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Blockchain Based Balancing of Electricity Demand and Supply

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Abstract. The growing number of Renewable Energy Sources (RES) in the energy system provides new market approaches according to price and decentralized generation of electricity. Local market, in which consumers and prosumers can trade locally by generation of electricity through RES directly within their community. This approach creates a balance between generation and consumption in a decentralized manner. In this paper, a distributed technology of Blockchain is used, which highlights the decentralized nature of local market. It provides a decentralized market platform for trading locally without the need of central intermediary through Periodic Double Auction (PDA) mechanism. With the introduction of Smart Grid (SG) systems, there have been improvements in how utility companies interact with customers with regards of electricity usage. However, there is a tendency for the data of users to be compromised in SG. In this proposed system, users are able to do trading through PDA and get access of their own previous history. The blockchain provides transparency, traceability and is utilized to mitigate the above mentioned problems. Smart contacts, are used to exclude the third party to provide a transparent system between users in the network.

Keywords: Smart Grid · Blockchain · Electricity trading · Periodic Double Auction

1 Introduction

Electricity plays a vital role in the development of the latest technologies. It is the basic necessity for the economic development of any country. It is helpful in various areas: transportation, education, banking and computing etc and it enables several revolutions. The integration of Information and Communication Technology (ICT) in the traditional grid it becomes Smart Grid (SG). SG is an emerging technology of this modern era [1]. It provides the facility of bi-directional communication between the utility and its consumers. It introduces the recently advanced energy generation ways such as solar panels and charging/discharging of Electric Vehicles (EV) [2]. Smart Home (SH) is an important entity to make

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any city smart. The SH directly communicates with SG through Smart Meter (SM) to get electricity according to its demand. SG enables consumers to properly manage their electricity consumption through the Home Energy Management System (HEMS) [3]. The data recorded from the SM is transmitted directly to SG in real-time through communication medium. SM's data is stored in the SG database and used for billing and also available for research purpose [4,5]. However, SG is a centralized system and it does not provide data access to the users. Furthermore, the data stored in the SG systems may easily be tempered by malicious attacks, which tend to increase the amount of electricity bill without knowing the consumer and utility companies. Users do not know why they are paying huge amount of bills. There are also many issues facing by consumer and SG about users data such that: traceability, authorization, immutability, security of data and single point of failure. To solve the above aforementioned issues, a new emerging technology of blockchain is introduced.

A scientist named Satoshi Nakamoto gives the idea of "Bitcoin" digital currency, a form of electronic cash in 2008. A concept of Peer-to-Peer (P2P) online trading of digital currency is introduced without the need of an intermediary party [6]. For electronic payments on the Internet, a trusted third party is required as a financial institution. Moreover, for P2P trading digital signatures are used as an initiator to verify the existence of both parties. The cryptographic proof is necessary to build trust that shows the willingness and trustworthiness of two parties. In this article, Satoshi proposed the system of P2P trading. However, this concept is beneficial for online trading, when any company or enterprise wants to use it practically. So, to implement this concept in a real-time environment, an idea proposed about the innovative technology [7] named "Blockchain" in 2015. According to this, Blockchain technology changed the vision of the business model all over the world. It is an innovative disruption in the world of computers, social networks. It is defined as structural database for decentralized storage of data [8]. A block is a collection of data containing related information known as transactions [9].

A timestamp shows the creation time of a block, when many transactions are done and after that, a block is generated. A block comprises of header and body. A header contains hash of the previous block, through which the current block is combined with the previous one and current block knows about its previous block through its hash. The body contains all the transactions and their hashes. Once a block is a part of the chain then, it is very difficult to be tempered. When block is created and validated then, it becomes the part of the chain due to its hash. Blockchain is classified into three types: public, private and consortium blockchain. Public is open, anyone can be a part of this. Private has some restrictions so, only authorized nodes are the part of the network. Consortium blockchain contains half features of public and half features of private. Its data is publicly available to users for read-only, while the write access is available to just authorized nodes [10]. Different characteristics of these three types of Blockchain are shown in Table 1.

