iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** IV **Month of publication:** April 2023

DOI: https://doi.org/10.22214/ijraset.2023.50314

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue IV Apr 2023- Available at www.ijraset.com

A Blockchain Based Energy Management System for Microgrids

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Abstract: ***The use of renewable energy sources is increasing, but their volatility makes it difficult to maintain a balance between energy generation and consumption. To address this issue, we propose a peer-to-peer microgrid energy market where consumers and prosumers can trade self-produced energy and keep the profits. This encourages investment in renewable energy plants and local balancing of supply and demand. To make this possible, we propose a blockchain-based microgrid energy market without central intermediaries. The permissioned blockchain framework ensures that only eligible participants can join, and each entity maintains its own transaction information while being able to retrieve information from other entities with permission. This model is distributed and promotes plug-and-play. We have developed a WebApp SET, which uses a blockchain wallet to sign in users and allow them to share their energy needs anonymously. The simulation results show that this method is feasible and suitable for privacy protection and P2P energy management in a decentralized energy system.***

Keywords: Blockchain technology, peer-to-peer trading, renewable energy, smart contract, microgrid, grid management, trading system

I. INTRODUCTION

Any country's socioeconomic development and growth are directly and immediately correlated with its energy usage. Today, it is nearly impossible to meet the energy demands of conventional energy sources due to the shifting internet usage paradigm and the industry 4.0 revolution. Additionally, the continued and excessive usage of conventional energy sources has a negative impact on the climate. Reduced carbon footprints and greenhouse gas emissions are required under the Paris Convention of 2016 [1], which also emphasizes the greatest use of sustainable and renewable energy sources.

The energy ecosystem has changed from a conventional centralized strategy to a decentralized Model/peer to peer energy management due to the incorporation of sustainable energy sources in the mainstream grid system. Secure, transparent, immutable, and effective digital interactions that are highly resilient to outages are made possible by the incorporation of blockchain technology into the smart grid. These benefits will be used to develop a decentralized, reliable, and more effective market for energy management while ensuring dependability and regulatory compliance.

A system that can distinguish between conventional energy and renewable energy must be created immediately. It must be transparent, reliable, non-auditable, and efficient. Smart grids [2] are used in designs for "smart cities," where all participants are connected to one another and energy flow occurs in both ways. Both the environment and consumers benefit from the usage of a smart grid. The essence of using technology that can operate in the stochastic and decentralized energy system and take care of all stakeholders, including customers, prosumers, utilities, and service providers, has been produced by peer-to-peer interaction in the Smart Grid. Decentralized energy distribution systems necessitate the use of new, effective technology. With benefits including a distributed ledger structure, data immutability, anonymity, peer-to-peer valid interactive smart contracts, and data security, Blockchain Technology is the ideal option. With its integration into Smart Grid, Blockchain's basic functioning is improved and a low-carbon global economy and sustainable energy management ecosystem are both created. Smart contracts have implemented machine-to-machine energy management in the industry 4.0 environment, as the most promising application in the context of blockchain. Additionally, in ref 1, a method based on blockchain is presented to manage the demand and transaction of grid. It realized the independent maintenance and management of transaction information through smart contract of blockchain technology [3] .

The rest of this paper is structured as follows. Section 2 introduces the blockchain concept and provides permissioned blockchain technology. Section 3 describes a typical energy management methodology and the use of blockchain technology in the energy sector. The implementation in Section 4 demonstrates the method's effectiveness and feasibility. Section 5 reaches a conclusion and discusses potential future work.

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II. SYSTEM MODELLING

In this paper, we combine the application value of blockchain technology in new energy trading and establish a new energy trading model based on blockchain and smart contracts.

