A Transactive Energy Microgrid Model using Blockchains

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ABSTRACT

The price of technology used in the production of renewable energy (RE) has come down significantly, and end users' roles have shifted from that of simple energy consumers to that of active participants in the creation of their energy. This new function is known as a prosumer, and it has led to the change in electricity markets by enabling prosumers to resell energy excess to electricity suppliers and other prosumers. As a result, there is a need for a peer-to-peer (P2P) energy trading network that makes use of the Ethereum blockchain and a smart contract mechanism to operate as an interface between prosumers and consumers. This paper develops a microgrid model incorporating Blockchain technology to simulate peer-to-peer energy transactions. In the simulation setup, solar panels are employed as the primary source of electrical energy. In addition, energy storage batteries when the sun sets complement the energy provided by the solar PV in the simulation developed. Furthermore, an automated bidding system to facilitate energy transactions is implemented. The bidding system consists of a full interface that shows houses supply, demand, batteries, and the bid on the energy. The simulation is carried out for 20 days, with 15 houses connected to the grid. Full transaction simulation resulted in peak prices that were more than 25 percent lower than real-life energy tariff coming from the electric utility company.

Keywords: Blockchains, Microgrid, Ethereum.

1 Introduction

Blockchain is a promising technology that allows P2P transactions between individuals in a trust less environment [1]. It can facilitate the distribution of power across the system, thus ensuring a level playing field for all participants in the absence of a central authority responsible for controlling the information (in some cases). Because the information is readily available, openness is not hindered. The use of blockchain technology to promote P2P power trading paves the way for a market transition from one that is highly centralized and controlled by a few big enterprises to one that is more decentralized and controlled by microgrids. P2P energy trading offers a solution to the problem known as the "utility death spiral".

Peer-to-peer (P2P) energy trading has emerged as the next-generation strategy in energy management. This technology enables prosumers (active customers that have some energy supply capabilities) to trade the excess electricity they produce. Prosumers will directly sell excess electricity to local consumers without the intervention of a retailer, hence allowing transactions that are beneficial to both parties. Customers are allowed to engage in energy trading with their contemporaries as a result of this development, which results in a shift in the way customers utilize energy. Consumers will pay less per kilowatt-hour and may be able to show their preference for renewable energy without having to purchase the technology if this arrangement is put into place. Meanwhile, prosumers will benefit from this arrangement because they will earn more than they would through feed-in tariffs. Because energy storage batteries can be used to store untraded electricity, auctions for renewable energy have the potential to generate a dynamic market that is to the advantage of both prosumers and consumers. Users in P2P power marketplaces may be given the option

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to freely choose the source of their electric energy, such as by investing in renewable energy that is created locally.

The untraded electricity is the result of an increase in the installation of solar panels on rooftops, which brings about a reduction in the overall power consumption taken from the grid, while having very little impact on the peak demand. Because there are fewer paying customers to maintain the vital infrastructure, utilities are compelled to hike the price of electricity, which in turn encourages more people to use PV panels. This is a situation that is occurring all around the world, and it has been made worse by the declining costs of PV technology. Although the installation of energy storage batteries by PV users could help to reduce peak demand, excess electricity is still sent back into the grid in an inefficient manner, when demand is low.

Blockchain technology is applied under various platforms. Ethereum is the most valuable solution platform for Blockchains [2]. Ethereum can not only be written in many programming languages, but also it has the smart contracts capabilities built into it, which provide main advantages over other blockchain technologies.

