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P2P Energy Trading Application In Smart Grids Using Blockchain

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Abstract: ***This paper helps one to understand the concept of smart grids, blockchain, and their interaction with one another in a real-world application of the energy sector, specifically in the smart grids. Initially, we will focus on the working of smart grids and compare them with traditional models. Formalize a list of existing gaps in the present technology and solve them with the introduction of blockchain technology as the principle solution. In the current energy distribution system, when a supplier produces electricity from a renewable energy source (RES), the distribution process is highly inefficient and mismanaged. The meter readings are first logged onto a spreadsheet and then sent to the registry provider to issue a certificate. Then multiple other intermediaries are involved in the whole process, such as one to broker a deal between producers and consumers. Then another external intermediary is tasked with verifying the certificates. This causes an increase in the operational costs, errors, and multiple third parties/mediators involved, which causes a lack of trust in the system. The current system is also highly centralized, and our proposed system; this is P2P energy trading in smart grids using blockchain aims to eliminate the above drawbacks.***

Keywords: blockchain, certificates, IoT, smart grid.

I. INTRODUCTION

Blockchain is the latest and upcoming technology that helps conduct and support real-time transactions by incorporating principles of cryptography. This technology is a series of blocks, with each block containing multiple transactions and connected to the previous block in the chain. Blockchain is a distributed ledger, and the transactions/data in each block are immutable and digitally recorded. Each block comprises of transactions/data that have taken place, timestamped, and verified. The blocks have multiple attributes such as unique identification, unique hash function, and also has the hash value of the previous block, which is connected to this block. Due to these factors, the transaction on the blockchain is secure and reliable, as the data cannot be changed or manipulated by anyone.

There is no requirement of a central administrator as all the transactions are stored on a distributed ledger, and these transactions are verified and approved using a consensus algorithm between the peers of the network. Since there is no central administrator, it eliminates the risk of Single Point of Failure. This technology has many diverse applications over a wide range of areas, such as the economic sector, government sector, healthcare sector, and recently Internet of Things (IoT). Therefore, using this technology increases safety, reliability, trust, and overall operational as well as transactional costs.

P2P energy trading will completely transform the age-old highly centralized network to a fully distributed system where the current energy buyers are inclined to producing their own renewable source of energy. However, implementing this framework has many constraints that need to be addressed. Some of the issues are price fluctuation, varied energy usage, recurring bills, communication between peers, dynamic management of transactions, privacy, and security.

This technology also is the main factor for constant change in data due to multiple reasons; some of them are:

1) The peers in the network verify these transactions with the help of the consensus algorithm, and hence it very reliable and trusted system.
2) The deployment and overall operational costs are considerably reduced due to the lack of a single central administrator in blockchain.
3) Since the peers interact and communicate within the network, uploading data and recovery is a smooth and efficient process.
4) Due to the lack of a central administrator and direct user-platform interaction, Single Point of Failure (SPoF) and Single Point of Compromise (SPoC) can be eliminated, respectively.

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5) Many IoT devices like smart meter perform computationally-intensive operations which require user authentication and access control, the overall operational overheads can be considerably reduced with blockchain platforms as they can efficiently process these operations.

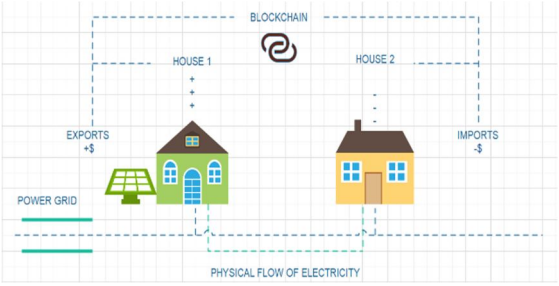


Fig 1. Concept of P2P energy trading

In Fig 1, the basic concept of how our P2P energy transaction takes place is described in a brief model. Later, in this paper, we will provide comprehensive architecture and a framework for P2P energy trading. This paper aims to demonstrate the benefits of blockchain for an energy trading platform and build a suitable model that can be used in a real-world scenario. We will also demonstrate how this can be implemented. This thesis mainly focuses on helping with the research in the interaction for the energy sector and blockchain to help build a sustainable future.