A. Blockchain Technology

Blockchains are distributed digital ledgers that are tamper-evident and tamper-resistant, usually operating without a central repository or authority (i.e., a bank, company, or government). At their most basic level, they allow a group of users to log transactions in a shared ledger so that, as long as the blockchain network is functioning normally, no transaction can be modified after it has been recorded. Modern cryptocurrencies were developed in 2008 [4] using the blockchain concept in conjunction with a number of other technologies and computing ideas. These digital currencies are secured by cryptographic processes rather than a central repository or authority. It can be difficult to comprehend blockchain technology due to its complexity, reliance on distributed networks, and use of cryptographic primitives. To comprehend the greater complicated system, each component can be understood easily and used as a building brick. Informally, blockchains can be described as: Blockchains are decentralized digital ledgers that contain blocks of cryptographically signed transactions. Following validation and a consensus decision, each block is cryptographically linked to the previous one (making it tamper-evident). Older blocks become increasingly challenging to change as new blocks are added (creating tamper resistance). The network's copies of the ledger are updated with the latest blocks, and any conflicts are automatically handled according to predetermined rules [5]. Based on their permission mechanism, which governs who can maintain them, blockchain networks can be divided into different categories (e.g., publish blocks). The system is permissionless if anyone can publish a new block. It is permissioned if certain users are the only ones who can post blocks. A permissioned blockchain network is analogous to a managed business intranet, whereas a permissionless blockchain network is comparable to the open internet and is accessible to everyone.

B. Permissioned Blockchain

Blockchain networks that need authorization from a third party for users to publish blocks are known as permissioned networks (be it centralised or decentralized). You can limit read access and who can issue transactions because only authorised users are maintaining the blockchain. Thus, permissioned blockchain networks can either grant everyone access to read the blockchain or they can limit read access to vetted users. Additionally, they may permit everyone to submit transactions for inclusion in the blockchain or, once more, they may limit this access to just approved people. Open source or closed source software can be used to create and maintain permissioned blockchain networks [6]. A permissioned blockchain network can have the same distributed, resilient, and redundant data storage system as a permissionless blockchain network, as well as the same traceability of digital assets as they move across the blockchain [7]. They also use consensus models for publishing blocks, but these techniques frequently do not need to spend money on resources or maintain them (as is the case with current permissionless blockchain networks). This is due to the fact that establishing one's identity is necessary to participate in the permissioned blockchain network; those who maintain the blockchain have a degree of trust in one another because they were all given permission to publish blocks and because that permission can be revoked if they act inappropriately. Some blockchain networks with permissions need all users to be approved in order to send and receive transactions (they are not anonymous, or even pseudo-anonymous). In such systems, stakeholders cooperate to complete a shared business process with built-in barriers against fraud and other undesirable behaviour (since they can be identified). It is clearly understood where the organizations were founded, what legal remedies are available, and how to seek those remedies in the appropriate judicial system if improper action were to occur [8].

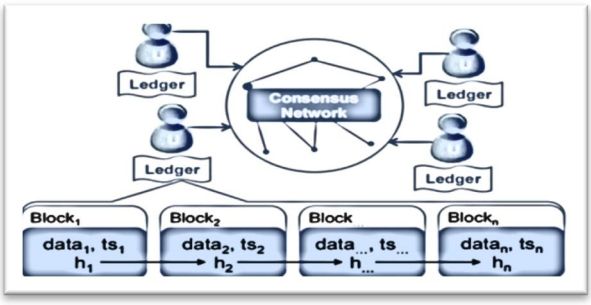


Figure1: Structure of the Permissioned Blockchain Network

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C. Blockchain Technology in Energy Sector

The ability of the technology to offer answers to the energy trilemma can help to differentiate the potential of blockchain applications in the energy sector:

1) *Energy Security:* Enhance cybersecurity and supply chain security measures for the world's increasingly intricate and digitalized energy systems.
2) *Energy Equity:* By combining RES and cutting-edge peer financing techniques, more people in developing nations and remote locations will be able to access affordable, clean energy.
3) *Environmental Sustainability:* Encourage the integration of RES and assist in the development of the production of renewable energy or other low-carbon alternatives. Support O&G companies in their efforts to be sustainable.

The majority of blockchain applications in the energy sector today are focused on the electricity sector, with more than half of the use cases focusing on two categories: Decentralized energy trading (33%), and tokens & energy project financing (20%). Both of these categories can provide valuable solutions to the energy trilemma44. Additional cases include the "support services" category of smart devices and asset management (11%), while 9% are focused on metering and energy system security [6].

