# Review of Market Clearing Method for Blockchain-Based P2P Energy Trading in Microgrid

Nor Ashbahani Mohamad Kajaan
Faculty of of Electrical Engineering Technology
Universiti Malaysia Perlis
Arau, Perlis, Malaysia
ashbahani@unimap.edu.my

Zainal Salam
Center of Electrical Energy System
School of Electrical Engineering
Faculty of Engineering,
Universiti Teknologi Malaysia
Johor Bahru, Malaysia
zainals@fke.utm.my

Raja Zahilah Raja Mohd Radzi
School of Computing
Faculty of Engineering,
Universiti Teknologi Malaysia
Johor Bahru, Malaysia
zahilah@utm.my

***Abstract*—The peer-to-peer (P2P) energy trading creates a platform for all microgrid users to exchange their energy surplus and demand without the presence of a centralized authority. With P2P, the dynamic electricity market between nodes will be developed, thus increasing the overall throughput of the microgrid. To ensure the energy transactions in local energy trading meet the highest level of integrity, the blockchain system is implemented. Appropriate classification and structuring the literature on viable designs for local energy trading can assist researchers in effectively developing their subsequent planning for the local energy market. This study reviews the current research related to market clearing methods for blockchain-based P2P energy trading for microgrid system. The focus is on the auction theory, constrained optimization, game theory and agent methods.**

***Keywords—energy market clearance, energy market design, peer-to-peer energy trading, blockchain, microgrid***

## I. INTRODUCTION

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. The transformation from the centralized to the distributed structure is realized in the form of microgrids; this concept is envisaged to be the future of electric power. The expected mass penetrations of PV, wind biomass and other renewable sources will be the key factors for the development of the microgrid systems. These development open-up numerous possibilities and opportunities, but at the same time present challenges that were not anticipated with the conventional system.

Microgrid is independent energy distribution system and a fundamental building block of the smart grid system. It enables the continuously consumption of the energy from the DER and decreases the dependency on the main grid supply. The microgrid system can be connected to the main grid system or operated in a standalone (islanding) mode. The decentralized manner of the microgrid offers several potential inventions. One of the exciting new ideas is the peer-to-peer (P2P) energy trading, i.e., an energy purchasing and selling transaction between the participating parties (nodes). The P2P energy trading creates a platform for all users with DERs to exchange their energy within the microgrid system without the presence of a centralized authority [1]. The participants, known as the prosumer (producer and consumer) balances its own local generation and consumption, as well as looking for opportunities to sell its surplus energy at the optimum cost. In the case of power shortage, the prosumer will seek to purchase the lowest price of energy from its neighboring peers [2], [3]. To encourage participation in the energy market, P2P energy trading system will take place in a local energy market (LEM), where energy transactions are available for public view.

The P2P energy trading exhibits a range of advantages: 1) it is allows energy sharing model to cope with the increasing penetration of renewables, 2) supports autonomous microgrid system and 3) complement the decreasing feed-in-tariff (FIT) rates [4]. On the opposite side, there are several inherent drawbacks of P2P. The main concern is the system exposure to security and privacy issues that affect the integrity of the system [5]. This contrasts with the conventional power system, in which the records managed and protected by the utility company. Now that such authority is absent, the P2P must provide a mechanism to ensure safe and secure passage for all transactions. This is important so that the entire microgrid ecosystem can be kept transparent and reliable. One solution to this problem is to introduce the distributed ledger that incorporates blockchain technology [6]. The blockchain system facilitates energy exchange by storing the collection of transaction information in blocks, while validating all transactions through the network nodes. Furthermore, the tamper-proof chain of data is ensured through encrypting, the protection and confidentiality of each transaction.