1.1 Energy Trading

Because of the vulnerability of transactive energy systems to natural disasters like Hurricane Maria and cyber threats like the attack on the power grid in Ukraine [3], there has been a growing emphasis over the past decade on decentralizing the operations of electrical power networks. Prosumers can collaborate in the absence of centralized control to dynamically balance demand and supply throughout their microgrid systems, which can consequently enhance the system's resilience. Having said that, this does call for the creation of a financial market at the distribution system level. When compared to a conventional grid, the current system has far less inertia, hence it requires additional control methods to ensure that the local energy sources remain constant. This is the core concept that underpins the operation of transactive energy systems (TES) [4]. If the amount of energy produced is greater than the amount of electricity required, then some of the surplus energy can be sold to nearby residents who also require power. This paper aims to develop a peer-to-peer platform for energy trading using the Ethereum blockchain platform. With a device algorithm to facilitate communication between prosumer and consumer with the blockchain using the smart contract and simulating it using solar panels energy harvesting as the main energy source. To make the transaction in the smart contract, establishing a bidding system algorithm to organize the energy transaction is needed.

1.2 Energy Trading Platform

The predictive energy trading platform is based on a modular design in which each layer is independent of the others. This gives the ability to rapidly adjust either the existing components or the newly added ones without affecting the rest of the system. The model of the distribution grid network is composed of a wide variety of scattered energy resources, such as solar energy and dispatchable loads, that are connected through the use of a bus transmission line. Each bus serves as a connection between the grid and a node, allowing for the consumption of and transmission of energy. The identity management, application programming interface (API), distributed ledger [5], peer-to-peer communication, and consensus manager are some of the blockchain features that are included in the energy trading service [6].

1.3 Blockchain Technology and Smart Contracts

A blockchain is a shared distributed database or ledger between computer network nodes. A blockchain serves as an electronic database for storing data in digital form. The most well-known use of blockchain technology is for preserving a secure and decentralised record of transactions in cryptocurrency systems like Bitcoin. The blockchain can be programmed with a smart contract, which is computer code, to facilitate, verify, or negotiate a contract agreement. Users accept a set of terms under which smart contracts function. The terms of the Agreement shall automatically be carried out upon the satisfaction of such requirements.

Smart contract's role:

1. Smart contracts enable the exchange of assets other than money or cryptocurrency.

2. Smart contracts enable the definition of rules for the blockchain's operation.

3. The smart contract simplifies the implementation of asset transfer policies in a decentralized network.

4. The smart contract enhances the blockchain's programmability and intelligence.

2 Materials and Methods

Using Ethereum's smart contract, this project replicates the peer-to-peer transmission of power in a microgrid. By beginning the process of establishing the server, which is the smart contract, the component of the system that enables the exchange of information in the market[7]. Within the peer-to-peer energy trading market, every prosumer has a unique key (serial number) on the smart contract that can be used to trade information and value with other participants.

At predetermined periods, a trigger is activated, which in turn causes the subsequent auction operation to take place: Execution by the system operator results in the creation of a new transaction, which is followed by the broadcasting of the transaction invocation request to the endorser peers. This action marks the beginning of the matching process. Endorser peers perform a validation check on the transaction, as well as a check on the contract.

After that, the chain code is executed to get and decode all of the user information that is stored in the database. The point of interaction can then be determined by the algorithm. Following the establishment of the price range and the temporary price following the payment rules, the smart contract is updated with the necessary key information (i.e., the price range, the temporary price p (TP), the optimal price (OP) [8], which makes it possible to track the progress of the auction. These vital pieces of information are brought up to date during the execution of the smart contract.

Prosumers are linked to microgrids, which can be isolated or interconnected. For the interconnected, prosumers are organized in groups, notably energy communities, in which resources, which are not necessarily physically adjacent to each other, are controlled in tiny pools. By connecting the prosumers to the network, the smart contract will gather information about the energy provided by the prosumers and list it in the market with starting bidding price as low as 1 cent per kW.

Information collected by the smart contract include:

i. The energy supplied is to be sold.

ii. Energy from batters when available.

iii. The asking price for the energy as an entry point to the market.

iv. The private key for the prosumer payments.