It should be acknowledged that blockchain technology is most useful when decentralization or transparency are required (usually when more than one parties are involved). DLT is not always the best solution, especially in the context of a private company network, because traditional databases with faster processing times can be used.

D. Smart Contracts

The term smart contract dates to 1994, defined by Nick Szabo as "a computerized transaction protocol that executes the terms of a contract. The general goals of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), to minimize malicious and unintentional exceptions, and to eliminate the need for trusted intermediaries" [9].

Blockchain technology is extended and leveraged by smart contracts. A smart contract is a collection of code and data (also known as functions and state) that is deployed on the blockchain network via cryptographically signed transactions (e.g., Ethereum's smart contracts, Hyperledger Fabric's chain code) [10]. The smart contract is executed by nodes in the blockchain network; all nodes that execute the smart contract must produce the same results, and the results of execution are recorded on the blockchain.

Users of the blockchain network can create transactions that send data to public functions provided by a smart contract. The smart contract uses the user-supplied data to execute the appropriate method to perform a service. Because the code is on the blockchain, it is also tamper-evident and resistant, and can thus be used (among other things) as a trusted third party. A smart contract can perform calculations, store information, expose properties to reflect a publicly exposed state, and, if necessary, send funds to other accounts automatically. It is not even required to perform a financial function

III. SOFTWARE METHODOLOGY

Simulink (ver. R2022b) was employed for the given data, which was created on MATLAB (ver. R2022a), to execute the microgrid simulations.

The website was designed with the help of the cloud-based design application Figma (ver. 93.4.0). Additionally, this website was developed using JavaScript (ver. ES2022), HTML5 and CSS3; the coding for the website development was carried out using Visual Studio Code (ver. 1.74).

Using Solidity (ver. 0.8.0), smart contract formation was accomplished. The webpage that was hosted on the block chain utilised the data that was collected from MATLAB. Furthermore, all the codes were uploaded to GitHub (ver. 3.7.3) using Git (ver. 2.39.0).

IV. IMPLEMENTATION

To verify the practicality of our proposed approach, our team implemented a simulation using a real testbed. The testbed was designed with an energy management system that allows for the trading of energy in a distributed manner.

In order to gather the data necessary for the simulation, the team used microgrid simulations with Simulink and MATLAB to design the circuits. This allowed them to create a model of how the energy trading system would work in practice.

To create the user interface for the website, the team used Figma, a Cloud-based design application. They then developed the website using HTML, CSS, and JavaScript to ensure that it was dynamic and responsive. The website allows users to log in and receive a specific key for operation. Once they have logged in, they can engage in electricity transactions such as selling and purchasing.

If a user has excess electricity generation, they can sell it through the website. The website facilitates these transactions through the use of smart contracts, which are formed using the Solidity technology. Smart contracts are essentially self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. This allows for secure and transparent transactions, as the terms of the agreement are written in code and cannot be altered once the contract is executed.

The mode of currency for these transactions is Ethereum, a popular cryptocurrency. This means that users can buy and sell electricity using Ethereum, which is decentralized and can only be controlled by the users. This ensures that all transactions are secure and transparent [11].

Overall, the project aims to test the feasibility of a distributed energy trading system. By utilizing a simulation with a real testbed and implementing smart contracts with Solidity technology, the team has created a secure and transparent platform for energy trading.