Different consensus mechanisms are also used for the validation of blocks and after consensus the block becomes the part of the chain. There are different kinds of consensus mechanisms which are as following: Proof of Work (POW), Proof of Stake (POS), Proof of Identity (POI) and Proof of Authority (POA) [10]. The base of all other types of consensus mechanisms are POW.

Table 1. Characteristics of blockchain types

Type	Openness	Decentralization	Write	Read
Public	Anyone	Complete	Any one	Everyone
Private	Specific individuals	Partially	Specific nodes	Specific
Consortium	Specific groups	Partially	Specific nodes	Anyone

Now-a-days Blockchain is used in different paradigms: in health monitoring, data sharing, getting feedback from users, decentralized trading. To minimize the chances of single point failure, unauthorized persons are not the part of any network to prevent malicious attacks.

In this paper, the solution of blockchain based different smart contracts are proposed that creates a system of P2P trading through Periodic Double Auction (PDA). Authorized users are just able to get access to their own data history. Due to immutability, the users can easily see their original record file and this data is not altered by anyone. Different smart contracts are used to eliminated the third party concept. It is beneficial for users to prevent them to pay the huge amount of taxes in their bills. Due to the deployment of smart contracts, the users pay a small amount of ethers for the transaction.

Section 2 described and discussed the related work. In Sect. 3, provided the implementation details of the proposed model. Section 4 summarized the main finding of this paper.

2 Related Work

In [11], Blockchain based P2P energy trading platform is proposed for efficient transaction of power between prosumers and consumers. The suggested platform is used two different types of P2P trading scenarios: one is Pure P2P and the other is Hybrid P2P. In Pure P2P trade, energy is used as a transaction item and in Hybrid P2P, energy tag is used as a transaction. A Tag is assigned to block for validation and transaction. The production of electrical energy from different domains are divided into ten different categories. Some of them are consumer-oriented and some of them are supply-oriented.

In [12], the authors presented the concept of sovereign Blockchain technology, which prevents data tempering from any malicious source. It also maintained the records of tempered data in side Blockchain. Consumers send their requests of electricity according to their demand to SG through SM. The users monitored

their usage and also know about how much electricity they demand. If the tempering happened then, the record of this tempered data is also kept in side chain of the sovereign Blockchain.

Authors in [13], discussed the idea of distributed trading of electricity in which nodes are used as: consumers and prosumers for P2P trading. They proposed a model consists of two layers: one layer is Multi-Agent System (MAS) used for the sustenance of prosumer side information of generation of electricity. MAS enabled users to negotiate the prices and form coalition. The second layer showed the secure and trustworthy trading through transactions between MAS and Social Coordination Agent (SCA). The trading is secure due to Blockchain based settlement system in which the double-chain and high-frequency verification mechanism worked parallelly, which helped to make trading transparent. In every negotiation system, data is chained one by one and stored in the first chain. The high-frequency mechanism are used to detect any malicious activity occurred between contract and ledger.

In this paper [14], the authors proposed the concept of Federated Power Plants (FPP) and Virtual Power Plants (VPP). VPP made P2P transactions through self-organizing users. They also discussed the incentive mechanism during trade between prosumers and consumers. Two different types of strategies are proposed: Coordination between Distributed Energy Resources (DER) into VPP and P2P energy trading platform.

Noor *et al.* [15] worked on the Demand Side Management (DSM) to improve the reliability of the whole system. A game theoretic approach is used in simple DSM model, which does not only minimize the peak-to-average ratio in SG. It also reduced the dips in a load profile of users. Blockchain technology implemented a DSM system to make P2P trading system secure. In [16], the maintenance and skillful usage of natural resources are essentially related and beneficial for utilization of electricity. The use of the enormous powers, i.e., coal, water, daylight, geothermal resources, wind and gravitational forces for electricity generation. In [17], the authors proposed a framework, which contains seven components. These components are used to implement private Blockchain in Brooklyn case study. In this paper, the authors introduced the merged concept of MG and Blockchain to introduced MG energy market. Homes are acting as prosumers and they generate electricity through PV. The physical layer is showing the infrastructure of MG. Virtual layer displays the price and trading mechanism. Regulation layer tells about the government policies, taxes and rules.