With the incorporation of blockchain into the P2P energy trading platform, the issue of trust deficit among the nodes is minimized. In addition, the smart contract is executed to regulate the transactions based on set of rules that are mutually agreed by all participants. In the context of a decentralized P2P trading, smart contracts are used to take over the role of centralized agents. All data associates with the market clearing and trading transactions will be written in the smart contract, which is transparent to all participants. Once the smart contract has been established in the P2P energy trading network, it will be coded and remain unchanged. Modification of the content in the smart contract are impossible without the consensus of all participants. All data of the successful transactions will be kept and generate as a new block and will be chain together with the previous block to form a block-chaining.

The rise of prosumers highlights one of the most exciting trends in the power system especially in renewable energy. It is expected that the incentives that prosumers would obtain from the participating in P2P trading will be

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significant, since prosumers are in charge of setting the terms and conditions of the smart contract [7]. Since the P2P is not regulated by a third party, there is a need to determine the market clearing method. The market clearing in energy trading or sometimes known as the market settlement, involves the algorithm for buying or selling the energy, auctions or bidding announcements and certain actions upon the energy transactions. Efficient and reliable market clearing technique is crucial for a sustainable and resilient P2P trading system. This paper includes a review of previous studies on the market design approach for P2P energy trading, including the implementation of the blockchain. The designed market clearing mechanism has been analyzed for its decentralization manner and security aspects in blockchain-based P2P energy trading system.

This paper is organized into six main sections. Section II covers fundamental overview on the P2P energy market trading while in Section III, a brief introduction regarding blockchain systems including the concepts been discussed. Section IV presents the information regarding market clearing method in P2P trading. In Section V, detail discussion on the different market clearing approaches in energy trading is provided in terms of distributed manner and the privacy in local energy exchange. Finally in Section VI, we conclude the paper and briefly summarize the contributions of having the blockchain system along with the P2P energy trading in the microgrid system.

## II. Overview of P2P Energy Trading Market

The P2P for microgrid involves not only electrical connection between prosumers, but also the information sharing among them [3]. This idea is illustrated in Fig. 1. In principle, every node is expected to control and manage its own energy generation, energy storage and their energy consumption. In the P2P energy trading, the node that is capable of generating surplus energy (that beyond its local consumption) is considered as seller. At the same time, it can be considered as the potential buyer too. It is expected that the incentives that prosumers would obtain from participating in energy trading between peers will be significant, since prosumers are in charge of setting the terms and conditions of the smart contract [7]. The goal of P2P energy trading is to optimize the electricity price by breaking away from the centralized grid infrastructure. main requirement is by enabling the direct communication among various prosumers with DER [8]. The P2P energy

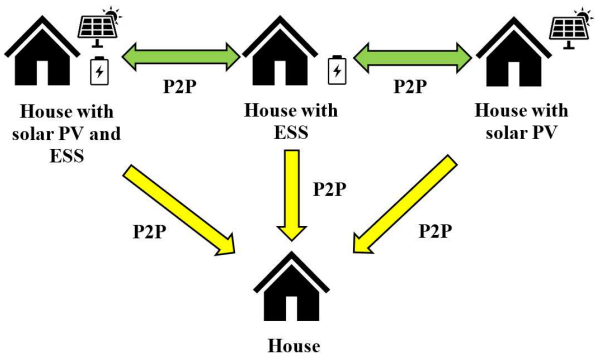


Fig. 1. Structure of P2P energy trading in local energy market in microgrid system

trading is a digital technology which enables the information to be exchange among peers and assist the system operators to monitor and control the distribution networks.

### A. Market Design in P2P Energy Trading

Energy policies adopted by different countries currently seek to encourage prosumers to consume its self-generated energy. The LEM provides a local balance between power generation and load as well as to eliminates the need for expensive grid expansion [9]. This includes the establishment of new market channels that enable an active involvement and direct contact with consumers. Via exchanging and using renewable and local electricity, the customer can gain economic benefits, while providing local power balance for supply and demand side. Since the microgrid system works well under autonomous mode, it can create a new energy market within local community. These features lead to significant benefit in P2P trading system where generation and consumption can be executes locally.

