Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 06, June-2023

Decentralizing Solar Energy Transaction with Blockchain Technology

Prof. N. M. Mule
Department of Information Technology
Government College of Engineering, Karad
Karad, India

Nishant Patil
Department of Information Technology
Government College of Engineering, Karad

Omkar Dhage
Department of Information Technology
Government College of Engineering, Karad
Karad, India

Vishal Kamble
Department of Information Technology
Government College of Engineering, Karad

Akshay Tupe
Department of Information Technology
Government College of Engineering, Karad

Abstract - The need for renewable energy sources, such as solar power, has surged in recent years on a global scale. This can be attributed to the mounting apprehensions about climate change and the urgency to shift towards more sustainable energy systems but ensuring the security and reliability of world energy has become a major concern alongside sustainability. As information and energy security is critical for present and future services, this paper aims to address the challenge of secure energy trading using distributed marketplaces. The core technology used is blockchain, which has gained attention due to its features such as transparency, immutability, irreversibility, and security. The blockchain network enables prosumers and consumers to trade their energy securely through a Peer to Peer channel. The system also provides management functionalities such as security, reliability, flexibility, and scalability through blockchain implementation. This paper focuses on current proposals for Peer to Peer energy trading using blockchain and how to choose a suitable blockchain technique to implement such a network. The system models, blockchain technology, and consensus algorithm are selected based on a literature review. Overall, the research paper presents a solution for secure Peer to Peer energy trading using blockchain technology.

keywords: blockchain, smart contract, peer-to-peer trading, consensus mechanism, privacy protection.

I. INTRODUCTION

The global demand for renewable energy sources, such as solar power, has increased in recent years due to growing concerns about climate change and the need to transition to more sustainable energy systems. For example, according to "IEA Report for Increase in global electricity demand"

The demand for electricity on a worldwide scale is expected to rise by nearly 5% in 2021 and 4% in 2022, after a decline of 1% in 2020, which was caused by the Covid-19 pandemic[1].

In traditional electric energy markets, a hierarchical model is followed that relies on the centralized authority of utility companies for power generation. However, this conventional architecture of utilities faces limitations in scalability when it comes to integrating distributed generation. Furthermore, the growing adoption of electric cars will further exacerbate this challenge in the future [1].

According to the semi-annual Electricity Market Report by the IEA, the Asia Pacific region, with a focus on China and India, will be the main driver of the anticipated increase in electricity demand. Although the use of renewable energy sources such as hydropower, wind, and solar PV is projected to increase by more than 8% in 2021 and over 6% in 2022, they will only be able to meet around half of the anticipated increase in global electricity demand. Remaining demand will be met by fossil fuel-based electricity generation, covering 45% and 40% of the additional demand in 2021 and 2022, respectively, while nuclear power will account for the rest. As a result, the electricity sector's carbon emissions are expected to reach an all-time high, rising by 3.5% in 2021 and by 2.5% in 2022. While renewable energy growth has outpaced demand growth in 2019 and 2020, the IEA report suggests that this trend may not continue, as it was due to slow or declining demand during that period. Solar power has surfaced as a prospective replacement for conventional fossil fuels due to its abundance, cleanliness, and ability to be harnessed locally in numerous regions worldwide[2]. However, despite the widespread adoption of solar energy, there are still significant challenges in its integration into existing energy grids and markets, including issues related to transactional efficiency, transparency, and decentralization.

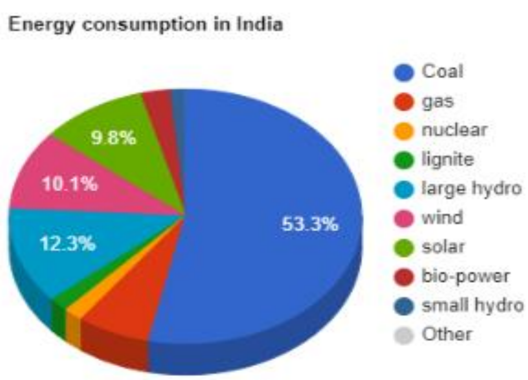

Fig 1. Energy Consumption in India [3]

Coal constitutes the largest proportion of polluting fuels in India. Fossil fuels are responsible for generating over 70% of the country's electricity, a practice that has been in place for several decades. Despite criticism, the Indian government has consistently defended its reliance on coal and its strategy for transitioning to cleaner energy sources, citing the need for energy security. In a significant move in 2021, India launched its largest-ever auction for coal mines, seeking bids for 141 mines across 12 states with the aim of producing 1 billion tons of coal by April 2024. According to data from Ember, from 2001 to 2021, India added 168 gigawatts of coal-fired power generation, almost twice the combined increase in solar and wind power. Coal India Limited, which is owned by the government, is the biggest state-run coal producer globally, responsible for roughly 82% of India's coal output. The average age of the nation's coal-fired power plants is 13 years, and India has plans for adding 91,000 MW of new coal capacity, which is second only to China. Nevertheless, according to the Draft National Electricity Plan 2022, the proportion of coal in the electricity generation mix is anticipated to fall from the present level of 70% to 50% by 2030[3].