3 Theory and Calculation

In order for P2P energy market to function effectively, a continuous double auction approach is used. It is a theoretical method in which the buyer changes the quantity of energy to buy in response to changing electricity prices in order to maximise benefit, the auctioneer controls it, and the seller does not participate but ultimately achieves the maximum social welfare The suggested solution not only helps the participants but also conceals personal information, such as bids and requests, for privacy reasons. It intends to lower the cost of electricity for community microgrids. Additionally, it helps to increase the resilience of distributed energy resources and systems in general. Residential microgrids have a consumer-focused P2P market unlike industrial microgrid which are more focused on big industrial uses. Under unpredictable conditions for power generation, unified and specified price techniques are proposed for facilitating fair and efficient P2P energy transactions and maximizing distributed energy resources profit.

The model used is a distributed multi-agent network used to model the interconnected microgrid system, with each agent (microgrid) acting as a node. The term "multi-agent coalition" refers to a method of completing a task where no one agent can do it alone.

This concept led to the first assumption that each microgrid (agent) was only composed of distributed renewable energy generation and demand. There is no grid backup because all microgrids are connected and isolated from the electricity grid. Because of this, all microgrid operators in the isolated system are responsible for balancing local renewable energy generation and demand. As a result, the happiness of all P2P traders is gauged by reaching zero net loads. Demand minus renewable generation is what is meant by "net load." As a result, all of the microgrids in the islanded system have agreed to work together to meet their net load.

The second assumption is no local non-renewable resources are available in each microgrid (e.g, dispatchable units, storage, controllable loads). As a result, microgrids are highly motivated to take part in P2P trading to maintain a stable netload.

Matching of power demand and excess power generation by homeowners is the basis for the determination of the bilateral trade coefficients in this method. To put it another way, Pi's willingness to trade at Pt is proportional to the amount of its anticipated deficit demand or excess generation. If this method is implemented, it is anticipated that households that have an excess of power will be more likely to trade energy with families that have a power deficit, and vice versa. Utilizing this method could result in the establishment of a bilateral trade market that prioritizes the operation of an economic mechanism. To include these assumptions in the bilateral trade coefficients, several different measures are done.

In this process, the expected net budget matrix is produced. This matrix includes the net power of all families over all timesteps. This matrix is then used to generate two new matrices called buy and sell, which include the amount of net power that each residence intends to sell or purchase at each timestep.

4 Results and Discussion

By starting the simulation, the objective is to make it as a real-world case study as possible, by implementing practical data data. In this project, 15 different data houses were connected independently from each other in the same network and acted as prosumers and consumers.

The system simulated the energy from the houses collected by solar panels. The houses provide the energy in daylight while the panels are active and stop once the panels no longer provide sufficient energy.

The dashboard will organize and list the details of each house in a manner that is appropriate according to how it is connected to the grid. It's possible that some houses have batteries that convert excess energy into a form that can be sold later on, or utilize the power by the house itself. The program will determine whether there are batteries connected and installed in the house or not.

In case batteries were installed and active which in this case were at night, with only a few houses in the simulation, it did not impact the final results as it is not as energy dense as the solar panels in terms of output.

The interface will show all houses that are connected to the grid via a smart contract. The information is shown on the interface:

1. Batteries with the energy that it contains
2. Supply and Demand in W.
3. The bid to sell or buy.

The simulation was run continuously for twenty days during the summer. Due to the characteristics of solar panels, it was not always consistent; on some days, the supply was higher than the demand, while on other days, the demand was higher than the supply by a margin of twenty-five percent.

The properties of the solar panel cause it to experience a significant drop in output while the sun is not shining, which is reflected in the graph. Because of that, the power will have to come either from the regular grid or from the power that was stored in the batteries when the solar panels were producing energy.