In [18], the authors addressed the issue of Demand Response (DR) with a decentralized system and encouraged the consumers use less energy consumption in on peak hours. The authors proposed the framework of Distributed Load Balancing Trade Framework (LBTF) with two different schemes: Utility-Grid contract and MG contract. Consortium Blockchain is used and POW consensus algorithm is public key encryption, digital signatures and hash functions are used to maintain security of users' information.

Pop *et al.* [19] used a Blockchain based model for storing, managing and validation of DR in low or medium voltages of SGs. Blockchain stored all that data in P2P distributed ledger network which is collected from IOT smart metering devices in a secure manner which is called as temper proof mannered. Authors implemented a new smart contract named as a self-enforcing smart contract which is used for checked out and tracked each Distributed Energy Prosumer (DEP) profiles. All DEPs are enrolled in DR program. Their penalties or rewards are calculated here and it also detects the unbalanced grid energy for DR events.

In [20], the authors described the P2P energy trading system using coalition formation method. Surplus energy and depicted energy MGs are also able to communicate directly with each other. They know about each other state and if they want to share electricity, they trade easily with each other. A Blockchain-based system provides this facility to maintain their state record, whether they want to sell or buy electricity to fulfill the demand of their consumers. Blockchain provided secure transactions and a consensus mechanism allows every valid transaction to add in a block.

The utilities realized their role in the power systems. When the consumers' need a power supply to fulfill their electricity demands. They directly contact utilities. The authors in [21] described the responsibilities of utilities. They collect domestic communities information because there is a rapid increase in the usage of electricity. These modern systems fully spread the power markets and also increased the accessibility of decentralized renewable power production. However, the utilities are able to modernize their business models and support SG markets by proficient knowledge.

Wang *et al.* proposed the system of transactions between MGs through Blockchain and they are using the continuous double auction mechanism for trading [22]. The authors proposed the concept of Unspent Transaction Out (UTXO) model. In this system, the authors used Continuous Double Auction (CDA) with Blockchain technology parallelly to achieved low-cost transactions and transparent data of MG. Satoshi is used as a digital currency which is the sixteenth part of the bitcoin. It is also used as a token. The mechanism of trading of electricity and transfer of tokens are very helpful. MGs can sell/ buy their energy with each other. MGs are able to fulfill the requirements of their consumers. In this system, the unique data structure of Blockchain confirmed the security of data. However, in this system, the authors ignored the power fluctuation in the main SG.

In [23], the authors discussed the issues of management and control of sustainable energy forms. To solved these problems, blockchain implemented with energy through the internet and gives the new concept of energy internet. It consists of renewable energy generation, Energy Storage Devices (ESD) and internet is used for connectivity between them. The energy internet involved various energy forms and different participants. The main contributions are to introduce the compatibility of energy internet and blockchain technology. Blockchain is implemented in many companies and is helpful to provide decentralized applications, however, the excessive power usage is considered. It is just suitable for

some small communities and the practical implementation on a huge commercial level needs more resources. Smart Community (SC) is a necessary part of the Internet of Energy (IoE) which connected all the RES, SG and EV. Permissioned blockchain is used on the basis of smart contracts for secure and private communication. The authors proposed reputation based Delegated Byzantine Fault Tolerance (DBFT) consensus algorithm for energy trading. Users also take electricity from traditional SG or electricity generated through RES, it depends on EV user. Furthermore, this system is designed for SGs, however, prosumers are not considered to participate in it.

