. The number of participants is then increased by increment of one buyer and then one seller for every execution of bidding module until all six participants are involved in the smart contract.

Table 2. The bidding data entered by the seller and buyer for the energy trading.

Participant No.	1	2	3
Sellers' bid	10 cent/kWh 200Wh	11 cent/kWh 100Wh	12 cent/kWh 150Wh
Participant No.	4	5	6
Buyer's bid	14 cent/kWh 150Wh	13 cent/kWh 200Wh	11 cent/kWh 100Wh

Thus, figure 4 shows the comparison between the market clearing price and the average bid price. By comparing the market clearing price, it is found that double auction provides better clearing price for both buyer and seller to trade energy among themselves in the microgrid. This is because, the clearing price above the above clearing price will bring more income to the seller, while the clearing price below the average clearing price will reduce the cost to buyer. Other than that, this bidding module allows the market to be more prosumer centric. It can be defined as a property that motivate people to participate in the trading. This is due to the fact that a prosumer might not always be motivated to trade energy locally if the scheme does not compromise the benefit to the prosumers.

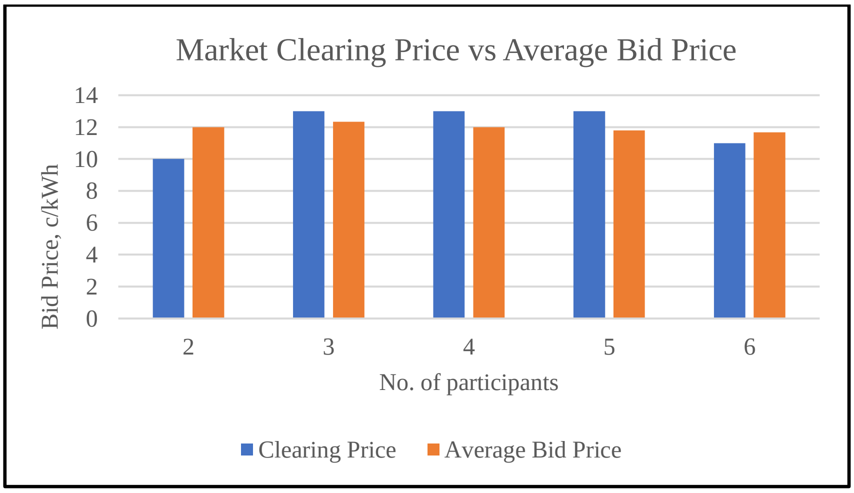


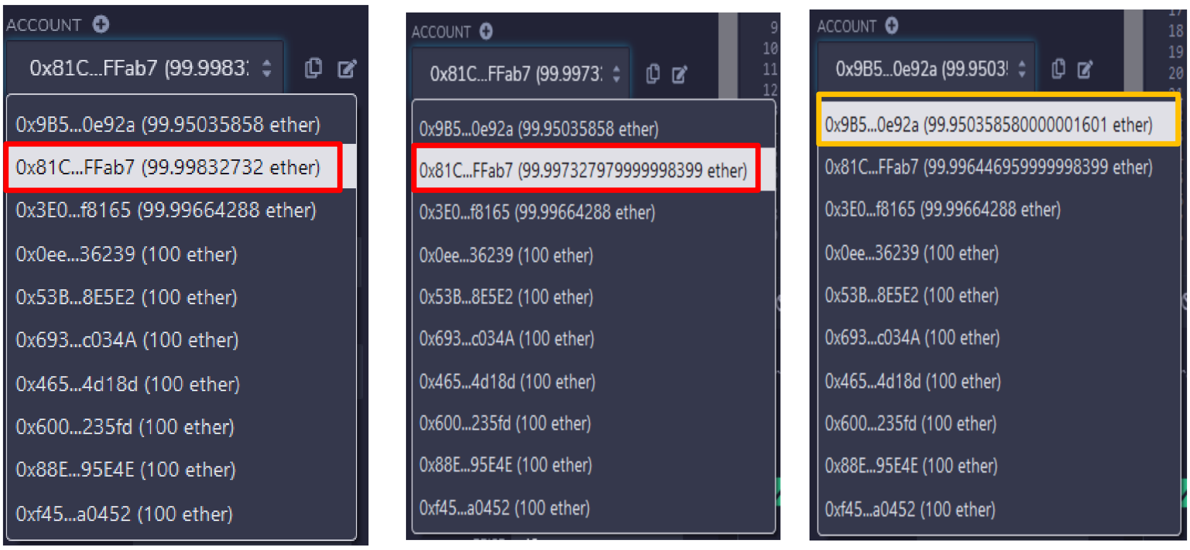
Figure 4. The comparison between market clearing price and average clearing price.

5.2. Result of Payment Module

In a simple form, transactions in this energy trading process consists of selling and buying from other participants. The execution of payment module is divided into two cases. The first case is successful transaction between seller and buyer. The second case is unsuccessful transaction due to energy is not received by buyer. The results for each case can be observed by the transaction of ETH in the account of each respective buyers and sellers.

