

Powering The Future: A Case Study on the Implementation of Blockchain with Smart Grids for Energy Trading using Powerledger

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Abstract— Traditional smart grids have some features that render them unsuitable for future requirements. There is a need for more efficient power management on the grid, and this is where the concept of smart grids comes in. Smart grids facilitate the generation of energy at a small scale by individuals, which can subsequently be sold back to the grid. However, the process of generating and selling energy can add a lot of complexity. Transactions between consumers and generators need to be verified and recorded. Additionally, smart grids have a decentralized nature compared to the centralized nature of traditional power grids. This decentralized nature makes them a potentially promising application for blockchain technology. Blockchain could provide tools such as smart contracts that ensure the transactions between consumers and generators are verified and processed in a secure way. This paper explores the potential of blockchain in enhancing the energy trading activities in smart grids and presents a case study of Powerledger, a blockchain-based energy trading platform. We conducted a literature review, identified research gaps and limitations in existing blockchain-based energy trading platforms, and analyzed Powerledger to understand how it addresses these gaps and limitations.

Keywords—Blockchain, Smart Grid, Energy Trading, Powerledger

I. INTRODUCTION

The traditional power grids have a centralized structure that makes them vulnerable to many disadvantages. The centralized nature makes it difficult to incorporate renewable energy. Furthermore, they are susceptible to failures and blackouts, and have less control over the distribution of energy. These limitations can make it impossible for the power grid to meet the ever-increasing energy demands of the modern world. This is where smart grids come in to counter these limitations and provide a more decentralized structure with more flexibility. One of the key benefits that smart grids offer is the integration of distributed energy sources into the main grid. A smart grid is an electricity network that incorporates the use of digital communication devices to facilitate easy monitoring and

control over electricity supply from energy generation sources while keeping track of the varying electricity demands of consumers.

Traditional power grids have been moving towards a more decentralized structure. Blockchain, due to its decentralized nature, can be a promising application for smart grids. Recently, blockchain technology has gained a lot of popularity in various fields such as manufacturing, banking, and healthcare. This surge in acceptance of blockchain is due to its distinctive features, including decentralization. Therefore, blockchain could be integrated with smart grids to leverage the advantages that this technology possesses.

The energy consumption rates in today's world have drastically increased, almost tripled in the past 30 years. The major sources of generating electricity for years have been fossil fuels. However, with the rapid growth in technology, people have changed the way they generate and distribute electricity. Renewable energy sources can now be utilized more efficiently than ever before. These technologies have empowered individuals to generate their electricity and even trade excess power. This enables them to serve as alternative power sources. Smart grids enable individuals to carry out energy trading activities, achieving better utilization of energy and quick demand response management. Blockchain can be utilized to ensure that these transactions can be processed more reliably, providing easy management of transactions and ensuring that electricity is delivered once the customer has paid. In this paper, we examine the integration of blockchain with smart grids for energy trading purposes. In addition, we conduct a case study on Powerledger, a blockchain-based energy trading platform.

II. RELATED WORKS

This section gives a brief introduction to smart grids and blockchain technology. Further, we explore the existing literature and identify research gaps that can help in the development of effective blockchain-based solutions for smart grid energy trading.

A. Smart Grids

A smart grid is an electricity network that incorporates the use of digital communication devices to facilitate easy monitoring and control over electricity supply from energy generation sources, while keeping track of the varying electricity demands of consumers. The use of digital technology, such as smart meters, in smart grids enables two-way communication. This two-way communication is what actually makes the grid smart. A traditional power grid comprises only one-way communication from electricity suppliers to consumers. However, the use of digital technology, such as smart meters, in smart grids enables two-way communication. This means that consumers can track essential data representing their energy usage patterns. Smart grids have made it possible to control the use of appliances and allow users to reduce power consumption costs by making useful information about current consumption available to them. In smart grids, we have consumers and prosumers. Prosumers are essentially consumers who also produce energy, meaning they can generate energy locally through renewable energy sources. Whatever surplus energy they have can be traded with consumers who wish to buy more energy. This way, consumers and prosumers can carry out energy trading, eventually leading to the creation of a peer-to-peer network that can alleviate problems like long-distance power losses. Energy demand and supply can be balanced, leading to a more reliable and effective energy system.