In [24], authors proposed the privacy preserving mechanism through private blockchain. Authors in [25,26] proposed incentive mechanism and repudiation

Table 2. Summary of related work of blockchain

Proposed models	Achievements	Limitations
[10] Energy Internet with blockchain	Reduced costs	Reliability and excessive power consumption
[11] LEM	Short term electricity trading, transparent	High Energy Consumption
[12] Grid Monitoring System	Customer utility control	Storage Capacity is small
[13] MAS system	Efficient negotiation System	Interruption of third party
[14] FPP platform	Confidential coordination between VPPs	Cost consumption is very high
[15] Game theoretic model	Reduce peak-to-average ratio and reduced dips	Storage capacity is less
[16] Brooklyn MG	Scalability and robustness	Cost is high
[17] LBTF	Privacy and integration of stored data	Computation time between nodes is very high
[18] Decentralized DR system	DSM system	Multi stakeholder market
[20] P2P using distributed coalition formation method	Trust and robustness	Specific for only two MGs
[22] UTXO	Low cost transactions and transparency	Ignored the power fluctuation in the main SG
[23] DBFT	Energy trading	Third party is involved
[36] Pure P2P and hybrid P2P	Invalid transaction, energy loss, cost efficient	Privacy and no access control of users
[37] POC	Saved the labor cost, minimized the human interaction	Fixed prices for users

system through blockchain for data storage of IoT devices on cloud edge network. In [27–29] authors used blockchain for data trading and store health records of patients on IPFS. Authors in [30–32] performed node recovery in wireless sensor networks and provide secure communication in crowd sensor networks through blockchain (Table 2).

2.1 Problem Statement

Home Energy Management Controller (HEMC) is a centralized system which monitors and controls the home appliances. A consumer requests its electricity demand through SM to SG which can reveal the consumption behavior in front of third party [33]. In such a way, all the data of users can be easily hacked and the malicious person can extract the behavior of users about the routine of the SH dwellers or inhabitants. Authors in [34] proposed cloud based systems to save the large amount of data. SG uses cloud to store vast amount of the information of users. They send their requests of electricity demand and get early responses of their requests. However, the communication between users and cloud is not secured. The record maintained about users detail cannot be seen by users. Users are not able to get access of their own profile history, i.e., demand history of electricity. So, any malicious person can hack the cloud server and can change the users data. In result, the users received huge amount of bills. SG is a single entity to fulfill the electricity demand of consumers. In [36], the authors provide the facility of P2P trading through DSO between users to divide the load of SG. However, authorization of users is not considered. Anonymous users can also become the part of the trading. Moreover, the users are not able to know about the available amount of electricity from DSO. In [37], authors used Blockchain for decentralized trading. However, the users purchase electricity on the defined prices of utility which is considered as one sided market. Users pay taxes to third party which acts as a communication link between prosumers and consumers. The data of users is maintained by DSO. However, there is also an issue of data integrity and confidentiality. In this paper, the Blockchain is implemented for decentralized and P2P trading between different consumers and prosumers. Authorized users can just participate through PDA [22] and do negotiation on prices. They also get access their own previous history of electricity (selling and buying). If an unauthorized user wants to change the data in Blockchain, or wants to add any malicious block in the chain the hash of the block will be changed and a new block is generated. Due to distributed ledger, P2P decentralized trading and immutable nature, the existing block of data remains same.

3 Proposed System Model

This section describes the methodology adopted for the study. The description of the system model represents in Fig. 1 is given below. This proposed model is designed by taking motivation from figs in [37].