To evaluate the efficiency of any marketplace design in the energy trading, one must identify and defined the market players. The three types of market players are seller, buyer, and mediator. The seller, or also known as an energy supplier is anyone who can produce or store the energy in the community. On the other hand, a player is an entity that require energy from other nodes. The mediator is an intermediary that gather buyers into an energy exchange unit to negotiate the purchase of power from electricity suppliers or sellers. There are three market structures that are widely been implemented in P2P energy trading network [10]:

*1) Distributed P2P*: The seller and buyer involved in this type of market structures interact directly on their energy trading without central control or intermediaries.

*2) Centralized P2P:* Participant of the energy trading in this case controlled by a mediator or a community supervisor to sell or buy surplus energy between the same community or participants from other community.

*3) Hybrid P2P*: This type of market is a combination of fully decentralized and centralized P2P market, where the interaction or energy exchange between the seller or buyer may be executed directly or through a mediator.

## III. The Blockchain System

The P2P transactions process requires a mechanism to ensure the integrity and visibility of each is maintained. Furthermore, it allows for secure implementation of the pricing system for the energy exchange market. The technology that are able to facilitate transparent and decentralized transactions is the blockchain [11]. 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. 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 system is a future trend of P2P system for energy exchange technology. Blockchain technology effectively keep track on the energy transactions in the P2P energy trading architecture.

The rationale behind applying blockchain idea in the energy market is to remove the trust deficit between stakeholder of the P2P network; thus allowing the prosumers to purchase and sell energy in a trusted environment [12]. By using blockchain system, each participant will hold a copy of the transaction records and engage in a consensus protocol for verification process by other members. Fig. 2 demonstrate the architecture for P2P energy trading with blockchain network. This architecture will enable the node owner (prosumer) to sell their surplus energy directly to another node that having energy deficit. All successful transactions will be chain in the distributed ledger in the blockchain network after been verify by the smart contact. Hence, this provides a platform of LEM for buying and selling of the solar PV generation. As shown in Table I, the blockchain architecture is capable to provide solutions to the security and integrity of the transaction issues in the energy market [13].

The security and integrity of the transaction data is enhanced by the blockchain platform [14]. It instills trust among peers and eliminates reliance on a centralized electricity management. Since blockchain is an immutable ledger structure, it provides reliability and unalterable transaction data. Hence, it could prevent any malicious activities in P2P energy trading network [1].

## IV. The P2P Clearing Method

To expand the DER usage and to benefit the stakeholders, the market settlement or clearing method has been a subject that of interest in P2P energy trading implementation [15]. The development of market clearing mechanism is a crucial phase in the process of designing an effective energy trading system, so that the amount paid for the electricity price will generate a profitable incentive for the prosumers. Market clearing aims to make sure the energy vends effectively at price called market-clearing price (MCP). The MCP is the price at which the energy supplied is equivalent to the energy demand. It also known as the equilibrium price of products, where in this case known as the energy trading price. Energy demand will be increased when the energy price been set appropriately, perhaps with the suitable clearing approaches.

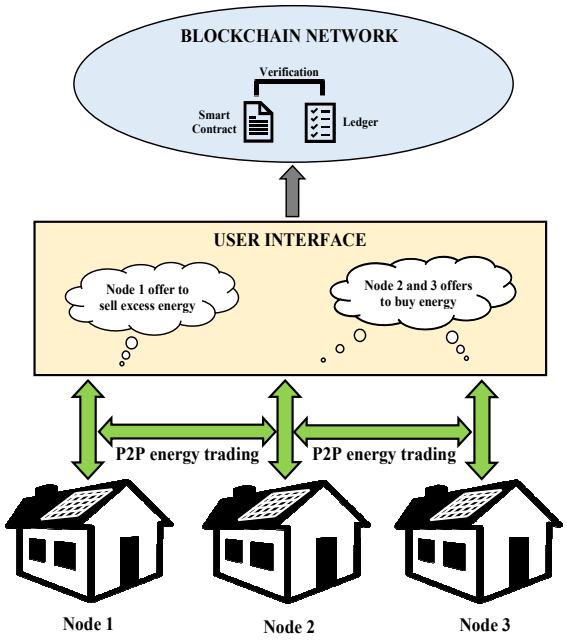


Fig 2. Concept of P2P energy trading with blockchain network

TABLE I. Blockchain Technology Solution For Issues In The Microgrid System That Attempt To Utilize The Energy Market