Blockchain technology, which is best known for its application in cryptocurrencies like Bitcoin, has been gaining attention as a potential solution to these challenges in renewable energy sector. The decentralized and transparent nature of blockchain, along with its ability to enable smart contracts and peer-to-peer transactions, offers new opportunities for the decentralized and efficient management of solar energy transactions [4]. This emerging field, often referred to as "decentralized solar energy transaction using blockchain," has the potential to revolutionize the way solar energy is produced, consumed, and traded, leading to increased energy democratization and sustainability [5].

This research paper explores the concept of decentralization of solar energy transactions using blockchain, and its potential benefits and challenges. It analyses real-world examples of blockchain-based solar energy projects and initiatives and identifies key factors that may influence the success of such implementations. Finally, the research paper will discuss the implications and prospects of decentralized solar energy transactions using blockchain, including their potential impact on energy markets, policy, and sustainability goals.

This research paper intends to offer a thorough and detailed analysis of the emerging field of decentralized solar energy transactions using blockchain and contribute to the growing body of literature on renewable energy and blockchain applications. By examining the opportunities and challenges of this innovative approach. The research paper endeavor’s to explore the potential of blockchain technology in bringing about a transformation in the solar energy sector and facilitating the transition toward a more sustainable and decentralized energy future.

II. LITERATURE SURVEY

A. Existing Blockchain Technique In Solar Energy Transaction:

Under the existing technology, various techniques that are currently available to promote renewable energy adoption and reduce carbon emissions can be discussed. One such technique is peer-to-peer (P2P) energy trading, which enables solar energy producers to sell their excess energy directly to consumers without intermediaries. This technique has the potential to increase energy efficiency and reduce energy costs, but its scalability is limited due to the need for many participants. An additional approach is the utilization of energy certificates, which are digital certificates that represent renewable energy and can be traded to offset carbon footprints, promoting the usage of sustainable energy. Despite its potential to encourage the adoption of renewable energy sources and mitigate carbon emissions, certain markets lack consistency and clarity in terms of standardization and transparency.

Supply chain management is another technique that involves tracking the origin and movement of solar equipment to ensure its sustainability and ethical use. While this technique can increase accountability and transparency in the supply chain, it can also increase costs and complexity for supply chain participants. Finally, energy financing can facilitate crowdfunding and other financing options to make solar energy more accessible and affordable. The implementation of this method holds promise for boosting the utilization of renewable energy sources and advancing energy equity. However, there are concerns regarding the risk of fraudulent activities and inadequate safeguards for investors.

Blockchain technology is being leveraged by a group of 37 households residing in the Schwimmwagen area of St. Gallen to trade their surplus solar energy. Projects initiated by university students changed the way transactions of electricity are done in the past. The platform aims to empower consumers to produce, consume, and trade electricity directly with each other, bypassing the need for a centralized utility company. Despite positive reception from local residents during the one-year trial period, the absence of regulations would impede the potential for widespread implementation of this initiative throughout Switzerland[6].

According to the paper cited as [7], the simulation period involves the computation of the direct solar irradiation for every second, which takes into account both the altitude and azimuth factors. The research paper determines the output of photovoltaic energy panels by considering several factors, including the solar panel area specified by the user, the solar panel yield, the direct solar radiation received by tilted panels, and the performance ratio coefficient that takes into account losses in the photovoltaic energy system[7].

Mr. Green and Newman conduct an analysis of the evolution of local communities transitioning into self-sustaining, local generation utilities, commonly referred to as citizen utilities. The authors of the study have analyzed how blockchain-based microgrid energy markets could promote the growth of distributed solar systems in Australia and the resulting implications for the traditional energy grid. In their analysis, the authors emphasize that the application of blockchain technology to electricity transactions can improve the reliability of microgrids by promoting trust between participants, especially concerning financial transactions and electricity distribution [8].

By discussing these existing technologies, a comprehensive understanding of the current state of renewable energy adoption can be provided, and potential areas for improvement and further research can be identified.

TABLE 1: Existing Blockchain Technique In Solar Energy Transaction

References	Basic idea	Status	Blockchain	Advantages	Disadvantages
[9]	The peer-to-peer (P2P) trading of NRG coins enables the exchange of locally generated energy within a microgrid.	Proof of Concept (lab-scale prototype)	Public blockchain (custom protocol, NRGCoin)	It provides demand response mechanism,Value determined on an open currency exchange market	Lack of regulatory framework, Energy-intensive generation process, more volatile
[10]	The trading of solar energy and storage capacity through peer-to-peer (P2P) channels takes place within the microgrid.	Proof of Concept (Simulation)	Private blockchain (Bitcoin)	Enhanced consumption monitoring, Ease in Energy trading, secure and private	It has Performance issues, Complexity of such implementation is more
[11]	Trading between distributed set of prosumers using an auction mechanism, demonstrated on a university campus	Proof of Concept (on-campus demo)	Private blockchain (Ethereum)	Elimination of central intermediaries, Resilience against single-point failure, Secure and transparent energy trading, Integration of DERs	Limited empirical evidence, Scalability concerns, Cost considerations, Regulatory and legal challenges
[12]	P2P transfer of renewable energy for PHEVs	Proof of Concept (simulation)	Private blockchain (custom protocol)	It has localized P2P electricity trading, Demand response and incentives, Consortium blockchain for transaction security	Transaction security and privacy concerns, Complex operations and pricing mechanism, Limited scalability

[13]	P2P transaction of solar energy within local microgrid	Field Phase, Germany, US	Private blockchain (Tendermint)	Local energy trading, Financial and socio-economic incentives, Innovative information systems, Integration of distributed renewable energy sources	Partial fulfillment of market components, Regulatory limitations, Volatility of renewable energy generation

B. Related Terminologies

a. Blockchain Technologies

Blockchain is a decentralized ledger system that enables multiple parties to securely store and share data in a transparent manner, without requiring intermediaries. It was initially proposed in 2008 by an unidentified individual or group known as "Satoshi Nakamoto," and the first cryptocurrency, Bitcoin, was developed using this technology[14].