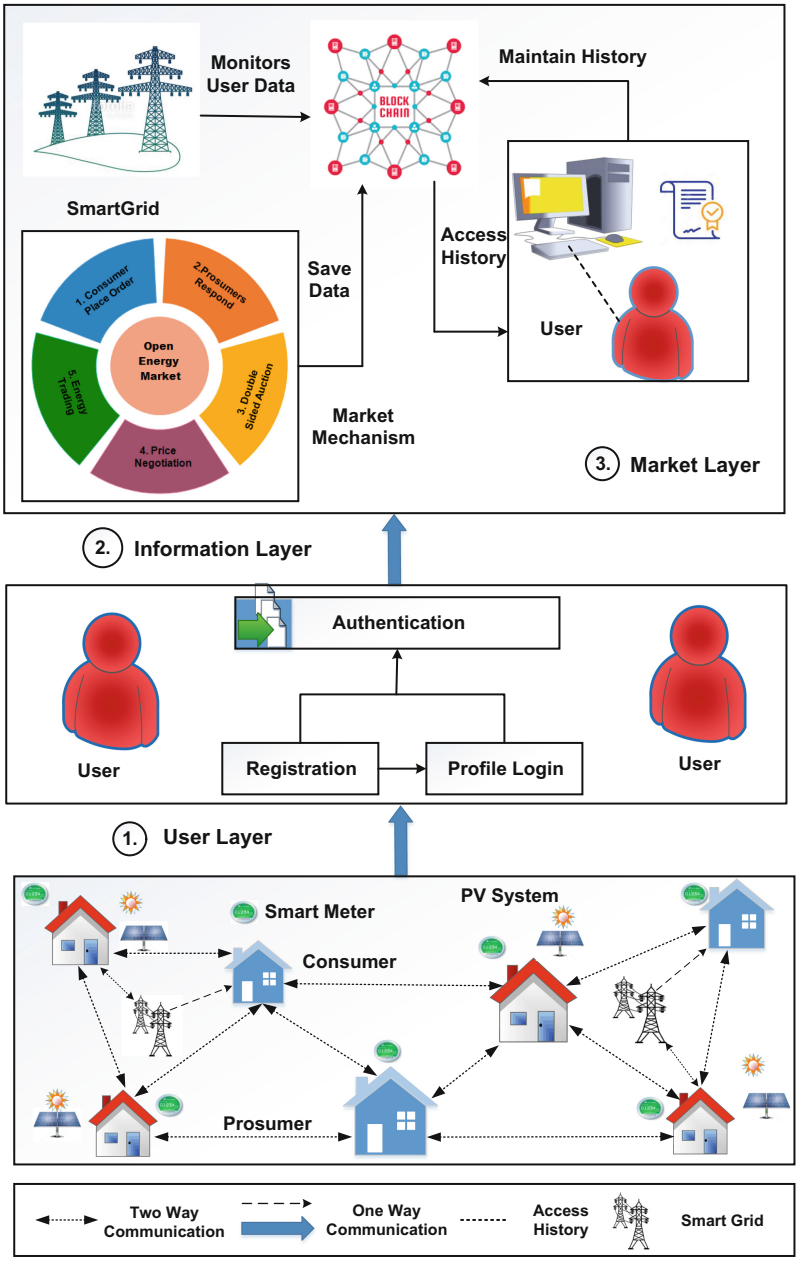

Fig. 1. System model

3.1 User Layer

The user layer contains all the entities who purchase electricity from the market for the beginning and running of processes that are necessary for routine works. Prosumers and consumers can directly communicate with each other without any central party.

They can share their information through blockchain either they want to sell electricity or they need to buy energy from any prosumer. There is a small community in which the registered users are able to do trading. All the information about available electricity sell and buy can be seen by authorized users. A home which has PV panel for electricity generation it acts as a prosumer. When a home has surplus energy after its own usage, then it is able to sell this surplus energy to those homes which are energy deficient. All those homes which purchase electricity to fulfil their electricity demand called consumers. This layer connects with information layer and users provide some information to get registered themselves for become the part of the network.

3.2 Information Layer

It is a second layer of the system model. It comprises of two parts: registration and authentication. When a user wants to be a part of this system then, he must register himself through interface by providing some necessary information his name, password and email address. In addition to this, the user gets its specific unique ID and every user has its own profile. All the information of user is saved on Blockchain and the data stored in the form of hash in block.

In this paper, users are firstly registered themselves and after the authentication they get access to see the history of their previous usage.

When user enters its unique ID and password, the hash will be calculated and matched with the copy of the existing hash which is already saved in Blockchain. If the user can enter wrong ID or password, then the hashes are different and it does not matched with the already calculated hashes. The system shows a message or give pop up notification, your ID or password is incorrect.