B. Blockchain Technology

Blockchain is a decentralized and distributed platform used for various applications. Essentially, it is a distributed database that can store data in digital format across a network of computers. Blockchain has gained a lot of popularity because of the several features it possesses, such as decentralization, transparency, security, immutability, and efficiency. Blocks are the fundamental building blocks of a blockchain. Each block holds a number of transactions, along with a cryptographic hash of the previous block in the chain. The hash is what actually makes it possible to link blocks to one another. The linking of blocks together using hash to eventually form a chain creates a situation in which it becomes impossible to alter the data stored in the blocks without being noticed. After adding a block to the blockchain, it cannot be updated or deleted. The block also contains other useful information such as the block header, Merkle tree root, and nonce.

C. Literature Review

With the recent developments in blockchain technology and the increase in popularity that blockchain has garnered across multiple fields, there is a need to study the benefits that blockchain could bring to smart grids. One of the purposes for which blockchain can be used in smart grids is to provide a means for secure energy transactions between prosumers and consumers, as demonstrated by Anak and Rini [1]. "Prosumer" is a term

used to identify consumers who not only consume energy but also produce energy that can be supplied back to the grid.

Anak and Rini [1] proposed a model that relies on smart contracts to ensure the immutability of transactions between users, thereby providing more traceability. One downside of the model is that the proof of work consensus algorithm used is not convenient for energy trading. Likewise, Edmonds et al. [7] also suggested the use of smart contracts in smart grids. One of the primary concerns that users may face in home energy management systems is that the consumer's privacy may be compromised. Consumers are required to send their load forecasts to the distributed service operator, which could be accessed by any attacker. Therefore, there is a need to address such privacy concerns. Edmonds et al. [7] proposed a model using smart contracts that would keep consumers' data secure while communicating with the distributed service operator. Moreover, further research is needed to evaluate the performance of using smart contracts in a private blockchain, such as Hyperledger.

One of the key benefits that smart grids offer is the integration of renewable energy sources into the grid, allowing consumers to store the energy generated using renewable sources for efficient demand response management. Kumari et al. [9] suggested a model based on smart contracts to create a decentralized energy trading system where energy transactions could be carried out securely. However, more work is needed to address the privacy issues of the proposed model. In our modern world, electric vehicles are not only seen as assets but also as storage units that can enable technologies such as Vehicle-to-Grid (V2G). Initially, an electric vehicle takes power from the grid to charge up, and then the energy stored in these vehicles can be fed back into the grid during times of peak demand. This is called Vehicle-to-Grid (V2G). In this way, electric vehicles can promote a more active way of consuming energy.

Umoren et al. [2] propose a model that enables prosumers (electric vehicles) and consumers to deal directly with each other to address temporary energy needs. Umoren et al. [2] suggest an application prototype that facilitates remote monitoring of energy trading between the consumers and prosumers.

Yihao, Zhiguo, and Xiuzhen [3] conducted a survey in which they studied numerous solutions for integrating blockchain with smart grids. They examined how blockchain could eliminate the drawbacks prevalent in traditional smart grid solutions. They concluded that blockchain provides many desirable properties that can be exploited to strengthen smart grid systems. Musleh et al. [5] also conducted a survey on modern blockchain applications in smart grids and found that blockchain has unique features that could bring great advantages to the management of smart grids. However, more research is needed to overcome some of the technical challenges that blockchain-based solutions face and to successfully implement blockchain with smart grids.

Further, Mollah et al [6] summarized the contributions of blockchain in various areas of smart grids, such as electric vehicles, energy trading, energy cyber-physical systems, and microgrids. Arjomand et al. [10] studied the various applications of blockchain in smart grids and emphasized the need for blockchain in energy transactions. They also provided future directions for blockchain-based smart grids, including the use of integrated forecasting mechanisms for future energy consumption and production.

Blockchain technology can promote peer-to-peer energy trading, which can help transform energy into a digital asset that can be traded using transactions. According to Antal et al. [4], the use of smart contracts can create a market for energy trading that ensures transaction immutability and privacy. The market enables each prosumer and consumer to create smart contracts. Prosumers can now bid or offer the amount of energy they are willing to buy or sell through their contracts. These smart contracts automate the process of submitting bids/offers, which are then matched. Prosumers have the final say on whether they want to proceed with the transaction or not. Once accepted, the transaction will be replicated throughout the network, ensuring immutability. The use of smart contracts, along with public key cryptography, ensures privacy.