The cryptocurrency for Ethereum platform is called as Ether (ETH) or Gwei. In cryptocurrency 1 cent is equal to 120×10^(-9) ether as of May 2021. Completed transaction records will be chain to the previous block that is visible to all with tamper proof manner.

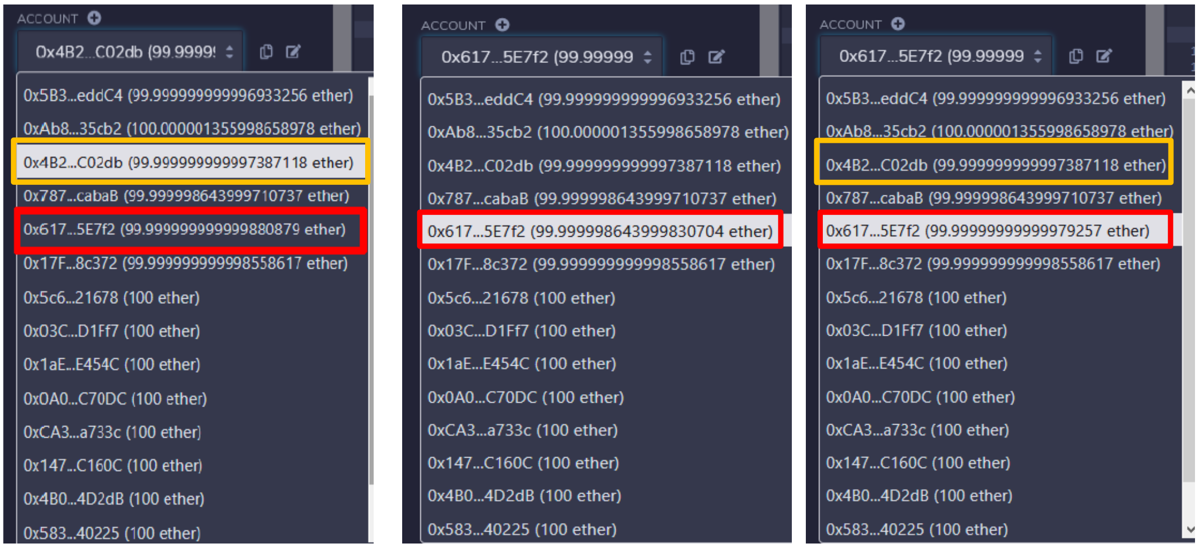
5.2.1. Successful transaction. The transaction of ETH is conducted successfully due to price matching between the successful buyer and seller. Next, buyer need to confirm the purchase of energy where the price of energy is deducted from buyer account and are not release until the energy is confirmed to be receive by the buyer. Then, increment of the amount of ETH in seller can be seen. The transfer of ETH into buyer and seller account is as shown in figure 5, where buyer account is highlighted with red box while seller account is highlighted with yellow box. Before the transaction, the buyer account (0x81C…) has the amount of 99.99932732 ether. After buyer confirmed the purchase, the amount of ether decreased to 99.99732797 ether. While the seller account (0x9B5…) has the initially 99.95035858 ether and increased to 99.959035858000001601 ether after payment had been released by the buyer.



(a) (b) (c)

Figure 5. (a) Buyer account before purchase (b) Buyer account after purchase (c) Seller account after payment release

5.2.2. Unsuccessful transaction. The transaction of ether is unsuccessful due to the absence of energy received by the respective storage system of the participant. Once the energy is unable to be transfer within a certain period of time, the amount of ether is refund to the buyer account and are not release to the seller (yellow box). The transaction can be seen in figure 6. The buyer account is highlighted with red box. In this case, seller with account address (0x4B20993…) sell excess energy to buyer with account address (0x617F2E2…). However, the energy is not received by the buyer. Thus, the amount of ether in buyer account before transaction start is 99.9999999999998809879 ether and decrease to 99.999998643999830704 ether and increase back to 99.99999999999979257 ether (In (c), noticed that the amount of the energy price already refunded back to the buyer account as initially deducted as in (b).)



(a) (b) (c)

Figure 6. (a) Buyer account before purchase (b) Buyer account after purchase (c) Buyer received the payment back (refund)

6. Conclusion

This project was undertaken to design market platform among nodes in microgrid environment by utilizing smart contract and to implement blockchain technology in P2P energy trading in order to minimize dependency for trusted intermediaries between transacting parties and increase the validity and reliability of data. This work indicated that bidding module provides both buyers and seller an opportunity to obtain positive profit by competition. The market platform using double auction benefits both buyers and sellers by computing better market clearing in a microgrid environment. Next, the observations from this study suggests that the excess energy produced by each node can be traded efficiently in the microgrid environment with less help from distribution system operator (DSO). It is also observed that the payment module transfer money into the account of players without third party successfully.

Furthermore, the implementation blockchain technology results in the transaction data are saved in the block and are chained together. Thus, making it impossible to be tamper. It can be concluded that blockchain technology increase the validity and reliability of data compared to conventional database technology.

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