II. LITERATURE SURVEY

A. Smart Grid Operations

Many of the research papers mainly discussed the topics on economic factors, power commitment to the grid, scheduling distributed energy resources and managing the voltage of the whole smart grid in order to maintain stability and control the load factor. A considerable number of recent models are developed around Optimal Power Flow (OPF), Demand-Response, which is another branch of related studies.

1) *Optimal Power Flow:* This model describes the best and most reliable operating procedures for a power plant in order for them to make sure the rising demand for energy in the transmission lines is satisfied, intending to reduce the operational costs. This model comes with its own set of drawbacks; they are:

- The producers or generators might reject the developed set of OPF guidelines for DERs.
- P2P energy trading within the model is not elaborated or discussed.

2) *Demand Response:* The process of changing the utilization of power to meet the demand to ensure efficient supply. By increasing/decreasing the rate of generation, switching generators form online to offline and vice versa, and getting energy from other resources in the area are some of the methods traditionally used to create a balance of supply and demand. These generating units do not produce maximum capacity immediately; therefore, there exist some limitations when energy is produced in plants. It also costs a lot to run these plants, and sometimes the demand can be higher than the supply capacity. Demand response changes the demand for power and not the supply of power generated. There exist three ways in order to implement this model; they are:

- With the help of DERs, we can minimize the demand.
- Changing controllable loads can reduce demand.
- Developing smooth generator guidelines to reduce overall production.

B. Blockchain and Energy Trading systems

Blockchain is a distributed ledger that stores transactions in a series of linear blocks that are connected to the previous block and are based on cryptography. Each of the blocks has several attributes, such as unique identification, unique cryptographic hash value, the value of the previous block, timestamp, gas used, and many more functions. The data stored in these blocks are immutable and resist any changes. It is an open method, in which two entities can efficiently make a transaction which is permanent and can be verified.

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Blockchain is safe and secure, as there is no central administration. All the transactions are verified by the peers in the network using the consensus algorithm. If the block is stored, the data in the block cannot be modified or altered proactively without all the other nodes in the network getting affected, and this needs the consensus of the majority of the nodes.

By design, the data on the blockchain is entirely secure and immutable even though they are not fully immutable. However, there are some limitations; such as:

1) *Consensus Mechanism:* This is a fool-proof mechanism which is incorporated in blockchain that the transactions are not open to more than one interpretation and ensures that the data integrity and consistency is maintained. This requires high-performance computational equipment with high energy usage. Some mechanisms are:

a) Proof of Work (PoW)
b) Proof of Stake (PoS)
c) Delegated Proof of Stake (DPoS)
d) Proof of Authority (PoA)

2) *Smart Contracts:* It is a computer program or code that acts as a digital contract to support, verify, and ensure that the terms of the agreement are met to facilitate the transactions. Smart contracts allow verified transactions to take place into the need of an external agent or any intermediaries. The transaction taking place using blockchain can be traced but cannot be reversed.

Blockchain can be divided into two groups; public and private. In a public blockchain, the miners involved can contribute to the consensus algorithm and blocks. However, in a private chain, the creation of blocks is given to specific individuals. Therefore, in our case where a management responsibility is required, a private blockchain is generally preferred.

III. SYSTEM FRAMEWORK

A. *Smart Energy Grid*

Smart grids incorporate various revolutionary technologies, commercial ideas, have several guidelines as well as regulations. The term smart grids do not have a specific definition. The closest definition would be, “A smart is a collection of many nodes in the network that are connected intelligently to make sure that the system is highly efficient, sustainable, stable and economically beneficial.” In Fig 2, some of the components of the smart grid are represented.