The distributed nature of blockchain technology makes it resistant to attacks and ensures the integrity of the data stored on it. The verification and recording of transactions on a blockchain are carried out by a network of nodes or computers, resulting in a transparent and reliable system[14].

The term "blockchain" refers to a variety of different systems, including public, private, and hybrid blockchains. Public blockchains, like those used by Bitcoin and Ethereum, are accessible to anyone and are not under the control of a central authority. Private blockchains, on the other hand, are limited to a specific group of users and are commonly utilized in enterprise settings. Hybrid blockchains incorporate characteristics of both public and private blockchains[14].

The potential of blockchain technology to transform different sectors is widely acknowledged due to its ability to provide secure, decentralized, and transparent systems for managing and storing data.

b.Consensus Mechanism

A variation of the Byzantine Generals Problem can be observed in the process of reaching consensus among untrusted nodes in a blockchain network[15]. Describing the challenge of achieving consensus among a group of distributed nodes, some of which may be unreliable or malicious, the Byzantine Generals Problem is a well-known problem in computer science. The problem is named after the ancient Byzantine army, where a group of generals must agree on a coordinated attack plan, but some may be traitors who wish to sabotage the plan. To solve the Byzantine Generals' Problem, several consensus algorithms have been developed.

There are several approaches to achieving consensus in blockchain networks. Here are some of the most common:

1. Proof of Work (PoW): A consensus mechanism is employed in blockchain technology to facilitate agreement among network participants regarding the legitimacy of transactions and blocks that are appended to the blockchain. In PoW, nodes in the network, referred to as miners, engage in a competition to solve a cryptographic puzzle that demands a substantial amount of computational power. The miner who is the first to solve the puzzle earns the privilege of adding a new block to the blockchain and receives a reward in the form of freshly minted cryptocurrency[16].

A hash puzzle is utilized in PoW cryptography, which necessitates miners to locate a hash value satisfying a specific set of criteria. The network's difficulty level, which adapts automatically based on the overall computational power of the network, establishes these requirements to guarantee a predictable rate of new block additions to the blockchain. Irrespective of the number of miners in the network, the difficulty level guarantees a constant rate of new block additions to the blockchain.

The process of finding a valid hash requires miners to repeatedly run a hash function on a block header that includes the transactions to be added to the blockchain, along with some additional data. The hash function produces a random output, and the miner must try different inputs until they find an output that meets the difficulty requirements.

After discovering a valid hash, it is broadcasted to the network by the miner, and other miners can confirm its validity. When the hash is verified as legitimate, the miner who found it can append the new block to the blockchain, and the cycle repeats for the subsequent block.

The PoW mechanism has been used in several popular cryptocurrencies, including Bitcoin and Ethereum. While it is a proven and secure method for achieving consensus, it requires a significant amount of computational power, which can make it expensive and environmentally costly[16].

2. Proof of Stake (PoS): A consensus algorithm is utilized in blockchain networks for validating transactions and generating new blocks. This algorithm is known as Proof of Stake (PoS), which is an alternative to the more prevalent Proof of Work (PoW) consensus algorithm used by certain cryptocurrencies, including Bitcoin.

The PoS (Proof of Stake) consensus algorithm selects validators, also called "forgers" or "stalkers," to generate new blocks according to the quantity of cryptocurrency they possess and are willing to "stake" or commit as security collateral. The greater the amount of cryptocurrency a validator holds and is willing to stake, the greater the likelihood of being selected to generate a new block and obtain the resulting incentives.

To participate in PoS, a user needs to have a certain amount of cryptocurrency (known as the “stake”) and run a node on the blockchain network. Validation of transactions and proposal of new blocks is the responsibility of the node. To create a block, a node needs to stake a specific amount of cryptocurrency as collateral. Upon successful creation of a valid block, the node is compensated with transaction fees and newly minted cryptocurrency. However, in case the node attempts to engage in fraudulent transactions or cheat the system, it may lose its staked cryptocurrency as a penalty.

Several advantages of PoS over PoW exist, with one of the most significant being its lower energy consumption. Unlike PoW, PoS doesn’t demand same level of computational power to verify transactions & generate new blocks. This is because validators are not obligated to carry out intricate mathematical calculations (as in PoW), but are chosen based on the quantity of cryptocurrency they possess. Nonetheless, one of the critiques of PoS is that selection criteria based purely on the account balance can cause centralization, where the most affluent participants dominate the network. To address this issue, some PoS-based blockchains, such as Blackcoin, use a combination of stake size and randomization to choose the next validator [17].