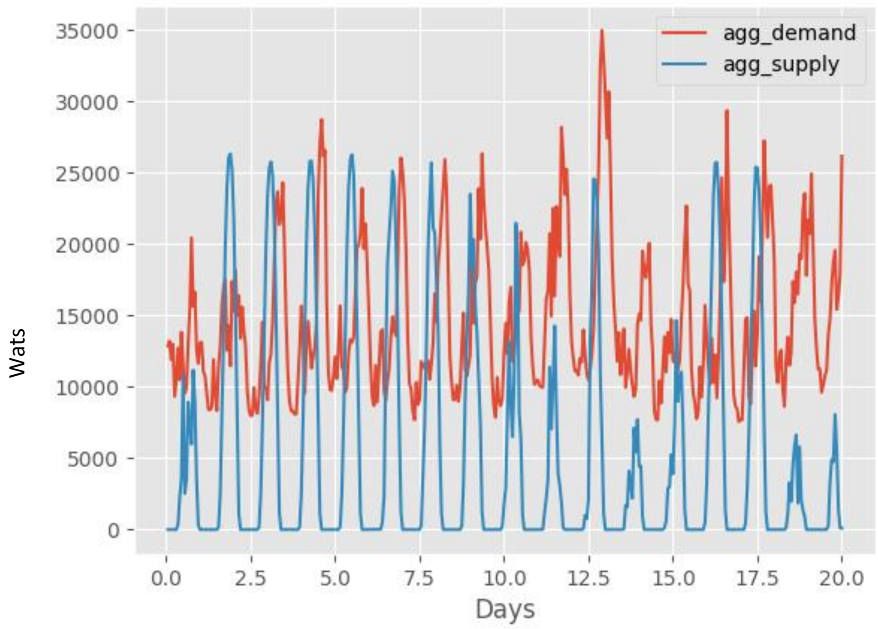

Figure 1: *Supply and demand in Watts*

All the houses in the simulation had supply-and-demand needs and as the graph shows some of them demanded more than could supply and that demand peaked at 35 kilowatts on day 13. The simulation started at night were no supply yet the demand was high respectively. On day 2, the supply exceeded the demand which let the price drop low. As night approaches there is no supply of any power as solar panels are not active.

On days 13, 15, 19, and 20 half of the houses were not able to supply due to the sky being cloudy (as showed in Figure 1.

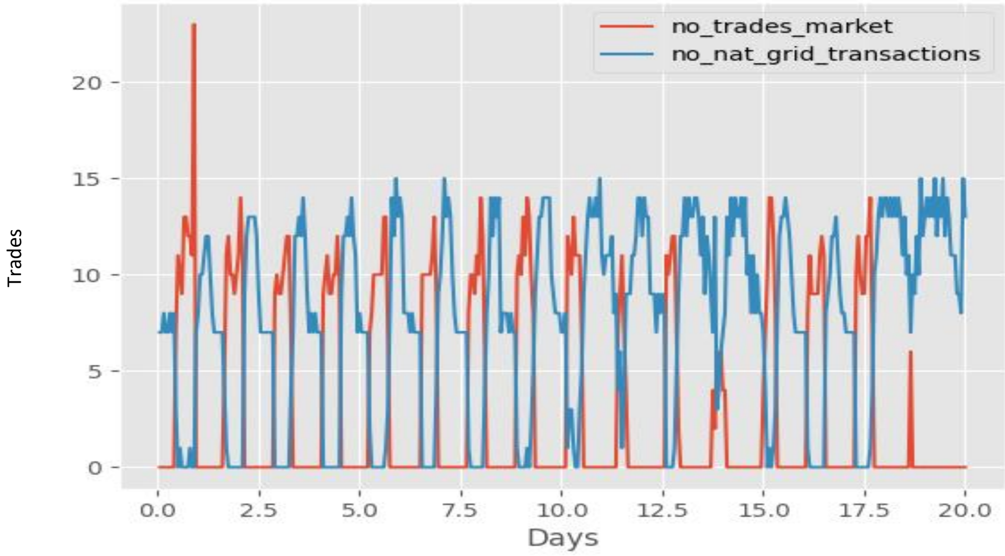

Figure 2: *Transactions/trades*

From Figure 2 an observation that can be made, based on the trades and transaction graph, having more trades does not necessarily result in having more money because the trades are only held up to the supply that is provided by the grid. When the maximum number of trades are made, the grid will start transacting all of them, and it will not accept any new trades until all of the existing trades have been transacted to the grid.