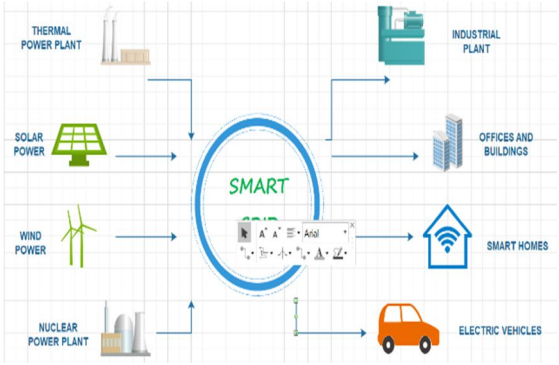


Fig 2. Smart Grids

B. *Blockchain Technology*

Blockchain is capable of revolutionizing many sectors, especially the age-old energy area. This technology issues smart contracts that enable the user to complete a transaction with another user under specific guidelines. It consists of a set of blocks that are connected to the previous block with each block having an identification, hash function, and hash function of the previous block. Therefore, any changes to these blocks would cause a change in the subsequent blocks as well. The data on the blocks are immutable.

In the peer-to-peer energy trading model, all the transactions are stored in blocks, which are part of a network that has both the parties involved in the transaction, which is suppliers and consumers. Blockchain technology provides users with transparency, trust, and security; therefore, being widely accepted across different areas. Blockchain can be divided into public and private network depending on the application. For P2P energy trading application using a private network is preferred. The information on blockchain is resistant to any changes or modifications.

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Blockchain has no central administrators and managed by the peers of the network under some protocols for communication and validation of block in the chain. Once recorded, the data/information in the chain cannot be altered without affecting the subsequent blocks in the chain. Implementing these changes requires a majority consensus between the peers of the network. Making changes in the network id very hard, and therefore by design, it is meant to be extremely safe and secure.

The consensus algorithm used by blockchain is a fool-proof system that requires the peers in the network to verify the transaction and create the blocks. However, this is a computationally intensive operation and requires a high-performance environment. The consensus algorithm ensures the integrity of the data and provides consistency.

A smart contract is a piece of program that has specific guidelines and negotiations under which the transaction is facilitated and verified. This contract ensures that legitimate transactions take place without the need for an external agent or an intermediary. The transactions taking place under these circumstances are trackable and can not be reversed once confirmed.

C. Smart Energy Grid based on Blockchain Technology

An innovative application of the Blockchain technology is being proposed here. The paper aims to demonstrate that blockchain plays a significant role in communication, transaction, and security purpose with the users or people involved in the smart energy grid. This enhanced solution comes with various benefits such as the decentralization of power plants, here there will be a significant shift to the new energy market from the conventional way in which energy was being distributed until now.

From the business perspective, the Smart Energy Grid will help to make a decentralized energy market, where the blend of Blockchain technology and communication advances will encourage secure transactions and payment between a million nodes in the network.

IV. PROPOSED SYSTEM ARCHITECTURE

In Fig 3, the proposed system consists of several essential components to build an efficient system. In order to explain the system, the architecture is divided into two broad categories, that is the working/layout of smart grids and the blockchain application.

A. Smart Grid Network

This network primarily consists of energy generators through renewable sources such as wind and solar, and energy consumers. Each house in the grid consists of smart meters and has an in-home display. The energy producers can find out how much excess energy is produced against their own consumption; this can help them determine the number of units that can be distributed to others in the network. The energy consumers can track their usage and requirements in order to establish the number of units to purchase on the platform. The houses on the grid have access to both the primary source of energy from the main power plant as well as secondary sources generated by individuals on the grid. In the case of a rare power failure, the houses can always use electricity from the Electricity Board (EB). The energy generated by the producers on the grid is sent to the central power station for distribution, to ensure that there is no requirement for storage units. Energy generation is a continuous process; hence it is not viable to store large amounts of energy in batteries, as they are costly and will require large quantities. Therefore, we have designed a continuous distribution process through the main supply lines. The power stations mainly consist of an island invertor to cut off the smart grid from the central power station for safety, a control unit to distribute the energy to various houses on the smart grid, and a transformer to step up or step down alternating voltage while maintaining power at the same level. In the case of excess energy generated and required, is re-distributed to other power station and acquired from other power stations, respectively.