One of the limiting factors for the integration of blockchain with smart grids is the inherent delay in energy transactions between prosumers and consumers. This delay could result in consumers being unable to meet their urgent energy demands. Onyeka et al. [8] proposed a model that incorporates the use of blockchain with microgrids and an optimized transaction permission protocol. They found that transactions were faster when using a consortium blockchain with microgrids and concluded that the transaction speed was directly related to the number of nodes, rather than the block size.

III. OVERVIEW OF THE CURRENT STATE OF BLOCKCHAIN AND SMART GRID TECHNOLOGIES

The current state of blockchain-based solutions for smart grids is rapidly evolving and holds great potential for the future of the energy industry. The use of blockchain technology is increasing as a potential solution to some

of the crucial challenges in the energy industry, such as the integration of renewable sources, enabling decentralized energy trading, and improving energy efficiency.

Several countries have started deploying smart grid technologies to modernize the existing power grid infrastructure, providing advanced monitoring, control, and optimization of energy utilization. Some of these technologies include advanced sensors, communication networks, and control systems. The integration of blockchain with smart grid technologies can potentially entirely change the energy industry by providing secure and transparent peer-to-peer energy trading and efficient utilization of distributed energy resources.

Since blockchain has only recently gained popularity, solutions for adopting it with smart grids are still in their early stages. There are numerous successful pilot projects and commercial deployments around the world, and governments and utilities are actively evaluating the potential of these technologies.

Overall, the current state of blockchain and smart grids is encouraging, and they could possibly play a significant role in revolutionizing the energy industry by providing a more resilient, efficient, and sustainable energy system.

VI. ENERGY TRADING

Energy trading is a convoluted process that comprises the buying and selling of energy commodities between market participants such as generators, utilities, traders, and customers.

A. Energy Trading In Traditional Energy Markets

In the traditional energy market, end-users do not have direct access to the market and are not involved in the actual trading process. Instead, they rely on their energy providers who buy energy on their behalf to meet their energy requirements. Energy trading is mostly an indirect process from the point of view of end-users, which is managed by their energy providers. The traditional energy market is subject to regulations and market rules that govern trading. Overall, the traditional energy market is centralized and controlled by a small number of energy companies where prices are determined based on the concept of demand and supply. However, blockchain-based energy trading platforms have emerged as an opportunity to establish a decentralized energy trading market that provides several benefits, including a more effective, secure, and transparent energy trading process among peers without intermediaries.

B. Decentralized Energy Trading Platforms

Decentralized energy trading platforms are online marketplaces that function based on blockchain technology to facilitate peer-to-peer trading of energy among network participants without the need for a central authority. Decentralized energy trading platforms run on a decentralized ledger that keeps track of all transactions in a secure and transparent way. This ledger is maintained by a network of computers to ensure that no single entity has control over the network. Each transaction of energy between a buyer and seller is verified by network participants, making the platform more reliable. Since there is no centralized authority, the question arises as to who will decide the prices for energy. Prices are determined based on demand and supply. The sellers may even set their own prices for the energy they sell. This creates a more flexible market in which energy prices are based on real-time market conditions. One principal advantage that decentralized energy trading platforms provide over traditional energy markets is the efficient utilization of renewable energy sources, since excess energy generated by prosumers can be sold to other consumers rather than going to waste.

C. Blockchain For Energy Trading In Smart Grids

Blockchain can enable peer-to-peer energy trading by creating a decentralized market where individual energy producers can directly sell their surplus energy to consumers without the need for intermediaries, such as utility companies. Prosumers, who produce energy, can use smart meters to keep track of their energy production and consumption in real-time. The amount of energy produced can be utilized by the prosumer for their own energy requirements, whereas the remaining amount can be displayed on the blockchain network. Consumers who demand more energy can now utilize the information available on the blockchain to purchase energy directly from prosumers using digital currency that they can spend through their wallet connected to the blockchain network. The energy will then be delivered to the consumer's home via the existing grid infrastructure. The use of blockchain not only ensures security but also provides mechanisms to ensure efficiency and transparency. Overall, blockchain provides an efficient platform that allows consumers to purchase energy directly from their peers without the need for intermediaries.