| Common Issue in Energy Market | Blockchain Solution |
|---|---|
| Centralization of nodes | P2P system |
| Instill trust among peers in the network | Smart contract execution |
| Transparency of trading transaction | Consensus mechanism and distributed ledger |
| Transaction confidentiality and safety | Encrypt hash algorithm |

The purpose of market clearing is to allow the participants to place their offers (bids) from their generated energy during certain time in a day; the clearing mechanism process automatically decides the successful or winning bids. In microgrid system, the engagement of peers in the electricity market will lower down the energy cost as the prosumers can is not subjected to the profit made by the grid operator. The technique used for the market clearing depends on the probabilities, market design structure, players behavior and particular regulations of the market. Based on the system design, several approaches can be used for the market clearing technique in local energy trading. These approaches can be combined to improve the accuracy and efficiency. There is a common market clearing methods by recent studies that can be regarded as significant in the design of current P2P energy trading systems, with or without the blockchain implementation. Most widely used market clearing techniques are auction theory, constrained optimization, game theory and agent- based methods. These methods extensively been used for a different application in the literature related to the power system. Table II summarizes the features of these techniques.

## V. Discussion

The literatures regarding the market clearing in P2P energy trading system are summarized in Table III. As can be seen, not all designs incorporate blockchain technology [16], [17]. The role of participants is important in local energy trading [18]. The local energy market should be capable in providing a trust less environment. As in conventional transactions, one need to deal with central authority or third-party organizations to perform a trading. The development of a comprehensive and appropriate P2P energy market also poses additional problems in terms of security. A secure and reliable database system need to be addressed in every market design to records all the details such as transactions data, that are transparent and tamper-proof. In this section, the energy trading market design in the blockchain-based research works are discussed for the decentralization (distributed) of P2P energy trading and security features.

### *A. Decentralization*

Blockchain technology is an innovative distributed ledger technology, which is able to create a trustable environment for trading between various entities in a

TABLE II. SUMMARY OF THE MARKET CLEARING METHOD IMPLEMENTED IN P2P ENERGY TRADING

| Market Clearing Method | Summary | Technique |
|---|---|---|
| Auction Theory | The negotiation between seller and buyer will be established in order to enable them to exchange their energy. Either only buyer send a bid or both seller and buyer participate in the bidding process | Single-sided auction, Double auction or two-sided auction |
| Constraint Optimization | Process to determine the best objective parameters or functions for the energy trading with presence of constraint in the variables. Objective functions can minimize or maximize depending on the market structure | Linear programming (LP), mixed-integer linear programming (MILP), non-linear programming (NLP), alternating direction method of multiplier (ADMM) and Heuristic method |
| Game Theory | Mathematical model that examines a strategic decision by various participants and understanding their behavior in energy market in making an optimum, stable and profitable for everyone in the trading network | Non-cooperative game (Nash equilibrium, Stackelberg game), cooperative or coalitional game |
| Agent Method | Used to build an interaction between market players that modelled as agents. It might be as a single player in the computer program or as a smart object with perhaps an endless number of actions to be accomplished or making a decision | Multi-agent |

decentralized manner. Hence, considerably more attention in using a blockchain technology in order to create a decentralized platforms for energy trading system. In a decentralized blockchain system, no participant has to identify other participant or to trust them since each of them hold the same database in forms of distributed ledger. A fully decentralized blockchain-based P2P trading is provided in [19]–[21] which establishes an analytical framework for blockchain-based microgrids by adopting double auction methods for market clearing purposes. Enabling P2P energy trading in microgrids in long term is considered to be one of the most significant aspects of blockchain technology [22]. The application of non-cooperative game between the consumers that aim for decentralized demand side management via P2P trading can be found in [23] and for decentralized energy supply as implemented in [24].