B. Blockchain Application

There is a requirement for data from the meter to be stored, compiled, processed, as well a platform for the transactions to take place. Blockchain technology, combined with the use of the Internet of Things (IoT) enabling technology, will provide a platform for P2P energy trading. The communication takes place with the help of wireless data links over a mesh network. The services offered on the platform is real-time, in terms of information related to energy and peak usage timing. This platform communicates wirelessly using a Wi-Fi module under specific protocols with the control unit, which distributes energy to the houses on the grid.

The transactions take place in real-time, which is extremely safe and reliable. The producers immediately receive the money in terms of Ether once the transaction is over. All this takes place on a web or mobile application, where all the relevant information is displayed, and the transactions can take place. The details of the transaction are stored on a distributed ledger that can not be modified. The whole system can is controlled with the help of the application. Therefore, it eliminates the need for any third party to be involved in the process. They can be implemented in communities, local area, or even cities. To implement these scenarios, we have designed a typical architecture that is the most viable and of high efficiency.

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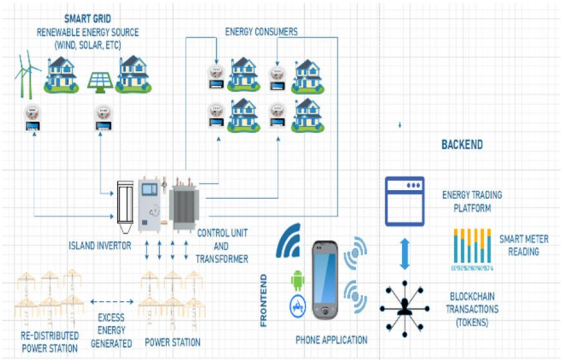


Fig 3- Architecture for P2P energy trading using blockchain

C. Components in this System Include

1) *Island Invertor:* The primary purpose of the island invertor is to cut off or remove the power grid from the smart grid detaching each other off and thereby being a sole power source. It is also used for safety purposes.
2) *Power Station (MicroGrid):* It is the primary producer of electricity; that is energy generated from fossil fuels. The MicroGrid concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides both powers to its area. They can generate power from both renewable and conventional. MicroGrids are controlled through a MicroGrid controller incorporating demand-response so that demand can be matched to available supply in the safest and most optimized manner.
3) *Control Unit:* The control unit (CU) is a component that helps with the distribution process and decides the flow of the electricity.

D. Blockchain Smart Energy Grid Application

The app that has been developed to reach the Trading Platform using Blockchain technology is composed of a set of main functionalities,

1) *Activity Monitor:* Once we log into the application, the user will be able to view a set of parameters in real-time, such as the instant energy consumption of the domestic equipment; the energy produced by the photovoltaic panels. The energy absorbed by the network (Microgrid), details on the percentage of energy used (own production and Microgrid)
2) *Blockchain Technology:* Through blockchain, the user may visualize the quantity of energy stored with the accumulators and select one of the available Energy suppliers in the Trading Platform, obtaining the corresponding daily sales rate; once the Company has been chosen, the user can indicate the quantity of energy to be sold among the Microgrid and previously visualize the final sale; after defining the revenue of each transaction, the user can authorize the sale transaction, whose parameters will be recorded in the Blockchain ledger, which is transparent.
3) *Reading:* Through the "Reading" functionality, the user can consult the daily operating parameters of his system (energy absorbed by the system, taken from the MicroGrid and produced by the plant) and the data of the transactions related to the sale of energy.