However, there are certain challenges and limitations as well. Scalability can become a concern since blockchain requires high computational resources that consume a lot of energy. The network must be able to handle large

volumes of transactions within the smart grid. Furthermore, interoperability can be another concern. Moreover, regulatory compliance can be a problem. Compliance with standards and regulations can be challenging since some of the regulatory frameworks are not well-suited to blockchain. Additionally, a lack of technical expertise is another major challenge. The integration of blockchain with smart grid technologies requires a high level of technical expertise that can be difficult to find. Implementing blockchain-based solutions can require a significant investment in terms of hardware and software infrastructure, which can be costly. These challenges must be addressed to realize the full potential of this technology.

V. METHODOLOGY

The methodology used for this research paper involves two important stages: a literature review and a case study analysis. In the first stage, we conducted a literature review to identify research gaps in blockchain-based energy trading platforms, resulting in the identification of several research gaps. In the second stage, we conducted a case study on Powerledger to analyze how the Powerledger platform overcomes the identified research gaps. The case study analysis involved the identification of key features of Powerledger that addressed the research gaps identified in the literature review.

VI. CASE STUDY: POWERLEDGER

A. Power ledger

Powerledger is a blockchain-based energy trading platform that enables users to buy and sell energy directly to each other without the need for a mediating third party. The platform uses blockchain to create a peer-to-peer decentralized market where individuals can sell their surplus locally produced energy to other consumers who need more energy. This way, a more efficient utilization of energy can be achieved. The main objective of Powerledger is to promote the use of more renewable energy sources while reducing carbon emissions.

B. Solana

Powerledger is a blockchain-based platform that runs on the Solana blockchain network, enabling peer-to-peer energy trading. Solana is a blockchain network that provides fast, scalable, and secure decentralized applications and transactions. Solana makes use of a unique consensus mechanism called Proof of History (PoH) that helps achieve high throughput. Powerledger transitioned from the Ethereum network to the Solana network for various advantages that Solana offers, which are discussed later in the paper.

C. Evaluation Of Powerledger Implementation

One of the critical issues that blockchain-based energy trading markets face is the inherent delay in processing transactions. In July 2021, Powerledger, which initially ran on Ethereum, shifted to the Solana blockchain to overcome the disadvantages of the Ethereum network in terms of scalability, transaction costs, and confirmation times. Furthermore, consumers using Powerledger faced scalability and cost issues due to Ethereum. Powerledger made this switch to exploit the advantages that Solana offers. It enables the handling of high volumes of traffic quickly and efficiently. Powerledger is able to process transactions quickly because Solana has developed a unique consensus algorithm called Proof of History (PoH). As we have seen earlier, the proof of work consensus mechanism is not really suitable for energy trading because of its computationally expensive nature. However, Proof of History (PoH), on the other hand, has proved to be a better option for smart grid trading. It is a clock-based consensus algorithm. Proof of history will enable the blockchain to work faster while maintaining security. What it does is sequence the transactions based on time. In PoH, every transaction has a unique hash as a function of real-time, which helps in sequencing the transactions. Each node will get a cryptographic clock that will help to come to a consensus by agreeing on the time and ordering of the events without having to wait to hear from the other nodes. This way, Solana is able to achieve high throughput. Solana makes use of the Proof of History (PoH) in conjunction with Proof of Stake (PoS). This way, Powerledger is less energy-intensive. Co-founder and executive chairman Dr. Jemma Green said, "Our new blockchain platform based on Solana will be tens of thousands of times faster than Ethereum but also energy-efficient. As we stated this project to allow renewables to be scaled, part of our mission is to be light on our carbon footprint." By switching to Solana, not only does Powerledger save on energy, but they also achieve high throughput necessary for carrying out energy transactions. Powerledger can now process more than 50,000 transactions per second [11].

One significant challenge in the adoption of blockchain-based energy trading platforms is the lack of privacy, mostly in the case of public blockchains. However, Powerledger provides a solution to this problem by using a

permissioned blockchain. By providing network access only to authorized participants, Powerledger ensures that the privacy of the users on the energy trading platform remains secure. In addition, Powerledger uses cryptography techniques to secure the transactions.