The decentralization feature of blockchain is considered to be well matched with the decentralization characteristic of P2P energy trading. Electricity supply is no longer provided by centralized large generators from the generating stations, but rather by small customers with DERs [25] including electric vehicles [26] and [27] with double auction market clearing strategy to obtained a balance MCP. Meanwhile, author in [28] developed a decentralized platform for energy trading with Ant-Colony Optimization method, includes an addition of blockchain layer to support the security of the system as well. Author [29] established an agent method framework at the residential area in Perth, Australia to developed a decentralized P2P trading with blockchain. In the era of energy decentralization and digitalization, having a central point for data may not be the most efficient approach, which makes blockchain technology become interesting.

### *B. Privacy*

In the implementation of any market design for decentralized P2P energy trading, smart grid system with a large number of components and complex connections may be a security, privacy, and trust concern which requires new and innovative technologies to address [30]. Blockchain provide an advantage in energy systems in terms of privacy and security through its cryptographic and digital signatures features. Its tamper-proof nature can digitally secure all the relevant information with high resiliency to cyber-harm and forger. This in turn, generates trust among all traders and facilitates the verification of shared information. A double-layer framework of energy transactions based on blockchain in multi-microgrids is proposed in [13] to provide decentralized trading, information transparency and mutual trust system of each node in the trading market.

Brooklyn Microgrid project case study in [31] and [32] is local community project that generates energy from solar to powered neighborhood. It aims at increasing the security of power supply for the local community, integrating local generation into the energy system, and empowering the community with double auction market clearing approach. Another application for double auction theory method in promoting secure trading environment between home prosumer can be found in [33]. With the aim of enabling the distributed optimization by using ADMM technique for market settlement, the market trading system in this paper [34] is developed with consortium blockchain platform. Smart contract will act as a virtual aggregator to ensure the safety of every transaction along the process. Author [35] propose a secure energy blockchain in industrial Internet of Things (IoT) and propose optimal pricing strategy by Stackelberg game theory approach. Research works in [36] and [37] have been conducted to address the security issue for the energy information between peers with blockchain using strategic game theory method for energy market. Author [38] propose a blockchain based system, which is based on a parallel double-chain that combined with a high frequency verification mechanism to enable a trusted and secure settlement of electricity trading transactions.

TABLE III. LITERATURE OF P2P MARKET CLEARING DESIGN IN MICROGRID DISTRIBUTION NETWORK IN RECENT YEARS

| Market Clearing Method | Blockchain Implementation | |
|---|---|---|
| | Without Blockchain | With Blockchain |
| Auction Theory | [39]–[42] | [13], [19]–[21], [25]–[27], [31]–[33] |
| Constrained Optimization | [43]–[51] | [28], [34] |
| Game Theory | [4], [52]–[58] | [9], [23], [24], [35]–[38] |
| Agent method | [2], [3] | [29] |

## VI. Conclusion

Energy trading in the local energy market is a recent and emerging topic of research that draws growing interests. Although this paper deals mainly with the market clearing approaches for P2P energy trading, there are many areas of research that can be expanded in the blockchain implementations. The integration with blockchain system is another concentrate area, where this paper reviewed the electricity market design for P2P energy trading with blockchain implementations. The literature in this paper is organized firstly with brief introduction on P2P market design trading comprises of market structures, market players and market clearing strategy as well as the blockchain system.

Blockchain technology may provide a useful solution. Nevertheless, it may pose challenges but it offers a great opportunity in the interfaces of energy market design and implementation. From the review papers on a different clearing market that enable P2P energy trading, blockchain technology allow the energy to be trade among peers in decentralized and secure environment. Furthermore, blockchain-enabled energy trading mechanism can efficiently encourage electricity sharing among the prosumers and in overall improve the energy efficiency of the distribution system.

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