V. IMPLEMENTATION

Smart meters present in each household measure energy consumed against the energy produced. The energy is produced using renewable resources and is used as a secondary source of energy in the grid. Excess energy produced is rerouted to consumers that require it. Ganache is a personal Ethereum blockchain which we used to run tests and inspect the state while controlling how the chain operates. It clones the features of a real Ethereum network, including the availability of several accounts funded with test Ether.

First, one needs to configure their environment for developing smart contracts. The first dependency one will need is the Node Package Manager, which comes with Node.js. It is the default package manager for the JavaScript runtime environment Node.js. It consists of a command-line client, also called npm, and an online database of public and paid-for private packages called the npm registry.

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From the web application, users are allowed to sell and purchase energy to fulfill their energy requirements. Details such as owner address and energy reserves available are specified alongside the cost in Ether within the web application. We use Web3js. A collection of libraries that allow people to interact with a local or remote ethereum node using an HTTP or IPC connection. This is accomplished through Metamask. Using Metamask as a bridge, we enable the running of Ethereum dApps right on their browser. It facilitates the tools required to visit the distributed web right on their browser without running a full Ethereum node. This, in turn, connects us to the simulated blockchain environment that we have created.

Truffle suite provides the tools required to create a blockchain environment. Ethereum Ganache, one of the earlier mentioned tools, is a personal blockchain for Ethereum development. It is used to deploy contracts, develop applications, and run tests on said applications. Smart contracts are deployed onto these environments. We have programmed smart contracts using Solidity to create a truly decentralized and distributed application. Our blockchain application implements various kinds of emerging technology in the effort to simulate a distributed and significantly more decentralized application. In Fig 4 and Fig 5, the complete transaction is displayed. The frontend along with the record of the transaction stored in the ledger.

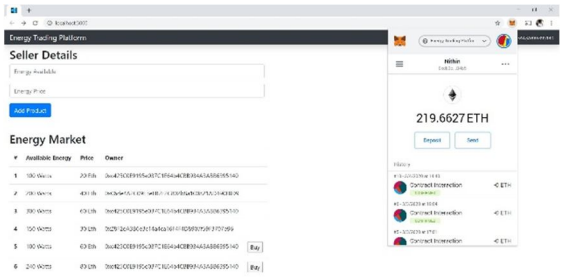


Fig 4. Frontend

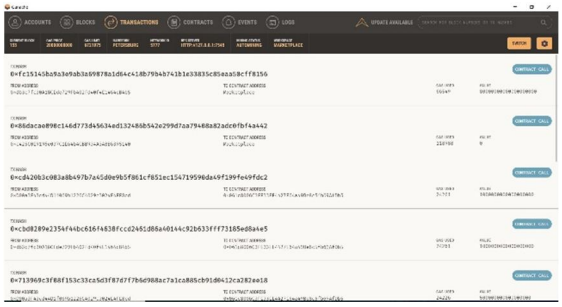


Fig 5- Transaction recorded in the ledger

VI. SUMMARY

Blockchain technology is the primary reason for solving significant challenges in this project. The nodes can verify the transactions, and all users have access to this ledger. Any single user cannot modify the data within the nodes without anyone's knowledge, which in turn eliminates any fraud. In the present-day system, it moves across many people before it gets o the buyer's hand. This system increases the risk of errors and transactional costs as well as lacks transparency.

In the proposed system, people on the smart grid can trade energy with one another directly. The requirements, data, and transactions are done through an app that uses blockchain technology. Our research was focused on the fundamental working principles of blockchains and how blockchain-based systems achieve the characteristics of decentralization, security, and audibility in IoT in which we were successful. From there, we built our narrative on the challenges posed by the current centralized models, followed by recent advances made both in industry and research to solve these challenges and effectively provide our blockchain model to enable Peer-to-Peer energy trading in smart grids using blockchain technology.

The resultant model is highly distributed and decentralized, where the power to control the energy sector is given to the consumers itself. The transactions are highly safe and reliable. It is also found that the trust of the user on the system is considerably increased with this model. The proposed system can revolutionize the energy sector.