Powerledger faced concerns regarding scalability on the Ethereum network, which is why they transitioned to the Solana-based blockchain. The popularity of decentralized apps in recent times has led to a wider adoption of Ethereum with more transactions being made. But this has also led to issues such as pending transactions and higher transaction fees to get the transactions processed, which could lead to slower working of decentralized applications and thus limit scalability. Powerledger, however, achieves scalability through Solana, which makes use of a Proof of History consensus mechanism. They simply use timestamps with a hash for transactions, which will convey when the transaction was validated. This consensus mechanism has short block times of 400 milliseconds and can handle more than 50,000 transactions per second. Proof of History can be thought of as cryptographic clocks. This way, Powerledger is now able to achieve scalability.

Another concern with blockchain-based peer-to-peer markets is that the cryptocurrency for the blockchain platform may easily rise or fall, which can have a big impact on the energy trading prices. To avoid this, Powerledger facilitates the creation of tokens. These tokens are created in exchange for fiat money to ensure that the prices do not vary. Powerledger provides Sparkz, a utility token used as a means of exchange within the platform. Sparkz represents a unit of energy that can be traded on the platform. Once an amount of fiat currency is received, Sparkz tokens corresponding to the amount will be created and given to the user. These Sparkz tokens can be traded to convert them back into fiat currency or any other digital asset.

D. Examination Of Powerledger's Pilot Project

Powerledger has conducted several pilot projects in countries like Australia, Japan, the United States, and Thailand. There have been a few Powerledger projects conducted in India; one of them was conducted in the city of Lucknow, Uttar Pradesh (UP). The pilot project involved the deployment of Powerledger's peer-to-peer trading platform, which would enable energy trading activities between rooftop solar panel owners and their neighbors. The project made use of smart contracts to automate the execution of the trading process. The project successfully demonstrated the feasibility and use of blockchain technology in the Indian market. This project was deemed successful and even led to the electricity regulatory committee creating a tariff order [11], which directed all utilities to make provisions for peer-to-peer energy trading.

VII. RESULTS

In this paper, we conducted a literature review that focused on the integration of blockchain with smart grids. We found that implementing blockchain in smart grids provides several advantages that could lead to better utilization of energy. One of the key areas in which blockchain could contribute is energy trading, which could enable individuals to trade electricity directly among themselves without the need for a centralized authority. Further, we highlighted the various research gaps that need to be addressed for the proper functioning of a blockchain-based peer-to-peer energy trading platform. To address these gaps, we performed a case study on Powerledger, a permissioned platform for peer-to-peer energy trading. We analyzed Powerledger and found that it successfully addressed the research gaps in the following ways:

Blockchain-based energy trading markets face delays in processing transactions. Powerledger makes use of Solana as a permissioned blockchain that enables faster transaction processing through its Proof of History (PoH) mechanism. Scalability is also a concern for energy trading based on blockchain. However, Solana enables Powerledger to process a large number of transactions, thus increasing throughput. Powerledger tackles privacy issues to some extent with the use of a permissioned blockchain. Finally, to address the fluctuating prices of platform cryptocurrency, Powerledger makes use of a token that can be pegged to fiat currency.

In addition, we examined Powerledger's pilot project in India to demonstrate the potential of blockchain in energy trading and thus check the feasibility of blockchain in energy trading.

Overall, we found that blockchain can play a pivotal role in smart grids by providing a secure means for peer-to-peer energy trading. This could lead to a more efficient and sustainable energy future.

VIII. CONCLUSION

Blockchain offers many advantages for its application in smart grids. It can facilitate the creation of a peer-to-peer market where smart grid technologies can promote energy trading among peers. Overall, energy trading is an important element of the transition towards a more sustainable and decentralized energy system. Blockchain has several benefits that make it a promising tool for application in smart grids. In conclusion, this paper

examined the integration of blockchain with smart grids for energy trading. Overall, the study suggests that blockchain-based energy trading platforms like Powerledger have the potential to transform the way energy is bought and sold. However, using blockchain with smart grids is still a recent topic, and thus further research is needed to address other challenges, such as regulatory barriers, in order to achieve widespread adoption of such platforms.

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