On the other hand, PoS comes with a distinct set of challenges, including the "nothing-at-stake" problem. This problem alludes to the potential scenario where validators attempt to validate several versions of the blockchain simultaneously, with the aim of maximizing their chances of earning rewards. To address this problem, many PoS implementations use penalties and other mechanisms to discourage this behavior.

3. Delegated Proof of Stake (DPoS): DPoS is a consensus mechanism that employs a specific set of nodes known as delegates to verify transactions and create new blocks for the network. This approach improves the consensus process's speed and efficiency compared to PoS.

4. Byzantine Fault Tolerance (BFT): This consensus algorithm focuses on achieving agreement among nodes despite the presence of malicious nodes. It involves a series of rounds where nodes broadcast their transactions and receives feedback from other nodes until a consensus is reached.

5. Practical Byzantine Fault Tolerance (PBFT): The Practical Byzantine Fault Tolerance consensus algorithm was created to address Byzantine faults and is capable of withstanding malicious Byzantine replicas by up to one-third. PBFT is utilized for consensus in Hyperledger Fabric. In the PBFT procedure, a primary node is chosen for each round to sequence transactions. The process comprises three stages: pre-prepared, prepared, and committed. In each stage, if a node receives votes from over two-thirds of all nodes, it proceeds to the next phase. However, it is critical for PBFT to operate that each node is recognized by the network.[18].

The Stellar Consensus Protocol (SCP) [19] is a Byzantine agreement protocol that utilizes PBFT as its foundation. SCP differs from PBFT in that it enables participants to select which group of other participants they trust. Antshares has incorporated a modified version of PBFT known as delegated Byzantine Fault Tolerance (dBFT) [20] [21], which designates professional nodes to validate transactions through voting. Hence, dBFT can also be regarded as a variant of the PBFT consensus algorithm.

6. Proof of Elapsed Time (PoET): Hyperledger Sawtooth utilizes a consensus algorithm that incorporates a random wait time to avoid nodes vying for the validation of transactions. Nodes are assigned a wait time randomly, and the node with the shortest wait time is designated to validate the transaction and add a new block to the blockchain[22]. In decentralized systems, achieving agreement among distributed nodes is crucial, and consensus algorithms play a vital role in this process[23]. The Byzantine Generals' Problem underscores the difficulties and intricacies involved in developing and executing such algorithms.

c. Smart contract

A self-executing computer program that enforces the terms of an agreement between parties is known as a smart contract. These contracts usually involve complex logic and rules written in a programming language. They are stored on a blockchain and are triggered to execute automatically when certain predetermined conditions are met, such as a specific date or time, or the occurrence of specific events[24].

Smart contracts are created to streamline and automate the implementation of agreements, obviating the necessity for intermediaries or third parties to enforce the terms of the agreement. They are characterized by transparency, security, and immutability, and have extensive use cases in various domains such as financial transactions, supply chain management, real estate, and more. Smart contracts possess a set of distinctive characteristics that set them apart from other contract types. Smart contracts are created to streamline and automate the implementation of agreements, obviating the necessity for intermediaries or third parties to enforce the terms of the agreement. They are characterized by transparency, security, and immutability, and have extensive use cases in various domains such as financial transactions, supply chain management, real estate, and more. Smart contracts possess a set of distinctive characteristics that set them apart from other contract types[25]. Finally, they are immutable, which means that once a smart contract is executed, it cannot be changed or altered.

III. PROPOSED METHODOLOGY

The use of Proof of Authority (PoA) and Practical Byzantine Fault Tolerance (PBFT) consensus mechanisms for solar energy transactions and blockchain technology is a promising approach for several reasons.

A. PoA and PBFT are suitable for permissioned blockchain networks where the participants are known and trusted. In the context of solar energy transactions, the parties involved may be a limited group of known and trusted participants, such as solar energy providers and consumers. By using a permissioned blockchain, the network can operate more efficiently, as there is no need to perform complex consensus algorithms that are required in open, public blockchain networks.

B. PoA and PBFT are more energy-efficient compared to other consensus mechanisms, such as Proof of Work (PoW). Since solar energy transactions involve energy production and consumption, it is important to use a consensus mechanism that is energy-efficient and does not contribute to carbon emissions.

C. PoA and PBFT are designed to be faster and more scalable than PoW. In the case of solar energy transactions, where fast and efficient transactions are required, PoA and PBFT can help to facilitate quick and reliable transactions.

Overall, using PoA and PBFT consensus mechanisms for solar energy transactions and blockchain technology is a promising approach that can provide a secure, efficient, and sustainable solution for the energy industry.

A. System architecture

The architecture consists of three key components, namely, the consumer, the prosumer, and the blockchain-based web component. Both the prosumer and the consumer are equipped with their respective smart meters that perform functions such as energy sourcing and metering. In blockchain transactions, user data is collected from each device. The data collected includes the amount of energy that the prosumer intends to sell., which is a critical piece of information as they cannot sell more energy than they desired. To receive their payment, prosumers are required to furnish their blockchain wallet addresses. Furthermore, they must ensure that their current energy balance is automatically updated to avoid selling more energy than they have. On the other hand, consumers are required to provide information about their preferred price per KwH to facilitate buying at the desired price. However, prosumers are at liberty to decline the proposed price and decide not to sell. Buyers must also provide their blockchain wallet addresses to enable payment in tokens, coins, or money. It's also essential to provide information about their remaining energy storage capacity to ensure that they do not buy beyond their capacity.