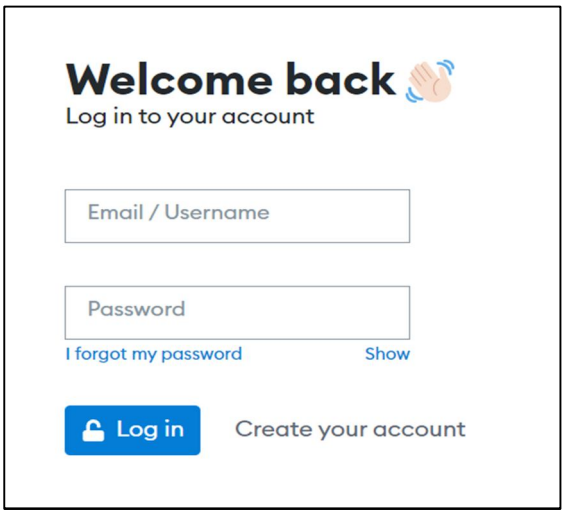


Figure2: Welcome Page

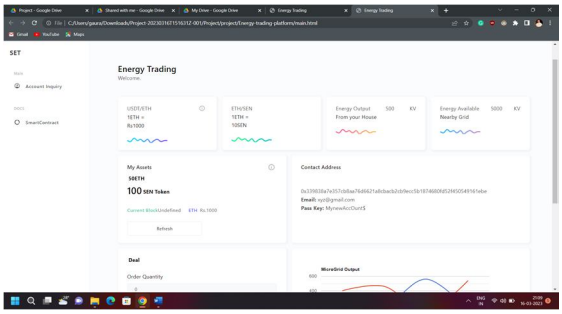


Figure3: Main Page

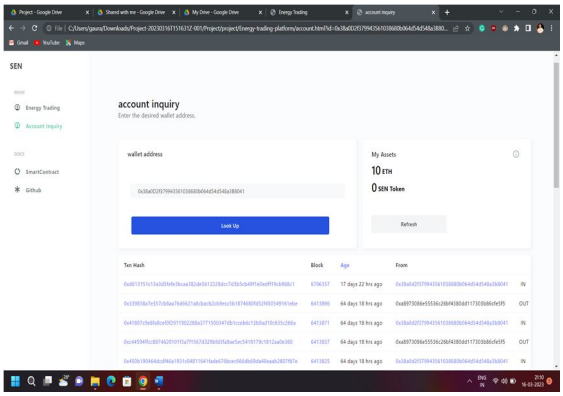


Figure4: Account Inquiry Page

V. RESULT

To verify the feasibility of the proposed method, a privacy-preserving P2P energy management system for a PV/FC generation microgrid was implemented [12]. It was assumed that PV equipment was added to address the issue of power scarcity. It was demonstrated that this method has high privacy security by registering new devices and joining the permissioned blockchain network, as well as verifying and storing all information on each node. Finally, the new device was simulated in plug-and-play mode to improve energy supply during power outages, demonstrating the system's feasibility.

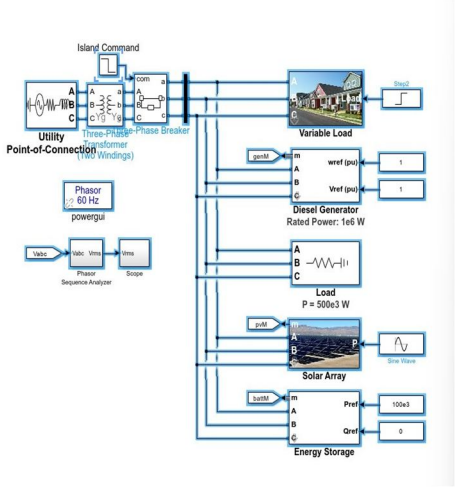


Figure5: MATLAB Model

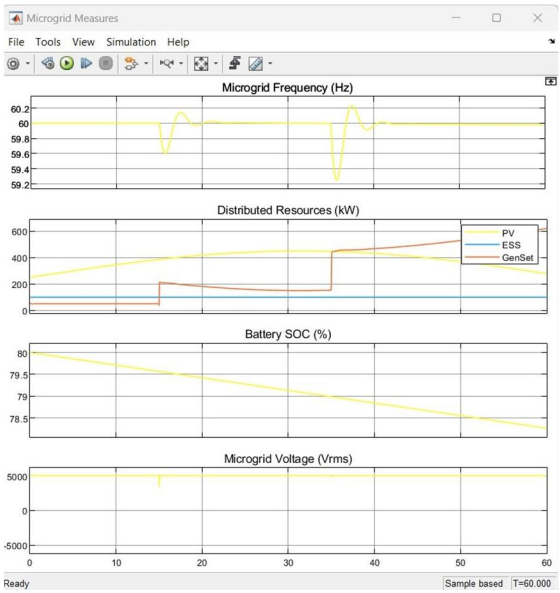


Figure6: MATLAB Microgrid Simulation

As a result, the web application known as SET (The WebApp, which will use a blockchain wallet to sign in a user, so that users can share their energy requirements while keeping their anonymity) is now operational under the name it gave. The electricity process has advanced significantly, and extensive microgrid systems have been installed. A microgrid is a network made up of various dispersed power sources and the loads that they are connected to in accordance with a specific topological structure.