The users demand and generation of electricity measured from SM details either this user have surplus amount of energy or energy deficient. On the basis of this information, the deficient and surplus energy details saved in a blockchain and it is a distributed ledger. Every user in the blockchain network have the record of all the transactions happened.

The users demand and generation of electricity measured from SM details either this user has excess amount of energy or needs energy to buy. On the basis of this information, the deficient energy and surplus energy details saved in a blockchain and it is a distributed ledger. Every user in the network have the record of all the transactions done in the blockchain.

3.3 Market Layer

First of all, the consumer gets login from his unique ID and after that, the consumers can place their order in an open market according to their requirement

and also their suggested prices for buying and selling. Prosumers give a response to that consumer who submit its required demand of electricity to buy. The PDA helds for price negotiation between consumer and prosumer. The price auction occurs within a specific time slot for one bid. When bidding is done, then trading occurs. A message is broadcasted in blockchain to SG provides this amount of electricity to that consumer. Every user is known by its special account address in blockchain. It provides the required quantity of electricity to that specific consumer. The transaction cost is deducted for double auction and for the transfer of electricity from the consumer account. All the data of sell/purchase is maintained in blockchain through hashes. It is a distributed ledger which maintains all the records of every transaction in a block. A block creates when all the transactions are added in it for single bidding. A single block can store more than one transaction and it depends upon the consensus mechanism is using in the system. After the generation and validation of a block, it becomes the part of the chain. The users can also be able to see the history of their own usage of energy. The history contains all the information of user details i.e., meter id, amount of electricity demand, electricity sell, electricity buy and timestamp. SG maintains all the history record of every user. Consumer and prosumer can access their own history of sell and purchase through profile. They can also see that how much extra quantity purchased from prosumer, how much electricity consumed. Blockchain provides transparency and immutability.

In this layer, blockchain used to make the system secure and users access their own history. SG acts as a prosumer here. SG is connected physically with all the consumers. So, when the bidding is going to be happen between prosumers and consumers, for transfer of energy to that specific consumer, then Prosumer sends message to SG to transfer electricity to a specific consumer. Every prosumer provides its surplus energy to SG. After the authentication, then user can also be able to do trading and also get access their own data: how much electricity sells at which time and at which price. It checks all the buying and selling transactions. When all the transactions are done then a block is generated and after the validation of a block, it becomes the part of the chain. Hashes of transactions are calculated. These hashes are used to verify about the ownership of sender through its address. Every node in a network has its specific address and all the nodes in the network are anonymous. So, no one can see the name or other details of any user, the address of the account is just visible.

For energy trading within a small community, electricity is generated through PV panels and the PDA mechanism is used. PDA used closed order book system for trading. A particular clearing price is obtained for every single time slot t. In this specific time slot, one bidder could be entertained. Consumer can send their demand of particular amount of electricity and price into the market for bidding. When prosumers received the order, then they reply their own prices and quantity for bidding. After that, the prices are matched between both of them. Then, prosumer sends encrypted message through its SM to SG, provide this specific amount of electricity to this specific consumer. SG decrypts this message through the public key of user. The price of per unit of sell/ purchase of electricity is followed by the tariff price given by utility market. Prosumers cannot send their

surplus energy to consumers below the minimum price limit of tariff. Consumers cannot purchase the electricity per unit more than the maximum price limit already defined by the utility. Electricity cannot be sell or buy from SG in this local market. SG is also acts as a prosumer here because it is physically connected to every SM to provide electricity.

4 Simulations and Results

In this section, the implementation details is based upon an open source platform of Ethereum blockchain, which inherits some technical features and block creation after validation. Market mechanism and authentication of users by RBACS are implemented through smart contracts which are written in solidity language. The specifications for implementation setup are: intel(R) core (TM) m3-7Y30 CPU@1.61 GHz, 8 GB RAM, 64 bit Operating system and X64-based processor. The programming language is solidity to write smart contract. Javascript using for front user interactive form. The tools used to develop this system are following:

Visual Studio Code: It is an open source editor designed by Microsoft for different windows and operating systems. It is used for code compilation and also supports java script for user interface. Ganache: It is a virtual emulator which has ten addresses of Ethereum accounts and each account contains 100 ethers. It is used as a wallet to test the smart contracts, to run test and to execute different commands. Meta mask: It is the extension which is added in a browser to create connectivity between ganache and smart contract for transactions.