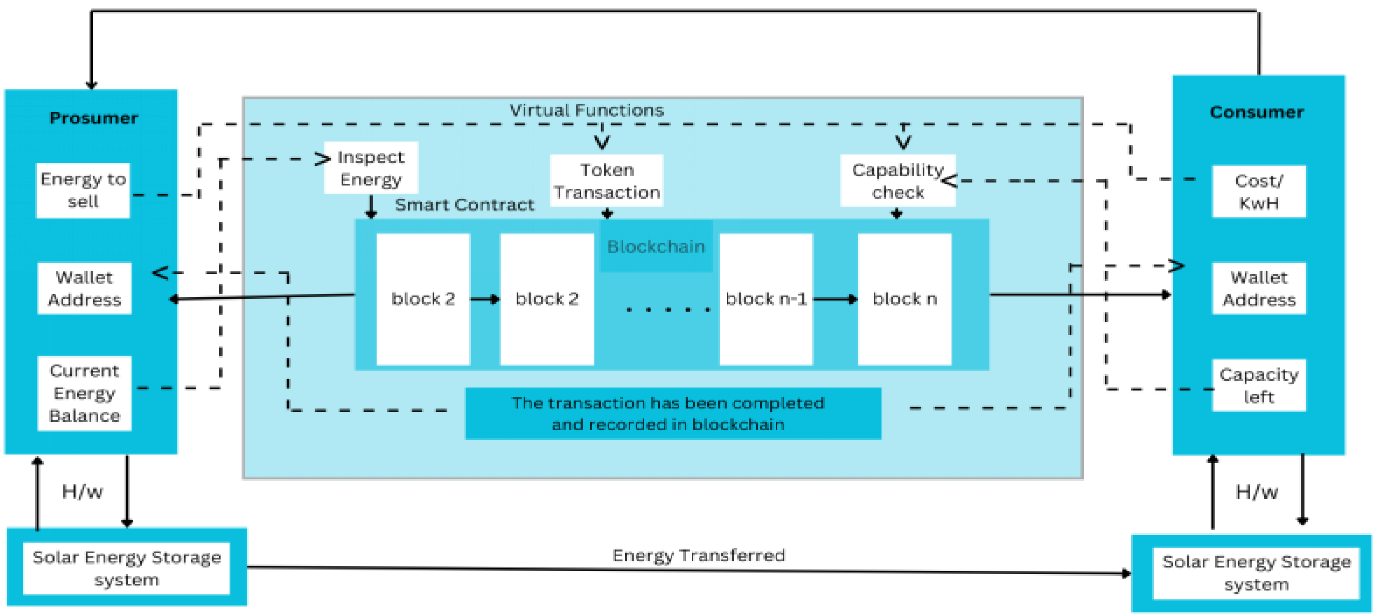

Fig 2: System Architecture

Figure 2 illustrates the general system architecture, where the smart contract executes each transaction and stores the details in the blockchain. During the transaction, prosumers provide vital information such as the amount of energy to sell, their wallet address, and their current energy balance. On the other hand, consumers provide information such as the cost per kWh, wallet address, and current Energy Storage System Capacity.

B. Architecture and Data Flow Diagram

The system's operations and data flow is depicted in Figure 3, which provides a concise overview of how the energy trading system functions, as well as a closer examination of the information involved. The proposed blockchain-based P2P energy trading system allows peers to carry out energy trading tasks with ease through an intuitive user interface. This interface enables them to buy and sell energy and meet their energy requirements or sell surplus energy. The application involves managing user accounts and connecting them to the blockchain server to ensure security. User interface includes MetaMask, which is a chromium extension. Peers can submit energy trading requests using the user interface, their account details will appear on the screen alongside the MetaMask extension. The interface's "My Account" section will display both the account number and balance. Users will be able to access their accounts to either accept or decline transactions on the proposed P2P energy trading platform. Apart from facilitating the buying and selling of energy, the platform will also provide users with the ability to keep track of the trading activities of their peers and their own.

The P2P energy trading system enables users to view the available energy quantity and price, as well as the owner of the transaction. Any trading activity performed by a peer will appear in the relevant section of the user interface, visible to all peers. Peers can initiate trading operations by utilizing the Buy or Sell buttons provided in the interface. The smart controller will determine the amount of energy to be transferred once a trading request is made. Upon successful completion of the energy trading request, the relay will halt energy transfer.