It allows the switch from conventional to intelligent power grids and is a typical active distribution network method. Microgrids are being used more frequently to distribute renewable energy as the cost of producing it falls and environmental issues gain notice. Because green energy production is intermittent, microgrid energy management becomes more crucial. Peer-to-peer (P2P) energy management, multi-agent management, and centralized management are the three main traditional energy management techniques for microgrid systems.

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Traditional administration involves centralizing all power generators in the microgrid under the control of an intermediary [13]. Since the energy management strategy of microgrids is predetermined, the system's flexibility and scalability are bad. Information security is a major concern because all data are kept in a single facility. Microgrids can use multi-agent management, but this mode has expensive operation expenses and is not appropriate for underdeveloped regions. P2P energy management is a typical type of decentralized management that enables the direct interconnection of power generation machinery and power consumers in microgrids [14]. P2P energy management is more practical and flexible than centralized management and multi-agent management. Comparing the three approaches reveals that P2P management is better suited for energy microgrids and has plug-and-play benefits for power devices. The use of emerging blockchain technology during method implementation guarantees a smooth and stable implementation of the solution. Smart contracts have implemented machine-to-machine energy management in the industry setting, as the most promising application in the framework of blockchain. In addition, a blockchain-based technique for managing grid demand and transactions is presented. It achieved independent transaction information maintenance and administration using blockchain smart contracts. However, because public blockchain is difficult to provide a more operable interface and there is a single point of failure, existing energy blockchain technology cannot be directly applied to energy systems, particularly because it cannot solve the information safety problem.

VI. LIMITATIONS

While several initiatives have emerged, blockchain still faces some barriers to widespread adoption in the energy sector, including:

1) *Scalability and Power Consumption:* Due to their design, public blockchains typically consume a large amount of energy per transaction, and long delays may occur before a transaction is confirmed. While technology is evolving, it is still in need of improvement [15].
2) *Lack of clear and Consistent Regulation:* While work on regulations has already begun in various regions, such as Japan and Europe, the lack of blockchain procedures or global regulations is a major barrier to blockchain adoption in the energy sector. To manage a future decentralized energy system, regulate electricity tariffs, and resolve potential disputes and transaction reversals, regulations are required [15].
3) *Limited Grid Infrastructure:* To optimise blockchain use in the energy sector, a more interconnected smart grid is required, where new players can participate on existing smart metres [15].

51% of the attacks: In some blockchains, attackers with majority control of the network can halt the recording of new blocks and obstruct the completion of transactions. This type of attack is more dangerous for small networks because the computing power required to take over 51% of large blockchains would be massive [15].

VII. CONCLUSION

Microgrids are typically made up of distributed energy resources, demand response, electric vehicles, local controllers, central controllers based on a microgrid energy management system, and communication devices. This paper provided a thorough and critical examination of the developed microgrid energy management strategies and solution approaches. The energy management system's primary goals are to optimise the operation, energy scheduling, and system reliability in both islanded and grid-connected microgrids for long-term development. As a result, a microgrid energy management system is a multi-faceted topic that addresses technical, economic, and environmental concerns.

A privacy-preserving P2P mode based on permissioned blockchain was established to reduce the credit cost of energy management in a renewable energy microgrid.

A permissioned blockchain model was proposed first, according to blockchain technology. Due to the large amount of electricity transactions, it would cause huge losses when users' privacy is threatened. The energy blockchain technology with privacy protection is in its infancy, and many problems remain to be solved. For starters, as mathematics, cryptography, and quantum computing technology advance, the asymmetric encryption mechanism of blockchains becomes more vulnerable, and the method of hiding identities through encryption algorithms becomes less secure.