For simulations, python language is used and Spyder is used as a tool to perform all of these results are showing here.

Different graphs are showing about the transaction cost and execution cost of various smart contracts. Transaction cost is the total gas consumption of sending data to the blockchain [6]. Transaction gas depends on four things: Base cost of a transaction is 21000 gas. Base fee is the cost of an operation which retrieve the sender address from the signature. The minimum deployment cost of the contract is 32000 gas, zero byte data or cost for a code of transaction and the cost of nonzero byte of data or the cost for a code of transaction. Execution cost is also included in a transaction cost. Execution gas is the cost which depends on the cost of computation operation of every line of code in a function. Basically, the execution cost is the everything cost which is used as a runtime cost used for the calling of single method or function.

Figure 2 shows the execution and transaction costs of the contract to deploy and calling of every function. The contract is used to do double auction at which the global variables call. This graph represents the difference in transaction cost and execution of every function. The total transaction and execution gas consumed for the deployment of these contract is $0.8541 and $0.4310, respectively. The different bars show the different amount for execution and transaction gas. Transaction cost of every function is high because it contains execution cost of that function and also it contains the deployment of every function in smart contact (Fig. 3).

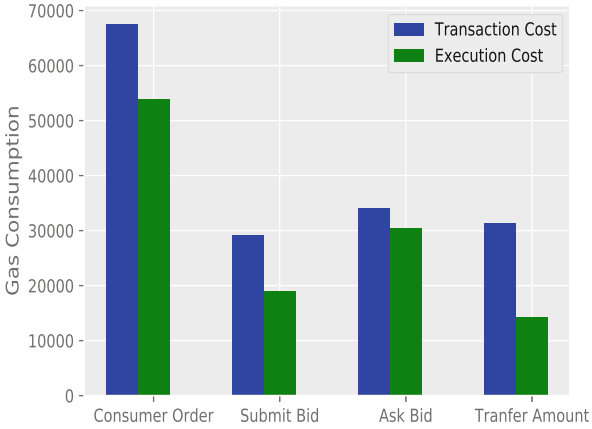

Fig. 2. Double sided auction

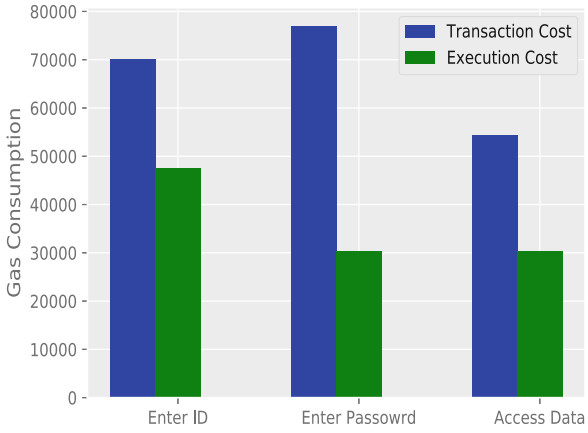

Fig. 3. Data access

5 Conclusion and Future Work

Blockchain is used to do decentralized trading. Through PDA mechanism, users are able to purchase electricity according to their own suggested prices. In this proposed work, authorized users are just able to do trading and also achieved immutability, decentralization and data security. In this paper, users are also able to see their own history (buy and sell electricity). Authentic users are just able to do trading and access their history through interface. Smart contracts are used to remove third party. PDA is used to do negotiation in prices and purchase electricity according to demand. Gas consumption prices are also analyzed through calculation of transaction cost and execution cost of smart contracts. The challenge of this work is limited amount of storage. In future, decentralized storage is used to store large amount of data on it.

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