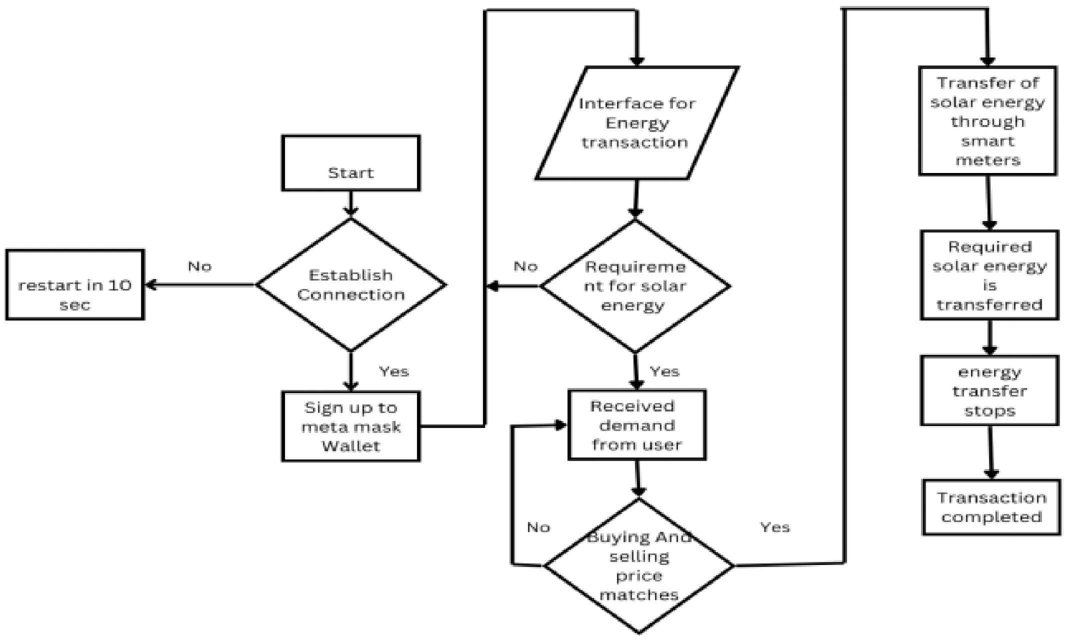

Fig 3. Data Flow Diagram

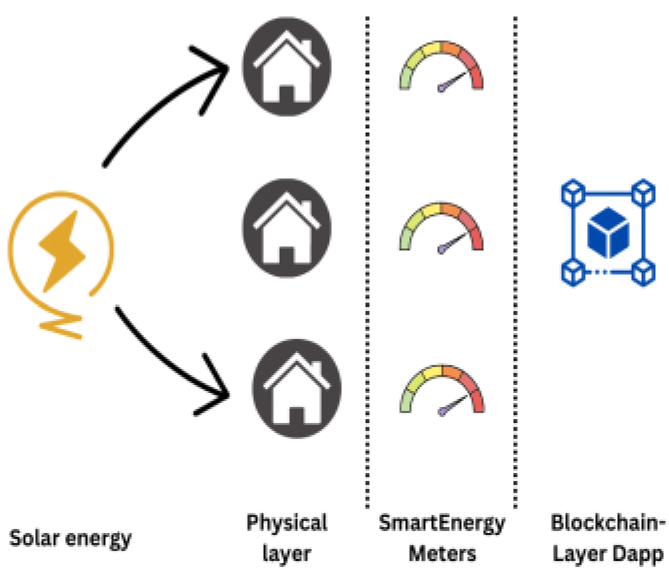

Fig 4. Architecture For Distributed Energy Resources

The architectural framework for decentralized energy trading is divided into four main sections. At a macro level, it generates and stores solar energy using various methods. The physical layer involves the consumption and generation of energy by individual households through modern grid and transformer structures as shown in Figure 4. Each household in the network is equipped with a smart energy meter to facilitate transactions in both directions, forming the next layer in our structure. Finally, our graphical user interface (GUI) in the form of a decentralized application (Dapp) provides a user-friendly experience for end consumers.

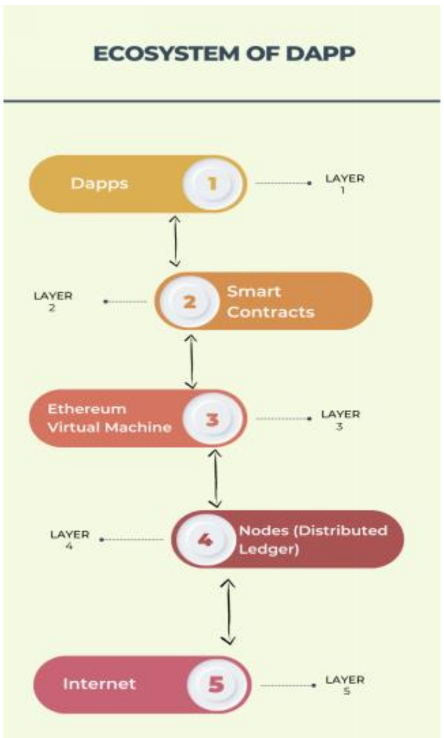

Fig 5. Ecosystem Of Dapp

Decentralized applications, or dApps, are applications that run on decentralized networks, typically using blockchain technology. Figure. 5 depicts an ecosystem of dApps that can be broken down into different layers, each with its own unique functions and components.

Layer 1: This layer consists of the underlying blockchain protocol, such as Ethereum, which provides the foundation for the dApp ecosystem. This layer defines the rules of the network and includes the consensus algorithm, data storage, and communication protocols.

Layer 2: The smart contracts represent the second layer of the decentralized application (dApp) ecosystem. Contracts are designed to enforce the terms of an agreement automatically, without requiring any intermediaries. As a result, dApps are empowered to automate complex procedures and conduct transactions seamlessly using smart contracts.

Layer 3: The EVM is a decentralized virtual machine that executes smart contracts on the Ethereum blockchain. It allows developers to write code in high-level programming languages and compile it into bytecode that can be executed by the EVM.