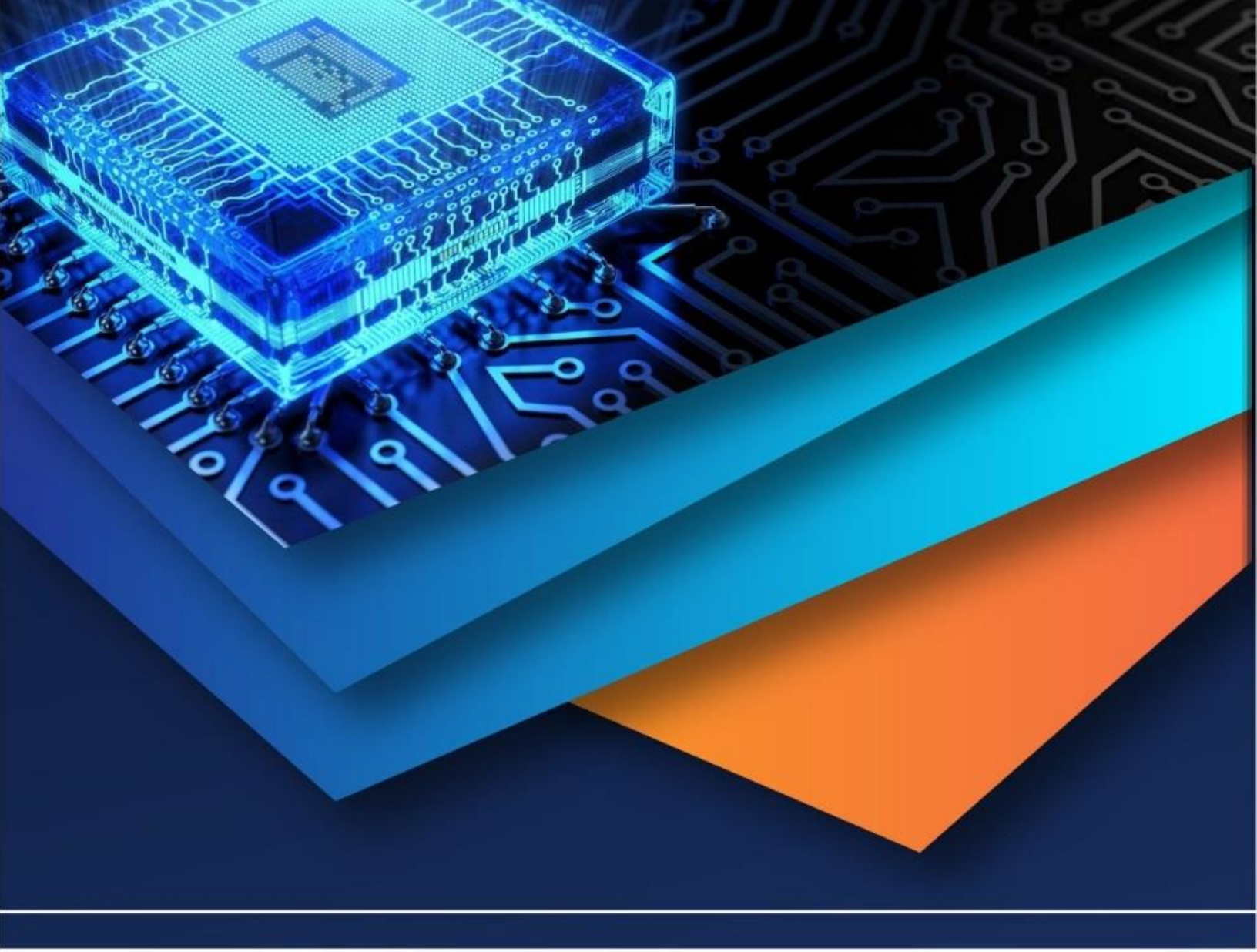
Second, the application of laws and regulations must be constantly improved. To a large extent, blockchain development conflicts with the existing legal system. Furthermore, blockchain transaction throughput must be increased to keep up with the growing scale of distributed energy systems. The current mainstream blockchain platform's throughput cannot meet the needs of a large number of energy users for real-time transactions.

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