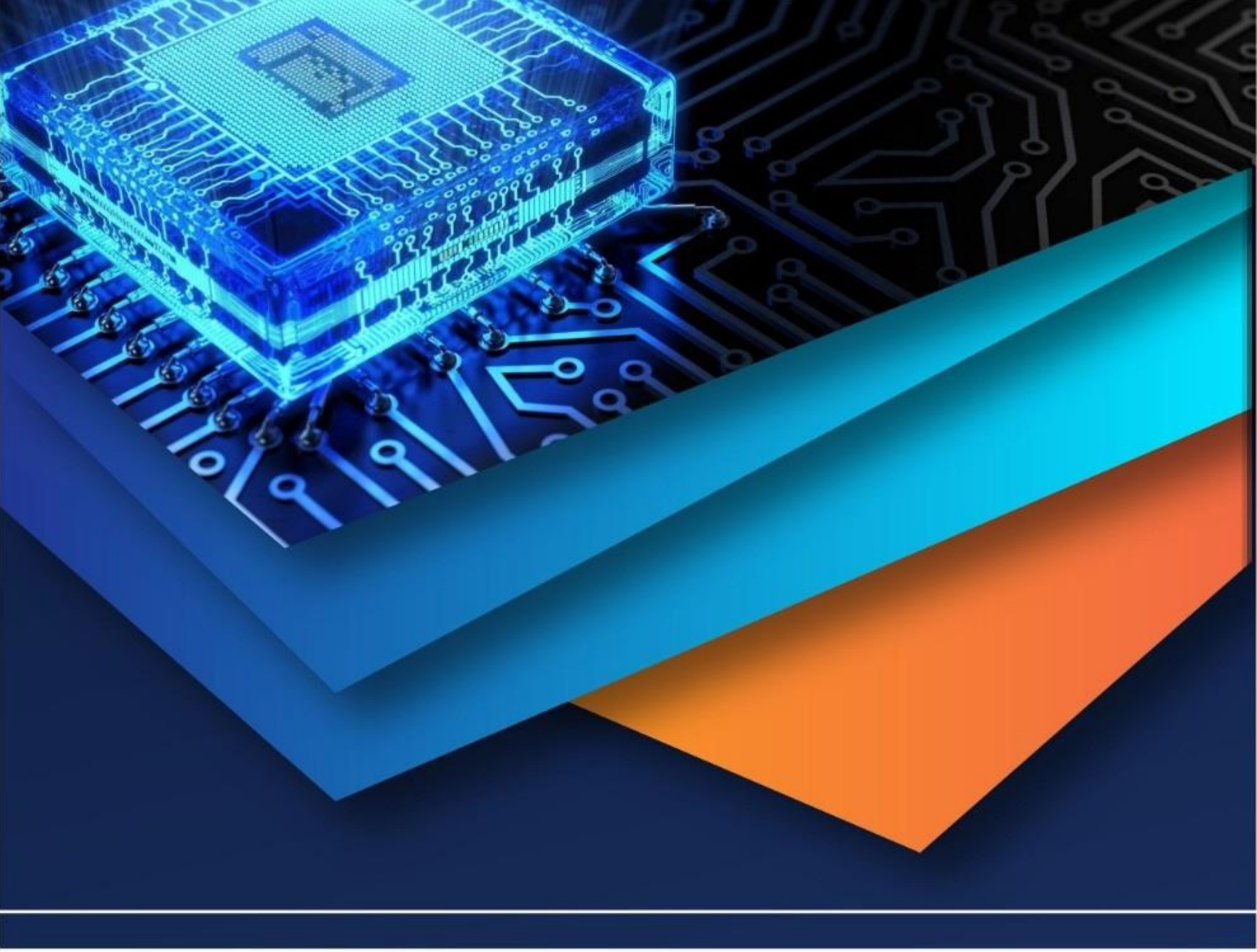
Future work in this field can be fixing the pricing model to maintain order and implement this in a small community for PoW.

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