Layer 4: The fourth tier in the dApp ecosystem is composed of nodes, which are essentially computers that participate in the network & maintain a duplicate copy of the distributed ledger. Their role is to verify transactions and store a copy of the blockchain, thus contributing to the security of the network by providing computing power and storage. Nodes can be run by any individual or entity.

Layer 5: The fifth layer of the dApp ecosystem is the internet. The internet provides the infrastructure for dApps to communicate and interact with users. DApps can be accessed from anywhere in the world, and they can interact with other dApps and services on the internet.

IV. ADVANTAGES OF DECENTRALIZING SOLAR ENERGY TRANSACTION WITH BLOCKCHAIN TECHNOLOGY

1 Efficiency: Blockchain technology enables the creation of a decentralized platform for P2P energy trading, which eliminates need for intermediaries such as utility companies. This can result in faster, more efficient, and cost-effective transactions.

2. Transparency : Through the use of blockchain technology, an open and immutable record of all energy transactions is created, which promotes transparency and accountability. This allows for seamless tracking of the energy flow and guarantees that all involved parties receive fair remuneration for their contributions.

3. Security: Due to its decentralized and distributed architecture, blockchain technology offers a robust level of security that makes it difficult for hackers to compromise the network. This is particularly crucial in the context of energy transactions, which typically involve significant amounts of money and sensitive data.

4. Sustainability: Decentralizing solar energy transactions using blockchain technology can promote the adoption of renewable energy sources, which can help reduce carbon emissions and mitigate the impact of climate change.

5. Flexibility: Smart contracts that automate energy transactions as well as increase flexibility in the buying and selling of energy can be created using blockchain technology.

Overall, decentralizing solar energy transactions using blockchain technology can promote greater efficiency, transparency, security, sustainability, and flexibility in the energy market, leading to a more equitable and sustainable energy future.

V. DISADVANTAGES IN DECENTRALIZING SOLAR ENERGY TRANSACTION WITH BLOCKCHAIN TECHNOLOGY

1. Complexity: Many individuals and consumers interested in using solar energy may find it challenging to utilize blockchain technology due to its high level of technical knowledge and understanding required.

2. Security: While blockchain technology is designed to be secure, it is not foolproof. There have been instances of blockchain hacks and breaches in the past, which could be a concern for the solar energy industry.

3. Cost: The use of blockchain technology can be expensive, and the costs of implementing and maintaining such a system may not be feasible for smaller solar energy players or startups.

4. Hardware requirement: One of the disadvantages of using decentralized solar energy transactions is the potential hardware requirements. In a decentralized solar energy transaction system, each participant may need to have dedicated hardware. This can be a significant upfront cost for individuals or communities that want to participate in the decentralized solar energy market. Additionally, the maintenance and management of hardware can also pose challenges, including regular monitoring, repairs, and replacements, which may require technical expertise and resources

VI. DISCUSSION

The shift towards renewable energy sources in the energy sector has turned energy consumers into prosumers and decentralized the energy market. However, despite the significant impact of renewable energy sources on the conventional electricity market, it has not been able to capture the overall market. The inability to generate a return on investment may be a contributing factor to the limited potential of distributed energy generation. To overcome this challenge and fully utilize renewable energy reserves, it is crucial to establish user-friendly energy trading platforms that offer returns on investment. Unfortunately, some countries with substantial renewable energy resources have not fully utilized them due to the lack of such platforms. However, the integration of blockchain technology and smart devices is expected to revolutionize the development of P2P energy trading platforms, which may facilitate the adoption of distributed generation. Thus, it is crucial to implement P2P energy trading models to promote the growth of distributed generation.

This article presents the use of PoA and PBFT consensus mechanisms in solar energy transactions and blockchain technology as a promising approach due to several reasons discussed above.

The survey paper proposes an energy trading system architecture based on blockchain, comprising consumer, prosumer, and blockchain-based web components. Prosumers set the amount of energy to sell and provide their wallet address, while consumers specify buying price and energy storage capacity. Each building acts as an autonomous agent in a network, managing resources such as sensors and power generation/consumption.

The P2P energy trading system allows users to easily buy and sell energy through an intuitive user interface integrated with MetaMask for secure account management. Users can monitor the trading activities of peers, view available energy quantity and price, and initiate trading operations.

Participants register and send transaction requests, which are validated by the Microgrid Energy Management System and smart meter. The smart controller determines the amount of energy to be transferred, and upon successful completion, the relay halts energy transfer. It highlights the benefits of leveraging blockchain features for establishing a decentralized and secure transaction system in the solar energy sector.

VII. CONCLUSION AND FUTURE SCOPE

In conclusion, the research paper has highlighted the potential benefits of using blockchain technology for solar energy trading, including increased efficiency, transparency, and accessibility. However, several challenges need to be addressed for the successful implementation of blockchain-based solar energy trading platforms. These challenges include scalability, energy consumption, regulatory and legal issues, and price volatility.

To overcome these challenges, solutions such as alternative consensus mechanisms, and the development of regulatory frameworks for blockchain technology have been proposed. Additionally, blockchain interoperability can create a more interconnected and efficient blockchain ecosystem.