The mechanism of bidding is operational and able to take bids. The cost of the bedding is first determined by the supply, and it will continue to increase in direct proportion to the amount of energy that is required.

The price will go up in a manner that is directly proportional to the amount of supply that is still available.

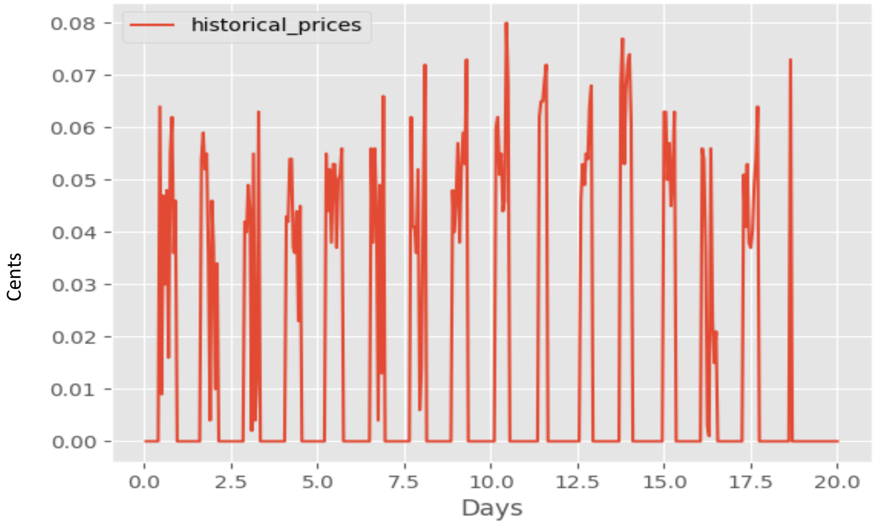

Figure 3: *Cent per KWh*

In the context of this discussion, the cost of one kilowatt of electricity could fall between $0.01 (as a starting price) up to $0.08 per kilowatt (as showed in Figure 3).

In America According to data from the most recent Electric Power Monthly report, in 2021, the average nominal retail price of electricity paid by residential electric customers in the United States increased at the fastest rate since 2008. This price rose by 4.3% from 2020 to 2021 at 13.72 cents per kilowatt-hour (kWh), marking the highest rate of increase since 2008 [9].

The use of solar panels and trading contribute to a reduction in the amount of power required by the utility company, which in turn results in less damage being done to the environment. Some homes generate more than three times the amount of energy that they need, resulting in a net profit that is two times as high as the initial investment. The low cost of peer-to-peer (P2P) trading of energy, which in its highest as 8 cents per kilowatt-hour (kWh), which is 41.7% decrease from the average price 13.72 cents per kilowatt-hour (kWh).

5 Conclusions

Blockchain is a fundamentally promising technology for energy sale and distribution. This paper has provided a detailed analysis of the blockchain application for the purpose of peer-to-peer (P2P) energy trading. To realize this purpose, a platform is created, using simulations, to organize the energy supply, from solar PV along with energy storage batteries, and demand from the prosumers and consumers. A bidding system was setup to aid this prosses and expedite the energy transactions between different parties in the system. Simulations were conducted for a period of 20 days, including 15 houses connected to the microgrid. Results have shown a 25% reduction in peak energy prices, using P2P energy transactions, as compared with the electric energy prices provided by the utility. P2P energy trading is still in the early phases of development. Further research is needed to bring the notions presented in the paper into a more comprehensive application.

6 Declarations

6.1 Competing Interests

There is no conflict of interest.

6.2 Publisher's Note

AIJR remains neutral with regard to jurisdiction claims in published maps and institutional affiliations.

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