To advance solar energy transactions, research can focus on optimizing storage and distribution systems, developing standardized contracts and pricing models, and analyzing the impact of regulations on solar energy markets. This would involve developing efficient storage solutions, exploring new distribution models, providing transparency for investors and consumers, identifying areas for regulatory improvements, and promoting equitable solar energy markets.

Additionally, by examining the potential advantages of interoperability in blockchain, it is possible to create cross-chain bridges, sidechains, atomic swaps, and inter-ledger protocols that facilitate the exchange of assets as well as data across multiple blockchain networks with greater efficiency. This will create a more interconnected and efficient blockchain ecosystem and revolutionize the solar energy trading industry.

REFERENCES

[1] IEA, “Global electricity demand is growing faster than renewables, driving a strong increase in generation from fossil fuels” 2021.[online] Available:https://www.iea.org/news/global-electricity-demand-is-growing-faster-than-renewables-driving-strong-increase-in-generation-from-fossil-fuels

[2] M. F. Hossain, “Solar energy integration into advanced building design for meeting energy demand and environmental problem,” *Int. J. Energy Res.*, vol. 40, no. 9, pp. 1293–1300, 2016.

[3] energy consumption in India

[4] Joshi, Hrushikesh, et al. "Blockchain-Based Solar Energy Trading."

[5] Pipattanasomporn, Manisa, et al. "Blockchain-based Solar Electricity Exchange: Conceptual Architecture and Laboratory Setup."

[6] Meet the Swiss town using blockchain to trade solar energy

[7] Nur Aitzhan and Davor Svetinovic, “ Security and Privacy in Decentralized Energy Trading Through Multi-Signatures, Blockchain and Anonymous Messaging Streams” IEEE Transactions on Dependable and Secure Computing PP(99):1-1
DOI:10.1109/TDSC.2016.2616861

[8] Esther Mengelkamp, Johannes Gärttner , Kerstin Rock , Scott Kessler , Lawrence Orsini ,Christof Weinhardt“Designing microgrid energy markets: A case study: The Brooklyn Microgrid” Applied Energy Volume 210, 15 January 2018, Pages 870-880

[9] Mihaylov, M., Jurado, S., Avellana, N., Van Moffaert, K., Magrans de Abril, I., & Nowé, A. (2017). NRGcoin: Virtual Currency for Trading of Renewable Energy in Smart Grids. IEEE Transactions on Industrial Informatics, 13(6), 3154-3163.
doi: 10.1109/TII.2017.2747580

[10] Aitzhan NZ, Svetinovic D (2018) “Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams”. IEEE Transactions on Dependable and Secure Computing 15(5):840–852
DOI: 10.1109/TDSC.2016.2616861

[11] Hahn, A., Singh, R., Liu, C-C., & Chen, S. (2017). Smart contract-based campus demonstration of decentralized transactive energy auctions. 2017 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington State University.
DOI: 10.1109/ISGT.2017.8086092

[12] Kang J, Yu R, Huang X, Maharjan S, Zhang Y, Hossain E (2017) Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains. IEEE Transactions on Industrial Informatics 13(6):3154–3164
DOI: 10.1109/TII.2017.2709784

[13] Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2017). Designing microgrid energy markets: A case study: The Brooklyn Microgrid. Applied Energy, 204, 300-310.
DOI: 10.1016/j.apenergy.2017.06.054

[14] S. Nakamoto, “Bitcoin: A peer-to-peer electronic cash system,” 2008. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[15] L. Lamport, R. Shostak, and M. Pease, “The byzantine generals problem,” ACM Transactions on Programming Languages and Systems (TOPLAS), vol. 4, no. 3, pp. 382–401, 1982.

[16] S. Nakamoto, “Bitcoin: A peer-to-peer electronic cash system,” 2008. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[17] P. Vasin, “Blackcoins proof-of-stake protocol v2,”2014.[Online].Available: https://blackcoin.co/blackcoin-pos-protocol-v2-whitepaper.pdf

[18] Yu, X., Qin, J., & Chen, P. (2022). GPBFT: A Practical Byzantine Fault-Tolerant Consensus Algorithm Based on Dual Administrator Short Group Signatures. Journal of Sensors, Wireless Communications and Control, 2022(8311821), 1-13. https://doi.org/10.1155/2022/8311821

[19] “Hyperledger project,” 2015. [Online]. Available: https://www.hyperledger.org/

[20] D. Mazieres, “The stellar consensus protocol: A federated model for internet-level consensus,” Stellar Development Foundation, 2015.

[21] “Antshares digital assets for everyone,” 2016. [Online]. Available: https://www.antshares.org

[22] Mic Bowman Intel Labs,”On Elapsed Time Consensus Protocols”[Online]. Available: https://eprint.iacr.org/2021/086.pdf

[23] “Antshares digital assets for everyone,” 2016. [Online]. Available: https://www.antshares.org

[24] A. Kosba, A. Miller, E. Shi, Z. Wen, and C. Papamanthou, “Hawk: The blockchain model of cryptography and privacy-preserving smart contracts,” in Proceedings of IEEE Symposium on Security and Privacy (SP), San Jose, CA, USA, 2016, pp. 839–858.

[25] Lin, Jason, et al. "Comparative Analysis of Blockchain-based Smart Contracts for Solar Electricity Exchanges."